New Directions in Colour Studies

Edited by Carole P. Biggam, Carole A. Hough, Christian J. Kay and David R. Simmons

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Preface

Colour studies as a research area is inherently multidisciplinary, attracting scholars from across the academic spectrum. Contributions to the present volume are no exception, ranging as they do from studies of individual languages through papers on art, architecture and heraldry to psychological examinations of aspects of colour categorization, perception and preference.

The chapters have been developed from papers and posters presented at Progress in Colour Studies 2008 (PICS08), a conference held at the University of Glasgow, Scotland, from 14 to 17 July 2008. The stated aim of the conference was to provide a multidisciplinary forum for discussion of recent and ongoing research, presented so as to be accessible to scholars in other disciplines. This objective has resulted in a volume divided into seven sections: 1. Theoretical issues; 2. Languages of the world; 3. Colour in society; 4. Categorical perception of colour; 5. Individual differences in colour vision; 6. Colour preference and colour meaning; 7. Colour vision science. To make the articles maximally accessible, each of Sections 2–7 begins with a short preface describing and drawing together the themes of the chapters within that section.

PICS08 continued a tradition begun with the pioneering PICS04 in 2004, which resulted in two volumes of papers (Biggam & Kay 2006; Pitchford & Biggam 2006). The second conference offered both continuity and novelty, since many people who had attended the first one returned to report on their research at the second, while others attended for the first time and introduced participants to new and exciting areas of colour research. As in 2004, we were delighted by the spread of topics covered, the high quality of the papers, and the number of nationalities represented by the speakers. Many useful contacts were made both within and across disciplines.

Running a conference draws on the goodwill and assistance of many people. We would like to thank all our speakers, and especially our keynote speaker, Prof. Fred Kingdom of McGill University, for their contributions and for their patience while awaiting the completion of this volume. For financial support, we are indebted to the Faculty of Arts and the English Language Department, University of Glasgow, and to Cambridge Research Systems. We are also grateful to Anke de Looper, our equally patient editor at Benjamins, to the reviewers of the papers for their helpful comments, to Flora Edmonds for help in preparing this volume, and to Marc Alexander and the team of students and others who helped during the conference itself. We look forward to our third conference in 2012.

Carole Biggam
Carole Hough
Christian Kay
David Simmons

Glasgow, April 2011

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Abbreviations

ANOVA	Analysis of Variance
Ar	Arabic
ASD	Autism Spectrum Disorder
BCC	Basic Colour Category
BCP	Berkeley Color project
BCT	Basic Colour Term
CHILDES	Child Language Data Exchange System
CIE	Commission Internationale de l'Éclairage
CIELUV, CIE Luv, CIE	
L*u*v	type of CIE colour space
CP	Categorical Perception
CRT	Cathode-Ray Tube
DKL	Derrington-Krausko-pf-Lennie (colour space)
DNA	Deoxyribonucleic acid
DOE	Dictionary of Old English
DTI	Diffusion Tensor Imaging
ECT	Elaborate Colour Term
EEG	ElectroEncephaloGraphy
ENG	English
ERP	Event-Related Potential
EVT	Ecological Valence Theory
F-M	Farnsworth-Munsell
fMRI	functional Magnetic Resonance Imaging
Gk	Greek
H	Hue
HCA	Hierarchical Clustering Analysis
IAPS	International Affective Picture System
IPA	International Phonetic Association
It	Italian
L	Long wavelength; Lightness; Luminance
L, Lat	Latin
LGN	Lateral Geniculate Nucleus
LH	Left Hemisphere
LHS	Lightness, Hue, Saturation
LR	Long Range
LVF	Left Visual Field
M or m	Medium wavelength; Mean; metre/meter
MDS	Multi-Dimensional Scaling
msec or ms	millisecond
N or n or *n*	(total) Number; negative
NCS	Natural Colour System
NIH	National Institutes of Health (U.S.A.)
nm	nanometre
OA	Old Arabic
OE	Old English (Anglo-Saxon)
OED	Oxford English Dictionary
OIt	Old Italian
OSA	Optical Society of America
P	Percent
p or p	probability; positive
PC	Principal Component
PCA	Principal Component Analysis
r or r	Correlation Coefficient
RH	Right Hemisphere
RT	Response Time

RVF	Right Visual Field	Sec	second
S	Short wavelength; Saturation	UV	Ultra-Violet
S, Ss	Subject, Subjects	V1-4	(Areas of the visual cortex)
SD or sd		WCS	World Color Survey
or s.d.	Standard Deviation	*	(unacceptable or
SE	Standard Error		reconstructed form)

SECTION 1

Theoretical issues

Illusions of colour and shadow

Frederick A. A. Kingdom
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Colour (chromatic) vision not only tells us about the colour of surfaces but about the structure of the visual world. One way that colour vision informs us about scene structure is by helping decompose the scene into its material and illumination layers. This ability is underpinned by the visual system's in-built knowledge that colour variations, and those luminance variations that are aligned with them, tend to be material in origin, whereas 'pure' luminance variations tend to arise from illumination. Evidence for such in-built knowledge is that shadows appear to be material in origin when strongly coloured, and colour variations enhance or suppress perceived shape-from-shading in luminance variations depending on their spatial relationships. These findings remind us that many of the benefits of colour vision only emerge when studying the interactions between colour and luminance rather than colour vision in isolation.

We normally think of colour vision for perceiving the hues of objects, enabling us to avoid a poisonous red frog, determine whether an apple is ripe and find one's car in a busy car park (Shevell & Kingdom 2008). But does colour vision reveal anything useful about the *structure* of our visual world? At first sight the answer is no. Figure 1 shows an image of an everyday scene that has been decomposed into its chromatic (i.e. colour) and luminance 'layers'. The chromatic layer shows the variations in colour, whereas the luminance layer shows the variations in light intensity. We perceive variations in light intensity either as variations in the lightness (or shade-of-grey) of surfaces, or as variations in illumination such as shadows and shading. Although some of the shapes are discernible in the chromatic image, much of the fine structural detail is visible only in the luminance image. In fact the chromatic image is reminiscent of the paintings by the Fauvist artist Derain, who depicted scenes using broad sweeps of vivid colour while leaving out most of the fine detail. Indeed some researchers in visual perception have argued that the main role of colour vision is to 'fill in' the blank areas that are left once the structure of the image has been encoded

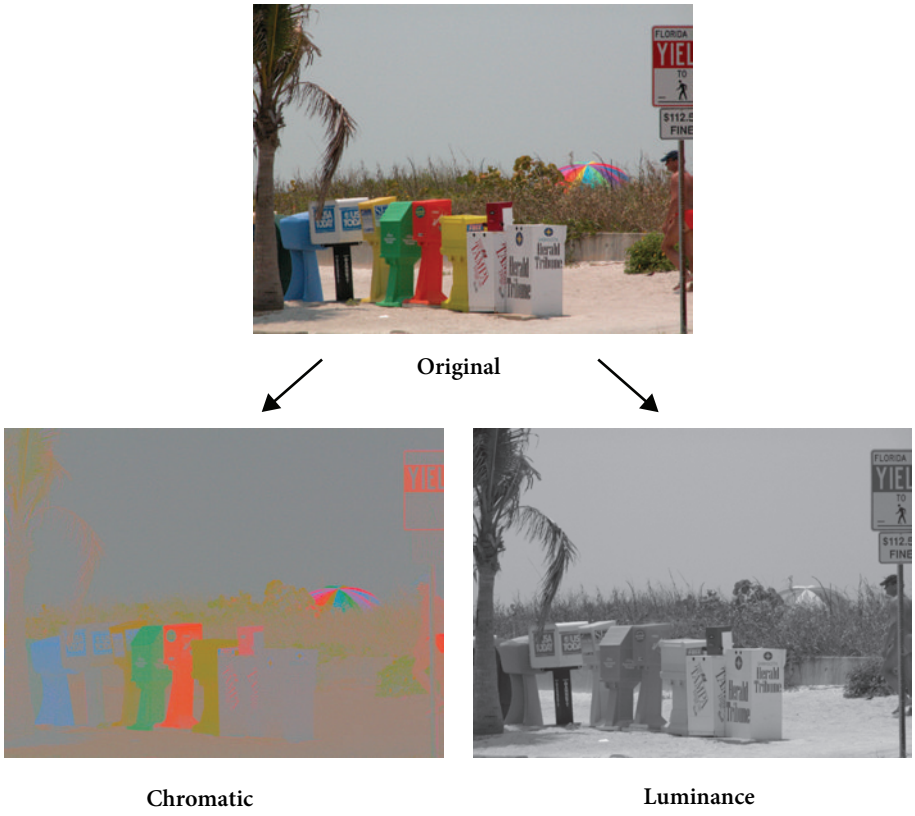

Figure 1. An image of an everyday scene (top) can be decomposed into chromatic (lower left) and luminance (lower right) layers

using luminance information, a view dubbed by McIllhagga and Mullen (1997) the 'colouring book' model of colour vision. The analogy with the colouring book also finds expression in the technique employed by watercolor artists in which pastel colours are liberally painted over carefully-drawn ink outlines, yet one hardly notices that the colour and luminance contours rarely coincide. So if there *is* any special information about image structure conveyed by colour vision, it is not obvious what it is.

One notable way in which colour vision provides unique information about image strucure is in the way it reveals camouflaged objects, as in Figure 2. However, colour vision contributes more to our perception of image structure than just camouflage-breaking. To understand how and why, it is necessary to stand back for a moment and consider the physical relationships between colour and luminance in our visual world.

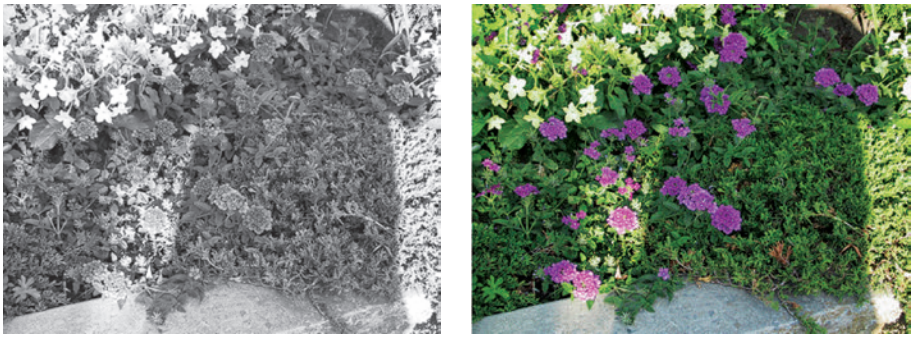

Figure 2. The purple flowers in the luminance image on the left are well-camouflaged but are easily seen in the colour image on the right

Figure 3. The grass-pavement border is a change in colour, luminance and texture, whereas the shadow border is only a change in luminance

Consider Figure 3. The cast shadow is primarily a change in luminance – there is little difference in colour with its surroundings (there is sometimes 'bluing' in shadows, but it is generally weak), and there is no difference in texture. On the other hand the grass and pavement differ in luminance *and* colour *and* texture; the grass is dark, green and coarse, the pavement bright, grey and smooth. This simple photograph reveals a fundamental truth about the physical properties of our visual world: differences in colour are in most instances a result of differences in material, e.g. paint or pigment, whereas differences in luminance that are unaccompanied by differences in colour are in most instances a result of variations in local illumination, e.g. shadows or shading. A corollary to this fact is that colour differences are as a rule more reliable indicators of

material differences than are luminance differences, particularly in scenes where shadows and shading are prevalent. These physical relations between colour and luminance in the natural visual world have been understood by computer vision scientists for some time (Rubin & Richards 1982), and have been exploited in image-processing algorithms aimed at separating the material and illumination layers of images of natural scenes (e.g. Olmos & Kingdom 2004). The question for biologists and psychologists, however, is whether there is evidence that the visual system has in-built knowledge that 'colour-is-material'. This in-built knowledge would not necessarily be conscious but should nevertheless have measurable behavioural consequences.

There are two sorts of evidence that the visual system adopts the colour-is-material assumption. The first is somewhat anecdotal, but nonetheless compelling: strongly coloured illumination changes often appear to be material. Shevell and Kingdom (2008) and Kingdom (2008) have recently published a photograph taken by Brian Micklethwait of a tower block at sunset. The tower block appears as if partially painted in orange, with the painters running out of paint two thirds of the way down, whereas in fact the orange is sunset illumination on a grey surface. Another example is the close-up of the garden exhibit on the left of Figure 4. We tend to see circular patches of coloured glass, yet these are coloured shadows, as revealed in the wider picture on the right. In both these examples a colour change that is illumination is mistaken for a material change that is paint or stain.

The second type of evidence for the colour-is-material assumption has emerged from psychophysical studies of a stimulus that is both compelling and easily manipulable. Figures 5a and 5b show two oriented gratings, one a sinusoidal modulation of

Figure 4. Outdoor exhibit entitled "Between Earth and Sky", by Juliette Patterson (JP) & Michel Langlois (ML). Photographed by the author and reproduced with permission from JP and ML

luminance, the other a sinusoidal modulation of colour. On their own the luminance grating appears almost flat, and the colour grating completely flat. However, when the two are combined to form a 'plaid', as in Figure 5c, one obtains a strong impression of a surface corrugated in depth. The corrugated-surface appearance is an example of 'shape-from-shading', whereby the visual system uses surface shading information to generate a percept of three-dimensional shape. In the plaid in Figure 5c, the spatial variations in luminance are not tied to the spatial variations in colour, promoting the interpretation that the luminance changes are shading, and therefore that the plaid is a colour-modulated, corrugated surface (such as a folded curtain) illuminated obliquely. If this analysis of the appearance of the plaid is correct,

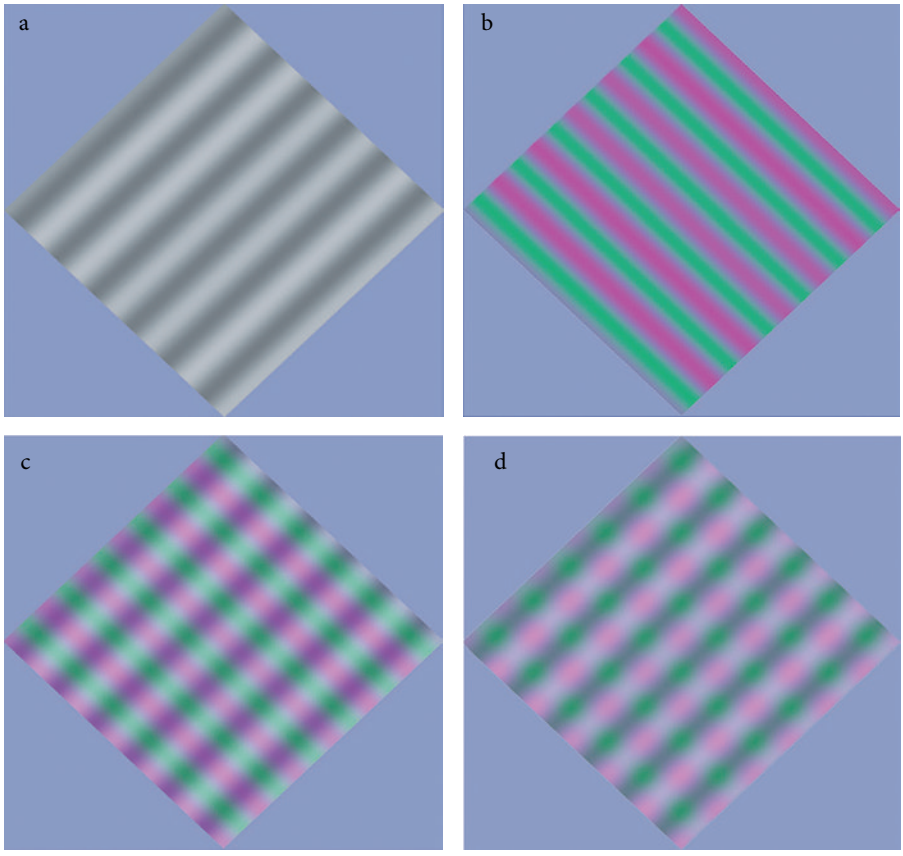

Figure 5. The colour-shading effect. (a) sinusoidal luminance grating; (b) sinusoidal purple-green colour grating; (c) when the luminance and colour gratings are combined to form a plaid one obtains a strong impression of a three-dimensional (3D) corrugated surface; (d) addition of a second colour grating aligned with the luminance grating suppresses the impression of a 3D corrugated surface

then one would predict that adding chromatic variations to the plaid in spatial alignment to the 'shading' grating would reduce the impression of depth corrugation. This is exactly what happens. Adding a second colour grating in alignment with the luminance grating, as in Figure 5d, strongly reduces the impression of a corrugated depth surface. Now, the changes in luminance are perceived to belong to the material surface rather than to the shading of the illuminant. I have termed the corrugated appearance of the plaid in Figure 5c the 'colour-shading effect' (Kingdom 2003).

Besides being a compelling phenomenon in itself and a useful laboratory tool for probing the colour-is-material assumption (e.g. Kingdom, Rangwala & Hammamji 2005), the colour-shading effect reveals another important truth. A strictly 'modular' view of colour vision holds not only that the main role of colour vision is to 'fill-in the gaps' (see above), but also that colour vision has its own visual pathway, one separate from that mediating form, motion and depth perception (Livingstone & Hubel 1987). However, the colour-shading effect shows that this view is not correct. On the contrary, it reveals that chromatic variations are a driving force for form and depth perception. Moreover, the colour-shading effect shows that colour vision contributes to form by *interacting* with luminance information – remember that the colour and luminance gratings only elicit an impression of depth when combined into a plaid. The colour-shading effect does not imply, however, that we should reject altogether the idea that there is a specialized brain module for colour. Rather, it means that we need to qualify what visual functions the module performs. The colour module appears to encode surface colour appearance, and as such is useful for the object recognition tasks mentioned at the beginning of the chapter. However, the contribution that colour makes to form and depth, as revealed by the colour-shading effect as well as many other phenomena (Shevell & Kingdom 2008), does not sit well with the idea that colour, form and depth are separate modules.

The colour-shading effect, as demonstrated with plaid patterns, reveals the strength of colour as a cue exploited by vision for classifying luminance changes into material and illumination. But of course colour is not the only cue available to vision for this purpose. The natural visual world is replete with cues for disambiguating material and illumination variations, including motion, depth, occlusion, shape and other contextual cues (reviewed by Kingdom 2008). As a result we are rather good at classifying luminance variations into material and illumination, even in purely black-and-white images of natural scenes, i.e. in the absence of colour cues. Given these other cues, how does colour contribute to material-versus-illumination classification when they are present? One possibility is that colour does not contribute at all when they are present because it is redundant. Another is that it combines with some but not other cues.

To test between these possibilities, we examined how colour and texture combine to promote and/or inhibit shape-from-shading in luminance patterns. In the discussion of the photograph in Figure 3, we noted that not only colour but texture changed at the grass-pavement boundary, but that there was no textural change across the shadow. Texture, however, is inherently more complicated than colour in the potential

ways it might facilitate material-versus-illumination classification. Variations in natural-scene textures are not exclusively material changes, as Figure 3 might imply. Surfaces that are uniformly textured but which undulate in depth produce variations in local orientation in their retinal-image projections, and these are exploited by vision for surface-shape perception (Li & Zaidi 2000). Undulating surfaces are often subject to shading, and the shading is combined synergistically with the textural variations by vision to detect the three-dimensional shape of the surface (Mamassian & Landy 2001). An example of this synergy is shown in Figure 6a. The image simulates a

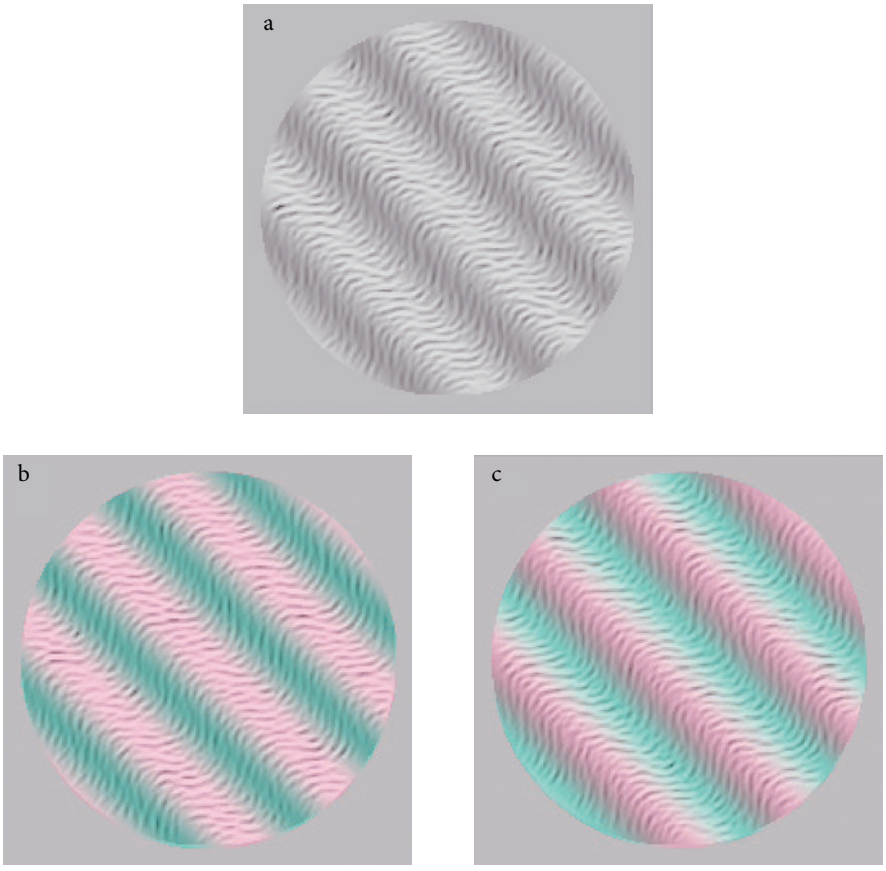

Figure 6. Stimuli used to study the interaction between colour, luminance and orientation-defined texture variations for perceived depth. (a) Luminance variations and orientation-defined texture variations combine to give the impression of a surface corrugated-in-depth surface; (b) adding colour variations that are aligned with the luminance variations reduces the depth impression; (c) adding colour variations that are non-aligned with luminance variations strengthens the depth impression. From Kingdom, Wong, Yoonessi & Malkoc (2006)

uniformly textured surface that is corrugated in depth and illuminated obliquely. The resulting modulations in local orientation and luminance, the latter interpreted as shading, evoke a strong impression of a corrugated depth surface similar to the plaid in Figure 5c.

The question is what happens if colour is now added to the mix? Remember the rule: variations in colour that are aligned to variations in luminance are interpreted as material changes, whereas those that are non-aligned to luminance variations are interpreted as illumination, e.g. shading. In Figure 6a, however, the textural variations have already promoted the impression that the luminance variations are shading, so perhaps the addition of colour variations will make little or no difference, neither promoting nor inhibiting the depth percept. But as Figures 6b and 6c show, the addition of colour variations increases the impression of depth when non-aligned with the luminance variations, and decreases the impression of depth when aligned with the luminance variations (the measurements that confirm these observations are described in Kingdom, Wong, Yoonessi & Malkoc 2006). Moreover, as one might expect, the impact of colour on depth in the textures is only manifest when the shading is present; the colour has no impact one way or another when the shading is absent. This leads to a simple schematic in Figure 7 of how colour, luminance and texture interact in the stimuli shown in Figure 6.

In the schematic, both shading and texture combine synergistically to help determine the three-dimensional shape of the surface, and colour variations promote or inhibit the contribution of shading, but not texture, to the perception of 3D-shape.

A final note: Chirimuuta, in her chapter "Touchy-Feely Colour" (2011), argues that evidence for the colour-is-material assumption could mistakenly be construed as supporting the idea that colour is an intrinsic property of objects. However, Chirimuuta argues, our experience of colour as a material property, i.e. something embedded in objects, is due to something specific happening in our visual system. Chirimuuta likens colour vision to touch, arguing that our experience of something as

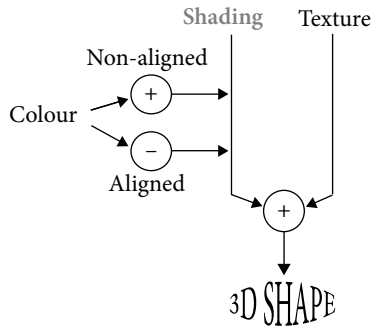

Figure 7. Simple model of how colour, shading and texture combine to elicit shape-from-shading and shape-from-texture in the stimuli shown in Figure 6

coloured arises from the active engagement of our visual system with the light emanating from it, just as fur feels soft because of the active involvement of our touch sense with the fur. Chirimuuta's relationist view of colour vision sits well with many of the themes of this essay. The 'feel' of whether luminance variations are material or light depends not only on the physical context but on our in-built knowledge of the visual world. In other words it depends on how our visual system interacts with the world outside. The fact that we can be misled into perceiving that a colour variation is material when in fact it is light (Figure 4) is testimony to how influential are assumptions on our perception of colour.

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Universal trends and specific deviations

Multidimensional scaling of colour terms from the World Color Survey

David Bimler
Massey University, New Zealand

Some trends are well-established across the 110 languages surveyed in the World Color Survey (WCS): colour terms are not distributed arbitrarily through 'colour space', and, of all possible combinations of terms within a single language, only a few are encountered. WCS data were analyzed to examine departures from these overall trends. To this end, colour terms were represented as locations in a geometrical 'colour-naming space' by calculating the 'co-extension' or degree of overlap between each pair of terms and applying multidimensional scaling (MDS) to the resulting pattern of relationships. The three-dimensional MDS solution shows departures from the consensus colour-term boundaries as fine structure in the clustering of points. These departures are not completely random, but show some association with language affiliation within language families. The MDS solution also focuses attention on 'wildcard' terms, highlighting the role of such terms as transitional stages in models of colour-lexicon development.

1. Introduction

Sturges and Whitfield (1995) used naming responses to 446 hue samples (Munsell chips) from twenty subjects to calculate a matrix of similarities among twelve English colour terms. Their index of similarity was subject inconsistency across repeated trials: each matrix entry was the number of occasions when any subject labelled any chip as A on one trial and B on the replication. Earlier, Boynton and Olson (1987) derived a similar table from 424 OSA samples. As well as tabulating these patterns of relationships among colour terms, both studies presented them graphically.

An alternative definition of 'similarity' involves inconsistency *between* subjects. Consider the number of chips that can in practice be described as A or B. Normalized by the range of both terms on their own, this is the 'co-extension' of A and B – their

shared range, the overlap or intersection of the regions of hues to which they are applied. If all the subjects who use A apply it to the same chips that are described as B by subjects who use B, so that the terms are operationally interchangeable, then their co-extension is 1. The value ranges down to 0 when there are *no* chips described as A by one subject and as B by a second. Nothing in this definition requires A and B to belong to the same language.

The present study applied this alternative definition to colour-naming data from the World Color Survey or WCS (Cook, Kay & Regier 2005). Having quantified the relationships among numerous colour terms from several languages, I reconstructed them by embedding the terms in a simple geometrical model. The intention here is to push this line of inquiry as far as possible. There is no expectation of disproving previous conclusions drawn from the WCS, or even of discovering anything particularly novel, but rather of seeing whether a different methodology replicates those earlier conclusions.

The gist of previous research is that, although individuals and individual languages vary widely in the size of their operational colour lexicon, these variations can be arranged within a small repertoire of sequences (Kay & Maffi 1999; MacLaury 2001: 1232) which may be developmental sequences of progressive lexicon enrichment. Stages within these sequences, and Basic Colour Terms (BCTs) within the lexicons, have generally received most attention. Here I focus on aberrant colour descriptors (not necessarily BCTs) that can plausibly be seen as transitional, intermediate stepping-stones between the established stages.

The WCS data are structured by the tool used to collect them: the Munsell palette (Lenneberg & Roberts 1956). This is a systematic, standardized and manageable-sized sampling of the colour gamut, consisting of 330 colour samples (chips). These include all combinations of eight lightness levels and forty hues spaced equally around the hue circle, all as saturated as possible, as if the lightness and hue coordinates acted as lines of latitude and longitude to mark out a grid on the surface of the colour solid. A further ten achromatic hues range from Black to White, with eight grey tones at the same eight lightness levels. Sturges and Whitfield (1995) supplemented the Munsell palette with less-saturated chips. Other field studies have halved the size of the palette by using only twenty hues (for example, Roberson, Davies & Davidoff 2000).

The Munsell palette is used to elicit colour terms; to record the broadest possible *extension* of each hue term – its denotata, the range of hues it describes; and to partition the colour surface into non-overlapping extensions. Subjects are asked to provide the best colour label for each chip in turn. The extension of a given hue term can be plotted in a kind of Mercator projection by 'unwrapping' the surface of the colour solid.

The data comprising the WCS were elicited from 2,606 informants representing 110 non-written languages from around the world (Cook et al. 2005). The custodians of the data have generously made them freely available through the Internet. Previous

analyses have highlighted the regularities within the data, including a strong cross-cultural consensus about where focal (prototypical) colours and the centres of colour categories are located within the colour gamut (Cook et al. 2005: Figures 4a, 5). These regularities mean that the colour terms in two languages can frequently be matched up to counterparts that cover a similar stretch of the spectrum, allowing statements about the colours of objects to be translated between unrelated languages (exact translation is not always possible since some languages have smaller colour lexicons than others, and may, for instance, lack an equivalent to English *orange*). It was not obvious before the WCS that this would be the case.

Even so, languages can disagree slightly about the exact boundaries between roughly equivalent colour categories. For instance, the boundary between the Berinmo terms *nol* and *wir* is not precisely the same as that between English *yellow* and *green* (Roberson et al. 2000). One question examined here is whether these disagreements are *systematic*.

The WCS contains many subjects who declined to name every hue sample. For at least one language (L31, Cree), all the speakers shared this reluctance: that is, the Cree colour lexicon does not partition the entire colour gamut (Kay & Maffi 1999). Cree speakers agree on the labels for regions of hue that they find sufficiently relevant to talk about, but for other hues they have no single accepted label. The 'emergence hypothesis' (Kay & Maffi 1999) is that other languages have also passed through or remain within a non-partition stage. An example is Yélî Dnye (Levinson 2000). From this stage, a culture can progress down several pathways of lexicon enrichment, depending on the dimension of colour variation on which most weight is placed. Other theorists maintain that the non-partition property must be a secondary state – the result of a retreat or unnatural restriction of the meanings of the BCTs (MacLaury 2001) – because languages naturally possess a colour lexicon that spans the entire gamut and provides a BCT for any hue one might encounter.

The concept of a 'wildcard' colour term is helpful: that is, a term that is not restricted to a single region of the colour gamut, but rather that can apply to any hue that lies outside the ambit of more specific terms. The canonical examples are *łibaah* in Apache (Greenfeld 1986) and *k*^{h}*ósi* in Futunese (Dougherty 1978). Both are used in patterns that are distributed broadly across the Munsell palette and broken up by the 'catchment areas' of the local equivalents of English *yellow* and *green* (see Figure 4c). Wildcard terms seem paradoxical, but could be a transitional stage in a language that is emerging from the non-partition state. In the course of linguistic evolution, as hue-specific terms enter the language (corresponding to English *blue*, *yellow* and so on) and annex more of the colour gamut, the scope of a wildcard becomes progressively more fragmented.

Since *łibaah* and *k*^{h}*ósi* are also applied to the grey achromatic chips (though not black or white), MacLaury (2001) argued that they are primarily descriptors of low saturation, and classified them as manifestations of a 'desaturation pathway' for lexical development in which *saturation* is unusually salient for a language community, so that levels of saturation dominate hue as the focus of verbal distinctions (see also MacLaury 2007). In this account, the range or extension of a term might be

disconnected on the surface of the colour solid, but it would be continuous if we also had data for the less-saturated hues comprising the interior of the solid. A partial illustration from English would be *pastel*, applicable to a range of hues as long as they are too desaturated to be good examples of any of the BCTs. Other wildcards could be subsumed into MacLaury's brightness pathway, in which a term encompasses grey and chromatic samples alike within a range of *lightness*. However, neither pathway can account for a class of wildcard that applies only to chromatic chips and not to greys. The WCS presents us with many instances, some with disconnected extensions.

2. A comparison of two language families

Languages change slightly from one generation to the next. Isolated language communities eventually diverge to the point of mutual unintelligibility, as Latin split into French, Italian and others. However, languages betray sufficient family resemblances to cluster them into taxa such as the Indo-European, Malayo-Polynesian, Trans-New-Guinea (TNG) and Niger-Congo (NC) families, each linked by a (reconstructed) common ancestor.

Colour terms may be broadly comparable but not exactly synonymous. For present purposes, two terms may have different patterns of overlap or co-extension with other terms, due to slightly different boundaries demarcating their denotata within the Munsell palette. The question is whether these variations are random fluctuations, or are linked to family membership.

Figure 1 depicts the relationships among eighty-seven colour terms (represented as squares) from thirteen languages belonging to the Trans-New Guinea family (TNG),[1] and sixty-five terms (shown as circles) from twelve languages from the Niger-Congo family (NC).[2] The field linguists who surveyed the respondents recorded many more words, but a term was only included in this and subsequent analyses if it was used by at least one-third of the informants in a language sample. This criterion was intended to rule out idiosyncratic colour descriptions such as metaphors or concrete references coined on the spot.

Differing numbers of categories and category boundaries necessarily cause some differing patterns of usage at the family level, but these would not be especially interesting. These families were chosen because, for both, the member languages tend to provide relatively undifferentiated colour lexicons: among the TNG and NC languages respectively, an average of 6.7 and 6.5 terms meet the one-third criterion described earlier.

Using the definition of inter-term co-extension from Section 1, we obtained a 152-by-152 similarity matrix. Multidimensional scaling (MDS) accommodates such data

1. Agarabi, Ampeeli, Angaatiha, Berik, Kalam, Kamano-Kafe, Kemtuik, Kwerba, Maring, Menye, Podopa, Tabla and Tifal.

2. Abidji, Bete, Chumburung, Dyimini, Ejagham, Gunu, Konkomba, Mampruli, Mundu, Nafaanra, Vagla and Wobé. Yacouba is also in the NC family, but is anomalous (Bimler, 2007).

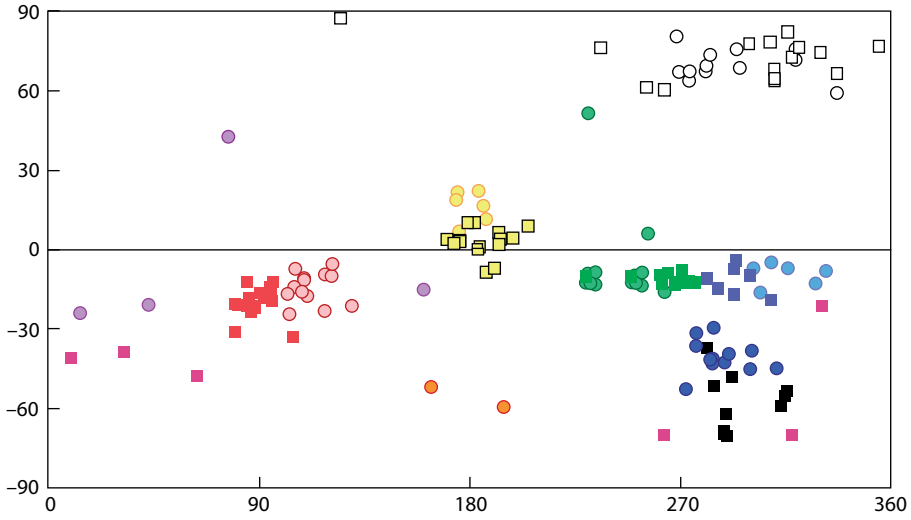

Figure 1. Angular coordinates of MDS solution for 152 colour terms from 13 Trans-New-Guinea languages (squares) and 12 Niger-Congo languages (circles), located within a 3D MDS solution. Azimuth = hue angle; altitude = lightness angle. Colour of symbols indicates their membership of clusters

by arranging points within a low-dimensional space so that the geometrical distance between each pair of points reflects the corresponding inter-term similarity as accurately as possible. The points representing synonymous terms should be geometrically adjacent; antonyms should be diametrically opposite.

A three-dimensional MDS solution accounted for the similarities sufficiently well. It approximated a hollow spherical shell, with most points being roughly equidistant from the centre of the sphere. It is convenient to locate these term-points in *spherical* coordinates (θ, φ, *r*). The solution was rotated to make φ an angular 'dark to light' coordinate, running between terms glossed as 'black' and 'white' (at the 'south' and 'north pole' respectively), while θ is a *hue angle*. For instance, a number of 'red' points are clustered around θ = 90°. The low variability of the radial coordinate *r* allows us to temporarily ignore it, and plot θ and φ in Figure 1, in effect unwrapping the shell into two dimensions (altitude and azimuth). Unavoidably, this projection has distorted the structure at the poles.

An alternative approach to a similarity matrix is to apply Hierarchical Clustering Analysis (HCA) and represent it as a system of nested clusters (Everitt, 1974). Symbols in Figure 1 are colour-coded according to their membership of clusters in a HCA solution, with the colour code chosen to highlight the correspondence to English colour categories.

The NC lexicons, as a group, show signs of being near the start of a particular developmental trajectory. None of them possesses an exact equivalent of English *black*.

Instead they have terms with broader denotations, applicable to black stimuli, but also to those in other dark hues, including green, blue and purple chips. These could be glossed as 'Black-with-Blue' or simply 'Cool' terms. The symbols representing these form their own cluster in Figure 1, above the cluster of more restrictive 'black' terms from the TNG languages.

Some of the NC languages divide the Munsell palette into three broad categories that could be glossed as Cool, Light/Warm (white and lighter hues), and Red (Stage II in the Berlin-Kay taxonomy). Others have more differentiated lexicons, perhaps influenced by European colonial contact, or responding to an internal logic. In some, an equivalent of *yellow* has split from the Red category; in others, terms comparable to *green* or *blue* or 'grue' are in the process of splitting away from the Cool category (in many cases there is a great deal of variability among subjects, and these terms are by no means unanimously accepted (MacLaury 2001)). However, when collective partitions recognize these splits, they do not obscure the boundaries of the primary Warm/Cool/Red division. In this respect, the data for TNG languages differ, with less subordination to any traces of an early three-way division.

Looking at terms that would translate into English as *yellow*, Figure 1 contains separate clusters from the NC and TNG languages. The TNG 'yellows' extend out to include yellowish-green chips as well, creating a cluster of symbols that is displaced laterally towards the green region, relative to the NC 'yellows'. In addition, the TNG terms are shifted down, implying that the boundaries of these terms have also shifted to include more brownish hues while allowing paler yellow hues to be labelled as the local equivalent of English *white*.

The NC equivalents of *red* extend further into the yellow/orange region of the Munsell palette, causing them to overlap more with terms focused in that region. Conversely, the TNG 'reds' seem to extend further into the purple region. The outcome of this divergence in colour category boundaries is to displace the NC 'red' terms to the right and the TNG 'reds' to the left.

We are led to the conclusion that, although there may be reasons why colour lexicons converge towards a single cross-cultural consensus, they are not overwhelmingly strong, since departures from that consensus can persist over the time-span of linguistic divergence. It may be that categories in the TNG languages have reached some sort of steady-state or 'punctuated equilibrium',[3] while the NC languages have recently acquired some colour terms, and their colour partitions are still in a state of flux. If so, the NC languages might eventually join the TNG group at the steady-state, after fine-tuning the boundaries of the categories. Another possibility is that the TNG languages diverged from a root language that was already progressing along a different lexical pathway from the root of the NC languages, forcing them all to follow it.

Returning now to the radial coordinate *r*, it can be seen as an index of 'specificity'. If a term is not very specific – if subjects apply it to a broad range of samples, so that it

3. A term first used in biology to denote evolution by means of episodic development rather than continuous gradual change (see Eldredge & Gould 1972).

displays non-zero overlap with a number of other terms that are not immediate neighbours – then the MDS algorithm locates the term near the centre of the sphere, where it can be equally close to all those other terms. The limiting case is a term that can be applied to *any* chip, and overlaps with *every* other term; it will gravitate to the centre.

Within Figure 1, two examples of terms with this sign of non-selective use – a relatively low *r* – are *sulusulu* from Mundu (L73) and *fiingim* from Tifal (L97). Figures 2a and 2b show 'term plots' for these terms, using contours to plot the

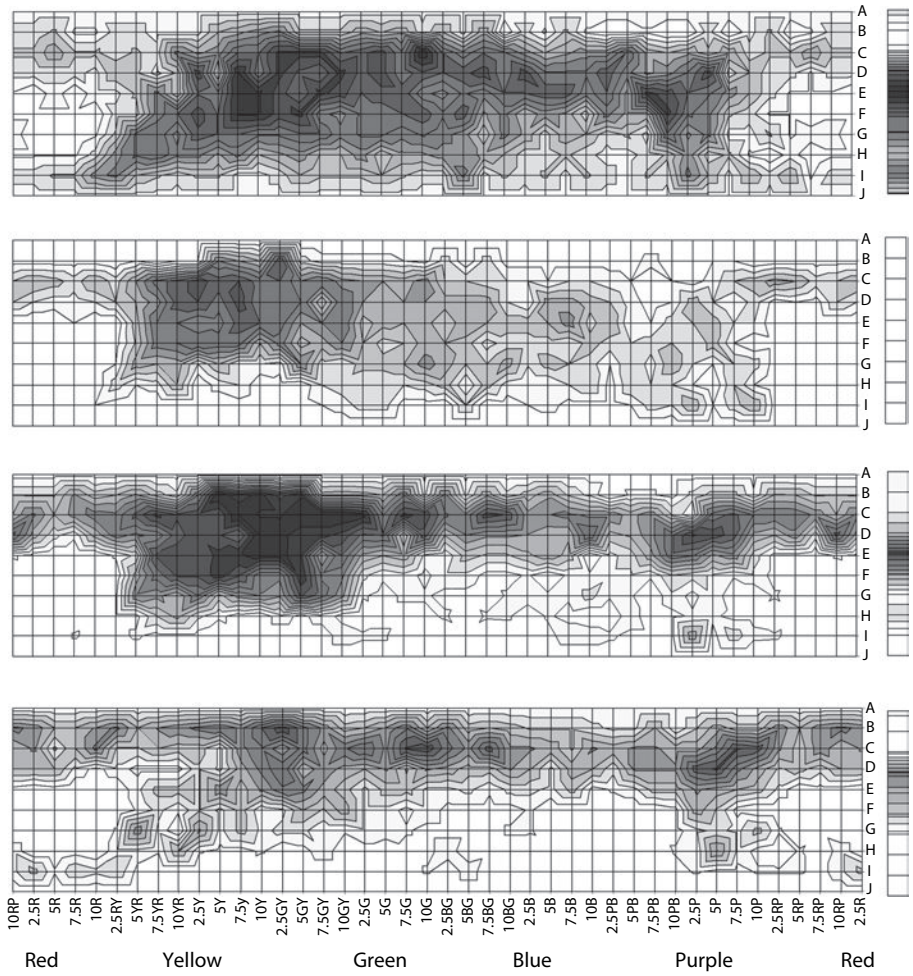

Figure 2. Contour maps (from top to bottom) for (a) *sulusulu* from Mundu (L73); (b) *fiingim* from Tikal (L97); (c) *huesseni* from Culina (L32); (d) *fwae* from Abidji (L1). Each map shows the proportion of subjects using the term to describe each combination of hue (horizontal scale, around the hue circle from 2.5R to 10RP) and lightness (vertical scale, from black = J up to white = A). Columns at right plot the frequency of use of the term to describe achromatic stimuli (greys) along the same lightness scale

proportion of informants from a language community who applied a given term across the lightness/hue grid built into the Munsell palette. For both words, usage peaks in the yellow region of the gamut, but, paradoxically, they are applied to light blue hues as well, and also to greens and purples. This broad extension was not an artefact resulting from individual variations or misunderstanding of the meaning of the terms, since inspection of the data revealed individual subjects who used *sulusulu* and *fiingim* all across their ranges. Neither term is an idiosyncratic coinage for a stimulus for which there is no name: all eighteen Mundu speakers nominated *sulusulu* at least once, while twenty-three out of twenty-five Tifal speakers used *fiingim*.

The two terms differ in one important way. *Sulusulu* fits into MacLaury's brightness route, where a language characterizes colours primarily by their lightness rather than their hue, with intermediate terms between the local counterparts of *black* and *white*. *Sulusulu* is applicable to grey chips, as well as to yellows, greens and blues (but not to samples of 'red', which attracts a special term). In contrast, *fiingim* describes purely *chromatic* qualities, with few subjects applying it to the achromatic chips. It could be viewed as a Y/G/Bu composite term, or as a chromatic wildcard.

3. Wildcard terms

This line of inquiry is easily extended to all 110 WCS languages. It turns out that 775 terms meet the consistency criteria described above. As before, we summarize the relationships among them (their degree of overlap with one another) by applying MDS and plotting the three-dimensional solution in spherical coordinates.

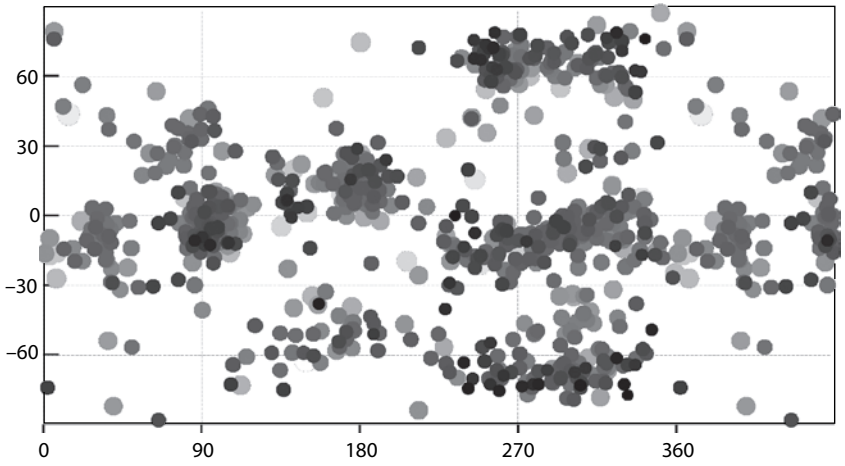

Figure 3. Angular coordinates with same axes as Figure 1: the lighter and larger a symbol, the nearer that term is to the centre of the MDS solution

The size and lightness of each circle in Figure 3 increase for smaller radial coordinate *r* to show the vagueness or broadness of that term's usage. Note that the diagram lacks separate clusters of 'blue' and 'green' terms; a strip of circles, representing the 'grue' terms found in many languages, forms a blue-green continuum. Below that strip, between it and the large cluster of 'black' terms, is a cluster of broad circles representing 'Black-with-Blue' composite terms. Above the blue/green band, a tight cluster of small, dark circles represents focused terms applied specifically to light blues. Spanish has a comparable term *celeste* for light blue as distinct from *azul* '(generic) blue' (Harkness 1973), and Russian has *sinij* 'dark blue' and *goluboj* 'light blue' (Paramei 2007).

Examining terms with low values of *r* reveals additional examples of words that characterize colour by level of lightness. These include *huesseni* from Culina (L32) and *fwai* from Abidji (L1), with patterns of usage that are plotted as Figures 2c and 2d.

We also encounter lightness-descriptive terms that are less inclusive, and attract a more fragmented pattern of usage because they belong to languages which have acquired terms for green and yellow as well as for red (Figure 4). That is, they can be applied to any hue that does not fall into the 'catchment areas' of those options. Thus they denote brown hues, greys, mauve, sometimes pinks, and light blue chips (or to put it another way, browns, greys and pastels). These are primarily but not exclusively low-saturation chips in the Munsell palette. For comparison, the Apache wildcard *łibaah* (Greenfeld 1986) is included in Figure 4. Futunese *k*^{h}*ósi* conforms to the same pattern (Dougherty 1978).

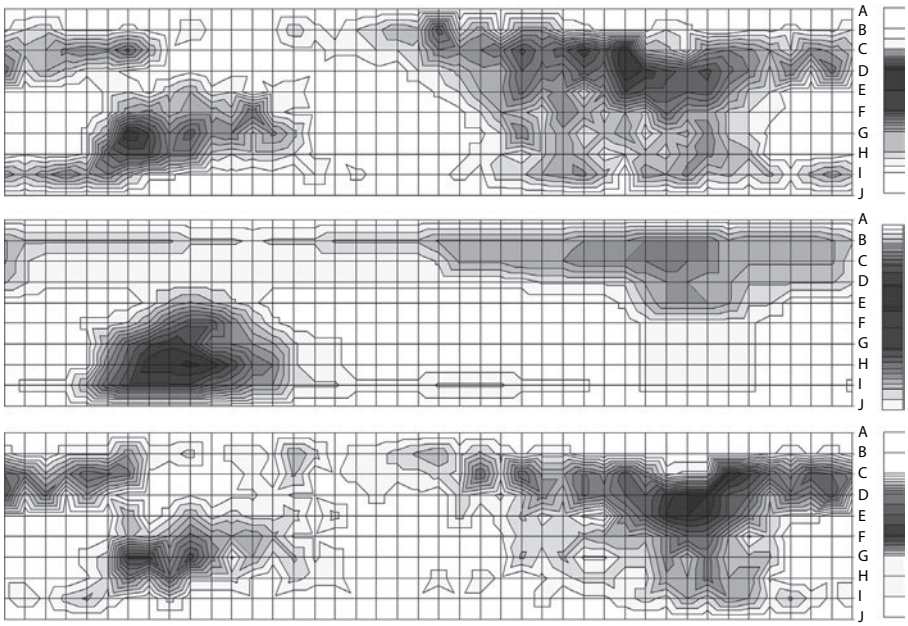

Figure 4. Contour maps (from top to bottom) for (a) *pohui* from Ese Ejja (L37); (b) *bulow* from Tboli (L94); (c) *łibaah* from Apache. Same scales as in Figure 2

However, a parallel line of lexical evolution contains purely *chromatic* wildcards, which are never applied to the grey chips. Two examples shown as Figures 5a and 5b are applied primarily to purple hues, with a secondary extension to browns. It happens that these are cognate terms from two related Indo-Aryan languages, Mawchi (L65) and Vasavi (L101). The same family also provides the converse: chromatic wildcards that are applied primarily to browns, and sometimes to the purple region of the colour gamut (Figures 5c and 5d).[4] It may be that these represent transitional stages, with *dzhabo* and *dzhambəlʌ* caught in the act of retracting from their brown usage and evolving into equivalents of *purple*, while *bur* and *bhurʌ* are specializing in the opposite

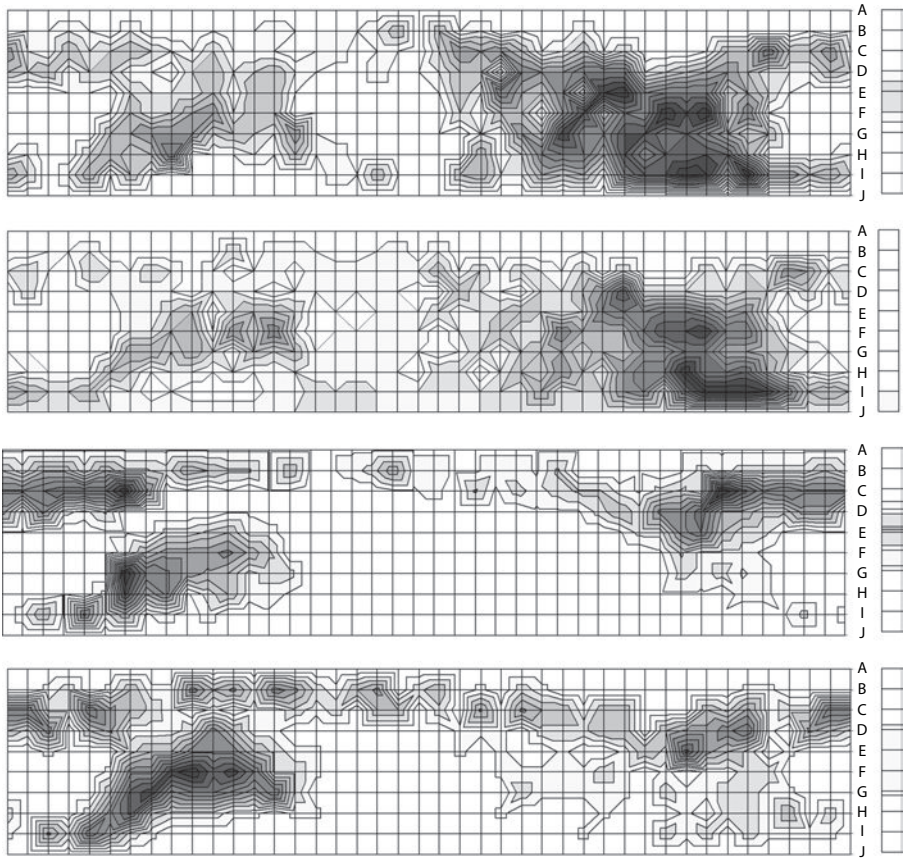

Figure 5. Contour maps (from top to bottom) for (a) *dzhabo* from Mawchi (L65); (b) *dzhambəlʌ* from Vasavi (L101); (c) *bur* from Bhili (L15); (d) *bhurʌ* from Vasavi. Same scales as in Figure 2

4. The Mawchi lexicon contains a cognate term *bhuro* that shows the same pattern of chromatic use but can also apply to grey chips.

direction into equivalents of *brown*. The data are also reminders that not all cultures are as preoccupied as we are with conceptualizing the colour domain or insisting that terms in that domain be used consistently, with niceties and nuances. It may be relevant that the nearest equivalent in Vasavi to *yellow* (*piuli*) is also applied by a significant minority of informants to the mauve and purple chips.

The distribution of disconnected regions of the Munsell grid that comprises a term's extension depends on the combinations of restricted colour terms also present in the language. The Guaymi (L42) term *kare* was applied most consistently to green chips, but also to purples.

Finally, there is the phenomenon of 'peripheral red' (Kay, Berlin, Maffi & Merrifield 1997: 34): terms applied to hues that contain some element of redness without being good exemplars of 'red' (that is, orange, pink, mauve, purple, maroon and brown). The WCS presents a number of examples (Figure 6). Such terms have been glossed as a concrete term, 'earth-like' (Kay et al. 1997: 48). Alternatively, they have been cited as evidence that 'redness' has a special status in human cognition, to such an extent that the special quality of diluted or imperfect redness attracts a term of its own. In the present taxonomy of wildcards, peripheral red can be understood as a special case of a chromatic wildcard that covers those hues left over after the restricted terms for red, green, blue and yellow have all accounted for their regions of the colour gamut.

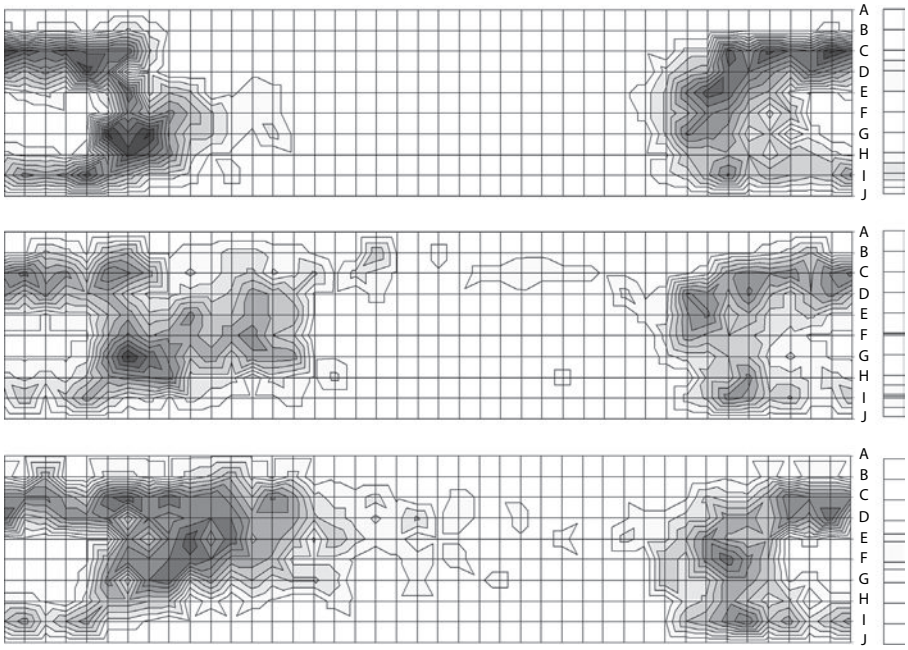

Figure 6. Contour maps (from top to bottom) for (a) mili from Behinemo (L11); (b) pareeca from Arabela (L10); (c) wãwanakoko from Abidji (L1). Same scales as in Figure 2

Roberson downplayed the universal constraints to which colour terms must conform, the common factors that unite them across languages. One constraint was that any term should form a single connected region when plotted on a map of the colour gamut: "No language has ever been reported to have a category that includes two areas of color space...but excludes an area between them" (2005: 65). We have seen a series of counter-examples to this generalization.

4. Discussion

In contemporary industrial cultures, colour has come to convey all manner of abstract information and arbitrary meanings, but not every culture talks about colour so obsessively (Kuschel & Monberg 1974). Many languages, furthermore, have terms for specific hues but not a superordinate word for 'colour' as a general abstraction – a word, that is, for the entire *domain*. One could infer that there is nothing to single out the spectral properties of surfaces as a natural, compelling topic of conversation, as distinct from other aspects of surface appearance such as texture, gloss, glitter, lustre or object identity. Critics of the Munsell-palette paradigm have argued that colour is a cultural construct rather than a 'natural kind' (for example, see Lucy 1997; Lyons 1995).

We began with the Emergence Hypothesis, which concedes that languages can lack a lexical partition of the complete colour gamut (in contrast to English, where the 'basic colour terms' between them cover any hue we encounter). The non-partition property may be more common than the WCS would suggest, since Munsell-palette data are not ideal for detecting it. If pressed to label a problematic sample of hue, informants resort to a number of strategies. They might, for example, extend the terms available in their colour lexicon beyond their normal boundaries, or use words from a specialized context-specific vocabulary with secondary chromatic connotations.

If WCS informants have no tradition of discussing colour as a universal attribute – detached from specific objects in their environment – then there is no evidence that any labels they nominate to describe the chips would be used the same way in real-world situations. They might be terms of broad symbolic implications: not colour terms at all outside forced research conditions. Lyons (1995: 212) cites the Hanunóo language, in which the terms *rara?* and *latuy* embody "an opposition between dryness or desiccation and wetness or freshness (succulence) in visible components of the natural environment" (Conklin 1955: 342).

Nevertheless, these are ways in which a language with a non-partition lexicon might acquire a wildcard term for colours that 'fall through the cracks' (see Section 3). Other avenues exist. A term for a prestigious fabric or a specific dyeing technique might be pressed into service, losing its original meaning and gaining a chromatic role, as in the case of *scarlet* and, perhaps, the medieval French term *pers* (Gage 1993: 80). The point is that the initial extension of such a term is not necessarily continuous (Figure 5). But interrupted ranges are unlikely to be stable: one imagines that speakers of the

language would settle on one portion as the term's central meaning while downplaying other portion(s), progressively shaping the term into a conventional hue-specific term. So this is one pathway for a language to acquire equivalents of *purple* and *brown*.

Another model of lexical enrichment interprets the eleven BCTs in English (and other languages) as expressions of eleven distinct qualities of colour experience. When a language initially lacks a term for one of these qualities, the name of a suitably coloured referent is applied as a metonym to fill the gap, then becomes an abstract term as routine use erodes its concrete denotation. However, this model does not predict the finding from Section 2. Inter-language variations among corresponding terms in their precise boundaries, and centroids in the colour gamut, are linked with language-family affiliations – as if the exact location of some terms depends on the pathway a language followed previously, as it acquires an increasingly differentiated colour lexicon.

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Touchy-Feely colour

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The default opinion in philosophy is that we perceive colours to be intrinsic properties of things, properties that objects have regardless of their relations with perceivers. This intrinsic-intuition is considered a crucial objection to *relational* theories of colour, ones that account for colours in terms of interactions between perceivers and objects. In this paper I defend relationism by analysing the motivation for the intrinsic-intuition. Firstly, I argue that intuition relies on a historically entrenched, passive model of vision. Secondly, I discuss recent psychophysical work on the connection between colour and perceived material stability. Finally, I develop a relationist phenomenology of colour by making the comparison between colour vision and the active – and interactive – sense of touch.

1. Introduction

Philosophers writing on colour have concentrated on one specific metaphysical question, "what are the colours?". It is agreed that if colours are anything, they must be some sort of property. It is often held that colours are *intrinsic* properties of objects. Roughly speaking, an intrinsic property is, "a property that a thing has (or lacks) regardless of what may be going on outside itself"" (Yablo 1999: 479). Being an intrinsic property excludes being a *relational* property. Relational properties are ones that describe how different things stand with respect to each other. So 'being round' is not a relational property, whereas 'being rounder than a rugby ball' is.

Many philosophers, including David R. Hilbert (1987) and Frank Jackson (1998), have claimed that the redness of a cherry is a property that the fruit has regardless of the way that perceivers respond to it, and regardless of the other objects surrounding it. It follows that the cherry is still the same red when shaded by leaves on the tree, when night falls, or in a world without creatures to perceive it. The primary justification for the claim that colours are intrinsic properties comes from the intuition that colours look as if they belong to external objects, that in our perceptual experience it does not appear that the existence of colours depends on our perceiving them.

Despite the popularity of the intuition that colours are intrinsic, and therefore not relational properties, there is much to be said for theories which posit that colours are relational (Cohen 2004). Various clues point to a certain perceiver dependence of the colours. For one thing, the colour visual systems of different species – from budgies to bees to chimpanzees – do not converge on the same physical properties of objects (Thompson, Palacios & Varela 1992). Nor do the visual systems of different human beings, which show substantial variation in wavelength sensitivities, and hence in subjective colour matching (Hardin 1993). Consequently, your assessment of the similarity of shades of peach and pink could well be at odds with mine, and we would be at a loss to find an objective standard to decide between us.

The most well known relationist theories are *dispositional* ones. These were first put forward in the seventeenth century, when there was a felt need to reconcile the new mechanical world view – which found no place for colours (as we see them) in the physical world – with the insight that visual perception is in some way caused by external events. The dispositionalist states that the colour orange is the disposition of an object to cause an orange experience in normal human perceivers in standard viewing conditions.[1] This is a dispositional property shared by satsumas and marigolds, as well as oranges and mangoes. Dispositionalists normally struggle at the point at which it becomes necessary to categorize normal perceivers and define standard conditions. This paper is not a defence of dispositionalism, but of relationism in general.

Relationist theories stand in opposition to the supposedly robust intuition that colours are intrinsic properties. Indeed, many philosophers believe that colour relationism is defeated by the strength of the intuition.[2] As Boghossian and Velleman (1989: 86) write:

> When one enters a dark room and switches on a light, the colours of surrounding objects look as if they have been revealed, not as if they have been activated... If colours looked like dispositions, however, then they would seem to *come on* when illuminated...just as a lamp comes on when its switch is flipped. Turning on the light would seem, simultaneously, like turning on the colours...Conversely, when the light was extinguished, the colours would not look as if they were being concealed or shrouded in the ensuing darkness: rather, they would look as if they were becoming dormant...But colours do not look like that; or not, at least, to us.

This paper is a defence of relationism against such claims. I will not be tackling the intuition head on, arguing that, contrary to consensus, the phenomenology of colour is that colours *are* simply relational. Rather, I will take two detours that I believe give us much insight into this intuition. The first detour is historical, where I examine the

1. E.g. John Locke, on most interpretations. See M. Johnston (1992) for a recent formulation of dispositionalism.

2. Called the "intrinsic-intuition" below.

links between the intuition and a popular model of vision as the most objective of senses (see Section 2). The second detour goes into the science of colour perception, looking at the reasons why colours normally appear stable, and observer and context independent (see Section 3). Then in Section 4 I offer up a new account of colour phenomenology, inspired by the sense of touch.

2. History of an intuition

There is a way of thinking about vision which casts sight as the most *objective* of the senses. That is, of all the senses it is believed that vision is the one to present us with a picture of the world best matching an external reality. This 'ocularcentric' vision of vision has been identified as the dominant view from the Middle Ages to the twentieth century. The basic idea is that *seeing* is the paradigm of *knowing* (Jay 1993; Rorty 1979).

The intuition of the objectivity of sight gets perhaps its most extreme expression in Jonas' (1954) article, the *Nobility of Sight*. Jonas was a phenomenologist and student of Husserl. He took it as evident from our experience that vision is objective, writing that, "all I have to do is open my eyes, and the world is there, as it was all the time" (512) and that "objectivity emerges pre-eminently from sight" (513).

The intuition of objectivity is obviously kin to the intuition that the properties revealed by sight are intrinsic ones. To recap, intrinsic properties are those that an object has regardless of its interactions with other objects. These are contrasted with relational properties which describe how an object stands with respect to other objects or perceivers. The objective-subjective distinction, on the other hand, contrasts our apprehension of things as they are "in themselves", i.e. regardless of the peculiarities of our point of view concerning them, with the subjective apprehension which is tainted by our peculiar slant on things. According to the objective intuition, visual experience represents the intrinsic properties of things, whereas the intuition of subjectivity takes vision to be representing how an object stands in relation to a viewer.

Also relevant is the notion that vision is the most passive of senses. Vision is taken to be the mere reception of light rays on the retina. In particular, it is not appreciated that the eyes customarily move, and that these saccadic glances constitute an active probing of the world. More will be said about 'active vision' in Section 4. The point to be made here is that this model has a clear historical lineage (Spruit 2008). In the ancient and early medieval world, intromissionist and extramissionist theories of vision vied for supremacy (Lindberg 1976). Extramissionism is the Platonic idea that sight comes about when 'fire' emitted from the eye encounters external objects and is then reflected back to be received by the eye, which harvests this information. It is an active model in the sense that sight is something that happens at the eye's own instigation, with the eye selecting what in the world is to be made visible. In contrast, the intromissionism of Aristotle made the empirically correct supposition that no rays come out from the eye. But this led to the casting of vision as a passive sense, the inert reception

of visual information. By the late Middle Ages, the Aristotelian model was the dominant one. The scholastics believed that visual information was imparted by "intentional species", immaterial copies of properties of objects, such as colours, that made their way to the eye (Lindberg 1976; Biernoff 2002; Knuuttila & Kärkkäinen 2008). Moreover, the Aristotelian view is marked by a strong perceptual realism: the world is, in itself, just as we see it. There is no corruption of the objective visual world due to the interference of our sensory apparatus.

The pattern of influence from Aristotelian realism to modern theories of vision is complex (Jay 1993; Clark 2007). Certainly, literal realism about colour was dropped by the leading figures of the seventeenth century. Galileo declared unambiguously that colours do not belong to external objects, that they reside only in the minds of perceivers. Descartes and Locke both wrote that in some sense colours are external properties, i.e. the physical causes of people's colour perceptions. But they did not subscribe to the Aristotelian and scholastic idea that things are coloured in just the way that we perceive them to be, and that there is a literal resemblance between our perceptions of colour and colours adhering to objects.

However, as I have argued elsewhere (Chirimuuta forthcoming), it seems that some other tenets of the Aristotelian view were *not* rooted out by the seventeenth century innovators. These include the idea that the aim of vision is to give a faithful measurement of external properties; the idea that vision is a passive sense; and thus the idea that when visual perception is veridical, we have true measurement of physical quantities, the intrinsic properties of things, rather than a subjective impression of how things happen to affect me. These views are reflected in the seventeenth century writing on primary, as opposed to secondary, qualities (Smith 1990). Even though perceptual realism came to be rejected when speaking of the secondary qualities, like the colours, it was still accepted that our perceptions of primary qualities (shape, motion, bulk, etc.) could be faithful representations of an external reality.

What does all this tell us about colours and the intrinsic-intuition? What is important is that an Aristotelian framework for vision did stay in place, one in which it was "intuitive" to think of vision as representing intrinsic properties of objects. After the scientific revolution it still seemed natural to believe that an intrinsic geometric property, like shape, was visible to the human eye. It was still "intuitive" to believe that colours appeared before our eyes, *as if* they were intrinsic properties belonging to things. What became paradoxical was this Aristotelian understanding of our colour phenomenology *combined with* a revised scientific ontology which posited that the only properties belonging to material things were quantitative or mathematical ones, not qualitative ones like colour (Des Chene 2006). This, in essence, is the metaphysical problem of colour: *how can it be that we see a world full of colours, if no such properties could belong to the world?* It would seem that vision is an elaborate hoax, a virtual reality conjured up by the brain (Hardin 1993).

However, what is clear now is that colours come to be seen as problematic because of the strength of the intrinsic-intuition. If it came naturally for us to take what we see

to be at least in part perceiver-dependent, then the finding that colours are not simply "out there", but that our perception of colour is influenced by the workings of our eye and brain, would not be disturbing. The idea to be considered here is that the intrinsic-intuition has historical roots: it might just be a hangover from the Aristotelian-realist theory of vision that has been so influential down the centuries. My claim is that the intrinsic-intuition would not seem so compelling from the perspective of an alternative theory of vision. And of course there have been alternatives. Above I mentioned the Platonic extramissionist view. There are recent theories that construe vision as an active rather than a passive sense – the philosophy of Merleau-Ponty would be a prime example. Art historians in particular have written about how frameworks for thinking about vision change from culture to culture, and era to era. The subjective, embodied 'visuality' of the early Middle Ages is often contrasted with the more theoretical, Aristotelian, approach of the late Middle Ages, which prized vision as an objective sense (Biernoff 2002; Camille 2000).

3. Secret life of an intuition

In this section I take another look at the intuition that colours are stable and intrinsic properties of things. In the previous section, I put forward the argument that this intuition has been shaped by our 'visuality', our commitment to the idea that vision is the sense most capable of representing to us an objective, external world. However, the historical explanation may be only part of the story. Here I present some psychophysical findings about colour perception that also shed light on the realist intuition.

Figure 1. Colour and scene segmentation. (Reproduced with permission from Fred Kingdom)

Vision scientists now hold that colour is very much involved with the perception of form. For example, with the parsing of cluttered visual scenes into different objects (see Figure 1), and with the recognition and memorization of those objects (Shevell & Kingdom 2008; Mollon 1989; Kingdom 2011). Note that the perceived salience of different colour contrasts seems to depend on the interests of the animal. If it were not for primates' vested interest in fruit as a food source, it is improbable that cherries and leaves would appear as different in colour as they do to us.

Colour contrast is particularly useful because it is more likely to indicate a material change from one surface to another than is achromatic contrast, since achromatic contrast often indicates the presence of shadows, rather than material objects. Kingdom, Beauce and Hunter (2004) conducted experiments to assess people's interpretation of boundaries in visual scenes when these were marked by achromatic or colour shifts. The achromatic shifts were likely to be interpreted as a change in surface material only when these were aligned with colour shifts.

Another observation of Kingdom's is that shadows which do happen to be coloured are less likely to be recognized as shadows and are more likely to be interpreted as indicating a change in surface material (see Kingdom 2011: 7 Figure 5). Kingdom has attributed these effects to the visual system's "colour as material" assumption.

Such results show that colour vision is very much tied up with our perception of objects. Moreover, the idea that the visual system makes use of prior assumptions about colour and materiality is a possible explanation for the strength of the realist intuition that colours are intrinsic properties of objects. For we do tend to take it for granted that the physical, material properties of things are intrinsic, not alterable by objects around them, or by our viewing habits. If, then, colour vision is part of the sensory process by which we recognize that one surface material differs from another, that a change in colour perception usually indicates a change in material, it makes sense that we should interpret colour perceptions as flagging intrinsic properties. But it is one step too many to say that our colour vision commits us to the belief that colours are intrinsic properties. The intrinsic-intuition has had a hold over the philosophical debate because it has been assumed that raw visual experience is attributing an intrinsic colour property to objects. Kingdom's results entail no such thing, though. What they do imply is that vision uses spectral discrimination to flag up stability in the material surfaces of objects. They suggest that we think of colour vision as indicating the *stability of things,* rather than that we think of ourselves seeing stable chromatic properties, intrinsic to objects. Perception of a change in colour as a change in surface material is compatible with a relational account of colour by which colour appearances are as much determined by my perceptual process as they are by objects in the world. This relational colour phenomenology is the subject of the next section.

4. Touch-like Vision

We have now completed two different detours. The first went back to the historical roots of our thought on vision. It revealed the association between the intrinsic-intuition and a passive model of vision which construes sight as the most objective of senses. The implication was that, were we to subscribe to a different theory of vision, our intuitions might well shift. However, the second detour, into the psychophysics of colour perception, gave us reason to think that our experience of colours as stably embedded in objects is due to some deep features of our visual system. One might conclude from this that the intrinsic-intuition will not shift, no matter how many intellectual revolutions we undertake. But I do not think that this is warranted, for the psychophysical results explain why we see colours as stable, and belonging to material objects, but they do not support the claim that our phenomenology commits us to believing that colours themselves are intrinsic properties of things.

The question is, how can these two different insights be combined, and in such a way as to defuse the objection to colour relationism? What I offer in this section is a reinterpretation of the phenomenology of colour that is compatible both with the psychophysical facts, and with the relationist colour theory. And it is an active theory of vision, one which deliberately breaks with the passive model that has made the intrinsic-intuition seem irresistible. The basic idea is to think of vision as a sense more like touch. Jonas illustrates what, in his opinion, is special about vision, by contrasting it with touch. He believes that with vision, as opposed to touch, the information that we receive is assuredly objective because uncontaminated by choices over how we explore the world:

> Touch has to go out and seek the objects in bodily motion and through bodily contact...whereas in sight selection by focusing proceeds non-committally within the field which the total vision presents. (1954: 512)

In Jonas's extreme version of the realist framework, vision is conceived of as the distanced, contactless sense, a pure reception of information rather than an active engagement with the world. This way of understanding vision is empirically false. As it happens, we would be unable to read or view photographs if our body and eyes were static, because of the fatiguing of our photoreceptors by constant stimulation. What is more, because of the heterogeneity of the surface of the retina, movement of the eyes (*saccades*) with precise gaze control is essential for normal vision (see e.g. Findlay & Gilchrist 2003; Burr & Morrone 2004; Schall 2004; Steinman 2004).

Empirical work gives credence to Merleau-Ponty's (1968) claim that the gaze is something like a grasp. That is, we use the foveating gaze, the targeting of an object on the highest acuity region of the retina, to gain a visual handle on the thing (see, e.g., Schütz, Braun & Gegenfurtner 2009 on saccades and object recognition). But subjective experience has been found to be an unreliable guide to eye movement, because of the effect of *saccadic suppression*, the momentary impairment of vision for the duration of

the saccade. So it is no wonder that the surface phenomenology of vision suggests to us that our eyes are relatively passive and immobile, even though, just as much as the sense of touch, sight relies on our active probing of the environment. As Land and Nilsson (2002: 178) summarize, "our eyes search the surroundings for information rather than simply absorbing it". Naturally, how we search depends on what we need to do (Yarbus 1967). And, what is more, our locomotion through the environment is best guided by the seemingly random saccades of the 'active free gaze' (Wilkie & Wann 2003).

With vision we may be inclined to forget, as Jonas does, that the objects that we see are physically impinging on us, through the medium of light, because of the distances involved – but that is just the prejudice which takes only mechanical effects in nature to be real ones, so neglecting optical and energetic actions and events. Likewise we may forget that our actions play a role in what we see, because their contribution is less obvious to us than is the action of a hand when it reaches for something – we do not pick things up with our eyes, but still our eyes glide over them. Moreover, these two senses often operate in tandem. It has been argued that haptic discrimination of spatial properties 'calibrates' visual judgement during early development, and vice versa (Gori, Del Viva, Sandini & Burr 2008). These are all points to keep in mind. I propose that the analogy between vision and touch can inspire a relationist interpretation of visual experience and colour phenomenology, as a counter to the assumption that we necessarily experience colours as intrinsic properties.

To see how this might work, let us remind ourselves of the intrinsic-intuition and the objection to colour relationism. The argument is simply that, say, when I turn on the lights it does not look as if the blue paint has just regained its colour. Rather, it seems as if the paint was coloured all along, even in the dark. The question is, *could the same objection be raised against a relationist account of touch?* Are the ways that objects feel to us – their hardness or softness, abrasiveness or smoothness, roughness or silkiness, etc., etc. – necessarily experienced as intrinsic qualities of those objects? I think not. Because touch is a mechanical, contact sense, where the interface between perceiving body and object is more obvious, it is natural to think of what we feel as being due to the interaction of body and object. One can imagine a sensation of touch being generated by the interaction of these two, something like the friction between two surfaces generating heat. Thus the qualitative abrasiveness of sandpaper is not understood to be a property it possesses in itself, but the particular way that its surface feels to me.

Since there is obvious physical contact between observer and object, it is easy to think of the sensory operation as linking them and *relating* them in some way. Furthermore, the patently active role of the body during tactile exploration makes intuitive the idea that there is a bodily contribution to what we feel. In order to learn about an object by means of touch, we must pick the object up or go up to the object, and place our fingers on enough different parts of the object. Therefore relationism can treat tactile experience in an intuitive way. For example, it is natural to say*, this fur is soft because of the way it brushes against my skin when I stroke it*. What I feel, and what I feel myself feeling, is due to *how* I touch this thing – a joint project of the thing and me.

Furthermore, in emphasizing the commonality of vision and touch, a relationist colour phenomenology may become an intuitive one. The question now is, if it is easy to say, *the feather is felt as tickly because of how the skin on my neck happens to respond to its stroke*, is it any less easy to say, *this tomato is red because of the way it selectively stimulates my retina when I glance at it?* Perhaps it is easier to give relationist readings of tactile experiences because we have less *invested* in touch. Berkeley aside, our intellectual tradition has not granted touch a primary role in our getting an objective picture of things (Jay 1993; Paterson 2007). If touch is not taken to aim at intrinsic properties, in the way that vision is, there will be less resistance to relational touch – but that is not to say that we should never revise historically entrenched intuitions. If we do resist historic prejudices, what does a relational phenomenology of colour actually look like? The idea is to think of colours as the *way things look to me*. One can say that the experience of a thing as being coloured flags a relation which holds between the thing and oneself – the perceptual relationship by means of which one comes into visual contact with the thing.

Another way of coming to this is to think back to the original objection to colour relationism. It was said that a tomato, say, does not look to become red when I go to the garden to pick it. It looks as if it had some property, 'redness', all along. But neither does the fur feel as if it has just become soft as I run my fingers over it. This is because we are not obliged to think of the softness as a property that could either come in or out of existence, or be permanently there in the fur. Instead, I can think of the softness as how the fur feels to me – how it interacts with my skin as I stroke it. Likewise, in a touchy-feely vein, I can think of the colour not as an entity that may or may not be there, but as the *way* that the tomato presents itself to my sight. Or equivalently, I can think of the colour as the selective grasp of the tomato made by my sight – a 'take' on the tomato which is particular to me or my species, one due to my particular retinal sensitivity, and to the particular use that my visual system makes of spectral information there gathered.

5. Conclusion

To describe how the world looks to us when we open our eyes may seem a straightforward task. Yet any such description will be informed by an intellectual tradition as old as the first theories of vision. With insight into this tradition, and awareness of our other senses, new ways of thinking about colour can emerge.

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Towards a semiotic theory of basic colour terms and the semiotics of Juri Lotman

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Semioticians like BCT theory, although there is no semiotic theory of BCTs. In Juri Lotman's modelling framework, one can analyze the BCTs using the formula "language = code + history" and abandon the technical definition of a BCT (a term is basic if it is frequent and passes some hurdles in experimentation). One can paraphrase Lotman's formula in the following way: "colour language = BCTs and non-BCTs + history of language and culture". In this formula, the BCTs form the nucleus of the colour code of a language. A semiotic theory of BCTs can be built up using the formula and numerous dichotomies, i.e. language axes, such as static vs. dynamic, syntagmatic vs. paradigmatic, synchronic vs. diachronic, semasiologic vs. onomasiologic, and logical vs. mythological. These axes organize and model the linguistic colour space (or field of colour).

1. Introduction

Semioticians like colour, for example in art, architecture and landscape. Although they see colour signs everywhere, it is remarkable that colour hardly constitutes a central topic in semiotic studies. Gunther Kress and Theo van Leeuwen, the authors of a provoking textbook on the grammar of visual design, write that

> ...colour has, on the one hand, developed into a 'mode', a systematically organized resource. But on the other hand, this system is a physical, rather than a semiotic system, a kind of 'phonetics', although the basic elements of the system, the... colours, have played a key role in visual semiotic practices and in accounts of the meaning of colour. *Semiotically*, a single 'system' has not developed. (Kress & Leeuwen [1996] 2006: 228)

According to Juri Lotman, one of the founders of the Tartu-Moscow school of semiotics, each modelling system can be viewed as a *language* (Lotman 1967). Colour is a modelling system. In visual semiotics, the colours form a phonetic alphabet of visual language. Lotman also argued that human language (i.e. national languages) is the primary and culture (i.e. the languages of culture, including visual languages) constitutes the secondary modelling system.

My task is not to analyze the whole visual semiotics of colour, but rather to narrow my study to colour language semiotics or, more precisely, to the semiotics of basic and non-basic colour terms.

In this paper, I will try to explain the theory of basic colour terms (Berlin & Kay 1969) in terms of Juri Lotman's semiotics. But first I will critically introduce the theory of basic colour terms and briefly discuss some of Lotman's basic ideas on language.

2. Juri Lotman's semiotic ideas on language

Juri Lotman held that each modelling system can be viewed as a language (Lotman 1967). Natural languages, including English, Estonian and Russian, should be viewed as primary modelling systems. Languages of culture constitute secondary modelling systems (see, e.g., Lotman 1977a).

In his article "Language as the Material of Literature", Lotman defined language (as common in semiotic disciplines) as "a mechanism of sign communication serving the goals of storage and transmission of information" (Lotman 1976: 17). For Lotman, the sign is the meaningful element of a given language. In semiotics and related information and communication theories (e.g. Roman Jakobson 1960 & 1972; Thomas A. Sebeok 1963), confrontation of code (language) and message (speech) is, relying on Ferdinand de Saussure, common, since language expresses the invariant aspect of the structure of a communication system, and speech corresponds to variant realizations of language.

In one of his last works, *Culture and Explosion* (1992), Lotman abandoned the traditional communication model and the idea of the equality of language and code. He warned that equating language and code in a communication process is not as harmless as it seems. Such an approach requires the identical nature of the addresser and addressee, which is transmitted to linguistic reality. It requires the use of the same code and identical memory (capacity). The term "code" is accompanied by the idea of a created and artificial structure validated by a momentary agreement. Code does not presume history, i.e. psychologically it makes us focus on an artificial language which is considered the ideal language model. "Language", on the other hand, provokes a subconscious idea of the continuance of existence. Language is a code with its history (Lotman 1992: 13).

In brief, the above-mentioned can be summed up in the following equations:

Language ≠ Code
Language = Code + History

Although the aim of communication is adequacy, Lotman pointed out that an addresser and addressee who are identical to each other understand each other perfectly but have nothing to talk about (1992: 13).

We could imagine the world with equal colour perception and language, without any variation. Although people have more or fewer colour terms, such a world seems black and white.

People are different; they have different education, memories, etc. For that reason, their communication is based on the contradictory formula "equivalent but different". According to Lotman, the first part of the formula makes communication technically possible and the second part makes it meaningful in context (1977a: 96).

Even when the codes used in languages are equal, the histories of languages, cultures, tribes, etc. are different. It follows that languages are always different.

If we take a look at the major dilemma of universalism vs. relativism in anthropology and linguistics during the last century, we can see that cultural relativism is characteristic of Lotman's approach to language. He wrote:

> The languages of the world's peoples are not passive factors in the formation of culture. On the other hand, languages themselves are products of a complex multi-century cultural process. Insofar as the vast, continuous, surrounding world appears in language as discrete and constructed, i.e. as having a distinct structure, natural language, which is correlated with the world, becomes its model, a projection of reality upon the plane of language. And insofar as natural language is one of the major factors in national culture, the linguistic model of the world becomes one of the factors regulating the national perception of the world. The formative influence of national language on secondary modelling systems is a real and indisputable fact. It is especially important in poetry. (Lotman 1976: 20)

Links between Lotman and relativism have been referred to by, for example, Susan Bassnett. She writes that Lotman's view, according to which language is a modelling system, and art and literature as secondary modelling systems have been derived from language as a primary modelling system, is directly related to the Sapir-Whorf hypothesis (Bassnett 2002: 22). Lotman himself, together with Boris Uspensky, has declared that "no language (in the full sense of the word) can exist unless it is steeped in the context of culture; and no culture can exist which does not have, as its centre, the structure of natural language" (Lotman & Uspensky 1978: 212).

For Lotman, language was not an unstructured system. On the one hand, he distinguished between language code and history and, on the other hand, between numerous dichotomies, e.g. static vs. dynamic, syntagmatic vs. paradigmatic, synchronic

vs. diachronic, semasiologic vs. onomasiologic, logical vs. mythological, etc. (cf. Mangieri 2006: 77–79).

3. Very short critique of the theory of basic colour terms

Since the publication of the much disputed *Basic Color Terms* by Berlin and Kay in 1969, little progress has been made in linguistic analysis of BCTs (cf. Sutrop 2002). The focus of research on BCTs has shifted even more towards psycholinguistics than in the original theory. The linguistic aspects of the BCTs are often underestimated (cf. Sutrop 2002). I define 'basic term' in the tradition in which Berlin and Kay (1969: 5–7) defined BCTs:

> A basic term is a psychologically salient, in most cases morphologically simple and native word, which belongs to the same word class and has the same grammatical potential as the prototypical member(s) of its domain. It is a term that generally denotes an object, a quality, or a phenomenon at the basic level, and which is applicable in all relevant situations. (Sutrop 2001: 275)

The real problem in colour language studies is that we often use the technical definitions of BCTs instead of the linguistic ones. It makes no difference whether the fieldworker or experimenter uses the original method of Eric H. Lenneberg and John M. Roberts (1956) or the method applied by Berlin and Kay in 1969 or the World Colour Survey or the Field Method developed by Ian Davies and Greville Corbett (1995). Technically a colour term is a BCT first if it is salient in a colour-listing task and second if the term crosses several technical hurdles in a colour-naming task. It is characteristic that, in the first task, the subject lists colour names without any reference to the real colour world and, in the second task, the sample colours are shown to the subject context-free on a colour chart or in random order on a light grey background.

What happens when we use such context-free methods can be illustrated by an example from the Estonian Sign Language. There are two reds. One term, RED_1 (hand points to cheek), is for solid objects, and another, RED_2 (hand points to lips), is applicable only to liquids. In the colour-naming task, the subject has no opportunity to sign the term RED_2 (Hollman 2008: 857; Hollman & Sutrop 2010: 149).

If we focus only on the BCTs, we ignore the rich non-basic colour vocabulary. For example, in the experiment (list task and colour-naming task) eighty Estonian subjects named 759 different colour terms; eleven BCTs constituted only 1.4% of the richness of the colour language of these people. Of course the eleven BCTs of Estonian were used more frequently. They covered 2921 instances, i.e. 43.5% of the terms (6712) used in the experiment (Sutrop 2002: 133). Considering these figures, it is evident that, by focusing only on the BCTs, we ignore at least 98.6% of the richness of the Estonian colour vocabulary. The Database of Estonian Colour Terms at the Institute of the Estonian Language in Tallinn lists more than 1500 colour terms, mostly from dialects

(Oja 1998). If we consider colour terms in the experiment and database, the BCTs form only 0.5% of the Estonian colour terms.

Jaap van Brakel wrote that it has been estimated that, by using Berlin and Kay's methodology (Munsell Colour Chips), 95% of the world's colour terms are left out of a study. Decontextualization also eliminates all aspects of semantic or symbolic depth of the colour vocabulary (van Brakel 1993: 112).

4. Semiotic theory of the basic colour terms

The main task of the semiotic theory of the BCTs is to place the colour terms back into a linguistic, historical and cultural context. In the following, I treat the BCTs as the core of the colour language code. The core consists of up to eleven or twelve bare BCTs in context-free or decontextualized (technical) environments, and numerous non-basic colour terms. It follows that colour language consists of basic (core) and non-basic colour terms (periphery), and the cultural history (colours in a real context) of a language.

Lotman drew a diagram indicating the growing complexity of language:

text in an artificial language, for example in the language of street signals	→	text in a natural language	→	poetic text

(Lotman 1977a: 97)

We can apply this schema to colour language in the following way:

BCTs, esp. in artificial (experimental) conditions	→	colour language	→	use of colour in poetic text

This means that the BCTs are at the lowest level of complexity in a language and do not represent the whole richness of the colour vocabulary in that language.

In a real language, a speaker hardly realizes that he or she sometimes uses basic colour terms and sometimes non-basic terms. People may be aware that some terms are more general, e.g. white and red, and some terms are very specific, e.g. colour terms from someone's childhood memories – the colour of my mummy's apron or the red stripe on my mummy's apron. In the everyday use of colour terms, a new problem arises: for some people black and white are not colours at all – they are colourless. The linguistic colour spectrum is not the same as the colour spectrum itself. Robert Lord, for instance, wrote:

> In the linguistic colour spectrum, colours are distributed not in representable two-dimensional space, but in notional (semiotically and sociolinguistically regulated) "fields". (Lord 1996: 51–52)

Dichotomies in Lotman's model of language represent axes that organize the field of colour. Consider first the axis of logical and mythological thinking. Van Brakel points

out that, instead of assigning a particular evolutionary stage to Khmer culture in Cambodia, "it is obviously more crucial to note that all Khmer speakers know various myths about the origin of colours, such as the story of 'Eight-Colours-Crystal-Woman'" (1993: 112). The evolutionary stage of BCTs corresponds to the logical axis, and myths of colours to the mythological axis. In the Khmer case, it is evident that colour terms form the code of the colour language and myths add the history. The logical axis of the colour language is equal to the technical axis in empirical colour-listing or naming tests. On the mythological axis, there are also our superstitions concerning colours, e.g. good luck and bad luck colours.

If we consider the dichotomy static vs. dynamic, we should keep in mind that, for Lotman, something was dynamic when there were at least two components – "the dynamic structure will appear as some number of static models (a minimum of two) which are in a definite mobile relationship" (Lotman 1974: 58). If we look at colour terms only in one language, or especially the BCTs in that language, our observations remain static but, if we try to look at differences in one language or between languages, we run into problems of intra- and interlinguistic translation. A good example of intralinguistic translation is the colour term *emerald.* For some people, it is green (emerald-green) and for others it is blue (emerald-blue). In Estonian there is no agreement on the border between blue and green. The region between focal blue and green can equally be *rohekas sinine* "greenish blue" or *sinakas roheline* "bluish green".

Hjelmslev's classic example of how English and Welsh divide the colour continuum differently illustrates interlinguistic translation. The Welsh colour term *gwyrdd* covers only part of the colour spectrum that is called green in English. The term *glas* covers parts of green, grey and blue in English; the term *llwyd* covers brown and a part of grey. To translate these terms, one should know the context and the colour of the object; e.g. the Welsh *glas* can be translated as "green", "blue" or "grey" in English, and green can be translated as *gwyrdd* or *glas* in Welsh (Hjelmslev [1943] 1993: 49; 1963: 53). Interesting translation problems arise with 'false brothers' in different languages. For example, in Estonian the term *lilla* is often translated as "lilac", but it corresponds to the colour term "purple" in most English uses. In very few cases should the term purple be translated *purpur* or *purpurpunane* "purple-red" and not *lilla* in Estonian.

Even if we speak of prototypical or good examples of colours, there are remarkable differences between, for example, English, Estonian, Finnish, Hungarian and Russian. The focal orange in an experiment using Davies and Corbett's field method is the Color-Aid O-orange for English speakers, but OYO-orange-yellow-orange for Estonians, Finns, Hungarians and Russians. The best red for Finns, Hungarians and Russians is RO-red-orange, but ROR-red-orange-red is best for the British and Estonians (for more details see Uusküla 2006).

On the paradigmatic and syntagmatic axis of a language, the speaker makes choices between colour terms. Of course the general paradigmatic pattern *something is black/red/blue/light blue/etc.* is not interesting for a linguist. More specific cases (collocations) are rich in information on the (use of) colour terms in a language. For

example, Berlin and Kay argued that there are twelve BCTs with two basic reds – *piros* and *vörös* – in Hungarian (1969: 95). Our empirical study with forty subjects in Hungary (note that Berlin and Kay questioned only one old émigré Hungarian man in America) showed that there are exactly eleven BCTs in Hungarian and only one term for red – *piros* – is basic (Uusküla & Sutrop 2007).

It is interesting to examine how the use of the basic term *piros* and non-basic *vörös* is distributed in Hungarian. There are two types of syntagmatic collocations with red; for example, apple, cherry (*cseresznye*), lamp and Santa Claus are used only with the basic term *piros* (if they are red) and cherry (*meggy*), hair, fox and star are always used with *vörös*. Beside the syntagmatic collocations there are numerous paradigmatic collocations where one can use either *piros* or *vörös*, e.g. with blood, rose, pen, pullover, lipstick, coat and bag. In the last case, *piros* and *vörös* behave like synonyms. The first case is more intriguing, for the use of the BCT *piros* is restricted. This is slightly contradictory to the definition because the application of a BCT "must not be restricted to a narrow class of objects" (Berlin & Kay 1969: 6).

On the semasiologic-onomasiologic axis of a language, there are colour terms and colour concepts. I will pass over this axis very briefly, only mentioning that they are rather diverse. On the one hand, there are theoretical discussions of what a colour concept is and what a BCT is and, on the other hand, there is the old chicken and egg problem. What comes first into language – a colour concept or a term? In the nineteenth century, cheap aniline dyes were discovered and door-to-door merchants introduced the German names of these dyes, *roosa* "pink" and *lilla* "purple" (German *rosa* and *lila*), into Estonian. At that time, neither of these terms was basic. The term *lilla* competed with another term, *violett* "purple". Did these technological terms (for Estonian; for other languages these terms have different histories) introduce new colour concepts into Estonian, or did they fill some empty slots? At least these terms for pink and purple narrowed the older concepts of red and blue.

The synchronic-diachronic axis is connected with the static-dynamic language axis. On the former axis, there are infinite static and/or dynamic intersections. Empirical investigations show colour terms or BCTs on a synchronic cut. For example, in Berlin and Kay's *Basic Colour Terms* the data are synchronically from or before the year 1969. If it is correct that their theory is an evolutionary one, the languages dealt with have changed during the past forty years.

If we try to reconstruct the development of the BCTs or the colour language, it is not enough to look at the colour terms, e.g. in the eighteenth century, using texts and dictionaries of that epoch. Such a study remains synchronic. If we try to make our study diachronic, we need a good theory and data from one or from different languages. On that point, Berlin and Kay's theory of BCTs is a strong one. Using numerous languages makes the theory dynamic; adding data from literature to the empirical makes the theory diachroníc.

Lotman, in his *The Structure of the Artistic Text* (1977b), argued that every language is not only a communicative system, but also a modelling system. If we look at

the intersections of colour terms on a time scale, we get not only the material for the diachronic analysis, but the different ways of modelling the semantic field of colour. Lotman gives us examples from Old Russian, where *sinij* (in modern Russian, "blue") was sometimes synonymous with *černyj* "black" or *bagrovo-krasnyj* "purple-red". Old Russian *seryj* (in modern Russian, "grey") had the same meaning as modern Russian *goluboj* (which is the second basic term for blue and the twelfth BCT in Russian; of course Lotman did not use such terminology) when it was applied to the colour of eyes, and Old Russian *goluboj* was equivalent to modern *seryj* "grey" when it was applied to animals or birds (Lotman 1977b: 14, see also Unbegaun 1963).

In Russian there seem to be two BCTs for blue – *sinij* and *goluboj.* Galina Paramei (2005) argues that *goluboj* emerged in Russian as culturally basic. The relationship between the two terms for blue is very complex in Russian. It is a very simplified approach when we translate *sinij* as "dark blue" and *goluboj* as "light blue". For example, in an experiment the colour tiles that were called *goluboj* in Russian were identified as "light blue", "blue" and "dark blue" in Estonian (Sutrop 2000). Perhaps colour temperature is important in discriminating *goluboj* from *sinij* in Russian. Lotman argued that

> in twelfth century texts, the sky is never referred to as goluboj or sinij, while for an observer of that time the golden color of an icon's background apparently conveyed the color of the sky with total verisimilitude... In all the cases we are clearly dealing with completely different models of...chromatic dimension.
>
> (Lotman 1977b: 14–15)

To deal with the linguistic aspects of the BCTs, one should use different models of the linguistic colour space, for example how the BCTs are linguistically motivated. In Germanic languages, green is the colour of growing: green < *grō- "to grow", but in Estonian *roheline* "green" is derived from *rohi* "grass", which characteristically is green.

5. Conclusions

Berlin and Kay's theory of BCTs is much disputed and criticized, and not only the theory but also the data they collected and used. This is a strong theory where, on weak evidence, very strong generalizations are claimed – the certain evolutionary ordering of the BCTs in any language. A weak theory establishes nothing based on very excessive empirical data.

Unfortunately, the focus of the study of BCTs has moved on to psychology or psycholinguistics. The combination of the theory of BCTs with semiotics opens up new horizons and brings the study of (B)CTs back to the linguistic sphere.

Although semioticians like the theory of BCTs, there is no semiotic theory of BCTs. In Juri Lotman's modelling framework, one can analyze the BCTs using the formula "language = code + history" and abandon the technical definition of a BCT (a term is basic if it is frequent and passes some hurdles in experimentation). We can

paraphrase Lotman's formula in the following way: "colour language = BCTs and non-BCTs + history of language and culture". In this formula, the BCTs form the nucleus of the colour code of a language.

The semiotic theory of BCTs can be built up using the formula and numerous dichotomies, i.e. language axes such as static vs. dynamic, syntagmatic vs. paradigmatic, synchronic vs. diachronic, semasiologic vs. onomasiologic, and logical vs. mythological. These axes organize and model the linguistic colour space (or field of colour). Different nations or tribes model their linguistic colour spectrum in different ways, although they follow some universal patterns at least in the evolutionary ordering of the BCTs. The modelling of the linguistic colour space is not static; it differs not only between the languages but also diachronically. In every historical epoch, a language uses different colour codes and modelling systems.

We can conclude that a colour field is regulated semiotically in any language. A BCT is not exactly the same for all the speakers of a language or in different languages. For that reason, the intra- and interlinguistic translations of colour terms help us understand a colour language. BCTs form the absolute minority (maximally 0.5 to 5 percent) of the colour terms in a language. Focusing research only on the BCTs minimizes the linguistic, semantic and semiotic richness of a colour language.

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SECTION 2

Languages of the world

Preface to Section 2

The eight papers of Section 2 turn the spotlight onto individual languages and what they can add to the constantly developing subject of colour semantics. A noticeable theme in the linguistics papers at PICS08 concerned the roles of two (or more) highly salient colour terms belonging to the same colour category. Are they all basic or not? Are the salient but non-basic terms poised for a future takeover bid?

Claudia Frenzel-Biamonti investigates the two salient terms for PINK in German: *rosa* and *pink*. Using the evidence of magazines, she considers how the adoption of *pink* from English has affected the usage of *rosa*, and whether the two terms now denote different shades of this hue. Mari Uusküla tackles the RED categories of Hungarian and Czech, both of which have two salient terms, and suggests that this phenomenon may be widespread in eastern Europe. Kaidi Rätsep has a similar issue with the two salient words for BLUE in Turkish; she presents the results of her field research in Turkey to elucidate matters. Abdulrahman Al-Rasheed and his colleagues are faced with *three* salient words for BLUE in the Arabic of Saudi Arabia, and report on listing and naming tasks carried out in Riyadh.

The more colour systems that are studied and published, the better semanticists can hope to understand them, so two papers concerning rarely discussed languages were most welcome at the conference and in this volume. Firstly, Adam Pawłowski and Danuta Stanulewicz present a substantial preliminary investigation into the colour vocabulary of Kashubian, a Slavic language with relatively few native speakers. Secondly, Alexander Borg tackles the intriguing Maltese language, a variety of colloquial Arabic with unstinting layers of Italian and English. This article amply demonstrates the importance of the historical dimension in understanding the colour vocabulary of a culturally complex society.

Two articles illustrate the value of corpus studies. Wendy Anderson, working with the Scottish Corpus of Texts and Speech, ranges across the many forms and uses of *red* in the Scots language continuum, allowing the reader to glimpse intriguing phrases such as *red curldoddy* and to be invited into 'collocation clouds' of *red* usage. Finally, a study of Russian colour terms by Ekaterina Rakhilina and Galina Paramei seems to touch on all the themes of this section, and then add something more. Based on the data in the *Russian National Corpus*, this article is another example of the value of corpora in semantic studies, and it also presents a further case of the 'rivalry' of two salient terms in a single category, this time in BROWN. In addition, the authors chart the development path of newly emerging salient terms in Russian, showing that a cognitive barrier between natural and artefact colour must be overcome by a colour term before it can achieve basicness.

Basic colour terms of Arabic

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This study aimed to establish the basic colour terms of Arabic and to clarify the status of three Arabic terms for blue: *azrock*, *samawee* and *khuhlie*. Data from a list task were collected from 253 child and 200 adult native Arabic speakers. The patterns of the terms ordered by their frequency from the two samples were essentially the same. In the colour-naming task, the child and adult samples (N = 61 and 60 respectively) had to name a set of 65 colours representing the whole colour palette. Both samples performed similarly. Based on these results, it appears that Arabic has eleven basic colour terms that correspond to Berlin and Kay's (1969) universal set. In addition, the terms of particular interest – *samawee* "light blue" and *khuhlie* "dark blue" – are not basic Arabic colour terms.

1. Background and aims

This paper reports a study of the basic colour terms (BCTs) of Arabic conducted within the framework of Berlin & Kay's (1969) theory of universal colour categories. Pilot work had suggested that Arabic might have more than one BCT for the blue region – *azrock* "blue", *samawee* "light blue" and *khuhlie* "dark-blue" – and thus a subsidiary aim was to investigate this possibility.

The essence of Berlin and Kay's (1969) theory is that, although languages vary in the numbers of basic terms they have and in the location of their category boundaries, all languages draw their inventories of basic colour categories (BCCs) from a universal set of eleven: [BLACK WHITE] RED [GREEN YELLOW] BLUE BROWN [PURPLE PINK ORANGE GREY] (see Hippisley & Davies 2006 for a fuller account). These universal categories are characterized by their best examples or category foci, and, if a language expresses a version of a universal category, then its best example should be similar to the appropriate universal focus. Terms earlier in the set, on average, are more likely to be represented than later terms; terms conjoined in square brackets are equally likely to occur. The first six terms (primary terms) were thought to be fundamental, in that they

were aligned with fundamental states of early colour processing (Kay & McDaniel 1978), while the remaining terms (derived) were thought to be based on combinations of the primary terms. This conjecture turned out not to be true (e.g. Jameson & D'Andrade 1997). Nevertheless, the empirical observation of the greater prevalence of primary over derived terms across languages holds, and there is evidence that primary terms are more salient than derived terms even in languages with a full set of terms (see below). The claim that best examples of equivalent categories are very similar in all languages has also been questioned (e.g. Ratner 1989), but Regier, Kay and Cook (2005) show that, although there may be exceptions, there is a strong statistical tendency for category foci to be very similar across languages.

Two tasks were used: a list task and a colour naming task. The list task is a simple and fast method of identifying likely BCTs (Davies & Corbett 1994). It provides two measures – frequency of use and order of occurrence – and assumes that the psychologically more salient terms will appear in more lists and in higher positions than less salient terms. Pich & Davies (1999) found that primary categories appeared more frequently than derived categories and that, in general, the eleven BCTs were used more frequently than non-BCTs. In the naming task, a representative sample of colour-stimuli (those used initially by Davies & Corbett 1994) were named. BCTs should be used frequently and with consensus across informants. Two groups of Saudi Arabic speakers were tested: eight to twelve year old children, and adults, both from Riyadh. However, as the pattern of results was essentially the same for the two groups, we report only the adult data here.

2. Elicited lists

There were 200 adult informants. Half were men and half were women, with an age range of eighteen to twenty-five years (mean = 19.83). They were students at King Saud University and they were all native Arabic speakers with some knowledge of English. They were asked to write down as many colour terms as they could in two minutes.

Table 1 shows the terms offered by at least 10% of the sample together with their English glosses, and the percentage of the sample that offered each term. It can be seen that the terms *ahmar* "red", *akhdar* "green", *asfer* "yellow", *azrock* "blue", *asswed* "black", *banafsagee* "purple", *abiyadh* "white", *boartoogaalee* "orange", *bonee* "brown" and *wardee* "pink" were offered by a clear majority of the sample. *Rassasee* "grey" was the next most frequent term offered by just under half the sample, while the two additional blue terms *samawee* "light blue" and *khuhlie* "dark blue" were offered by only about 30% of the sample.

Table 1. Tile-naming summary showing terms offered in the list task by at least 10% of the sample, their English glosses, the percentage of total usage in the naming task, and the dominance D_{75}

Elicited Lists Result			Colour Naming Result	
Term	**Gloss**	**Percentage**	**Overall frequency of Use**	**No. of tiles dominant D 75**
Ahmar	Red	99.0	03.62	01
Akhdar	Green	96.0	15.07	08
Asfer	Yellow	93.0	05.18	02
Azrock	Blue	90.0	07.90	03
Asswed	Black	89.5	03.13	02
Banafsagee	Purple	82.0	10.44	05
Abiyadh	White	81.0	02.72	01
Boartoogaalee	Orange	72.0	09.54	04
Bonee	Brown	70.0	08.51	04
Wardee	Pink	67.5	10.67	04
Rassasee	Grey	47.5	06.30	04
Samawee	Light blue	30.0	02.95	00
Khuhlie	Dark blue	27.5	01.38	00
Beige	Beige	18.5	00.67	00
Tarquazee	Turquoise	17.5	00.87	00
Dahabee	Golden	16.5	00.20	00
Zeatee	Oil-Green	16.0	02.38	00
Foshy	Fuchsia	16.0	01.00	00
Fadhee	Silver	13.0	00.00	00
Enaabee	Dark red	11.5	00.87	00
Tufahee	Apple	11.0	00.38	00

3. Colour naming

Sixty first-language Arabic speakers from King Saud University named each of a standard set of 65 colours shown in Figure 1 (see Davies & Corbett 1994 for their origin and technical specification). Here, we report overall frequency of use for each term, and a measure of consensus – the dominance index. Basic terms should have high scores on both measures.

Column 4 of Table 1 shows the frequency of use of each term across the colour set and sample (65 x 60 possible responses). The twelve most frequent terms in the list task are also the most frequently used terms in the naming task. Column 5 in Table 1 shows an index of consensus of use, which we call the 'dominance index'. A term is dominant

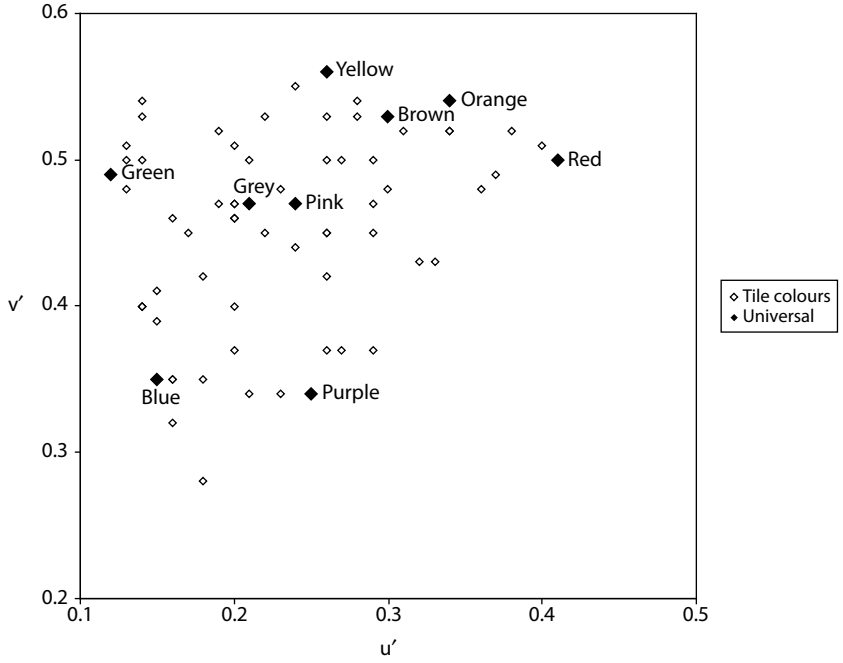

Figure 1. Location of the chromatic stimuli in CIE (1976) colour space (u′ v′)

for a particular tile if the proportion of the sample using it exceeds a threshold, in this case 75% of the sample. For instance, eight tiles were named *akhdar* "green" by at least 75% of the sample and the D_{75} score for *akhdar* "green" is accordingly eight. It can be seen that the eleven terms with non-zero scores are mostly the same terms with high frequency of use in the list task and naming task.

Figure 2 shows, for each Arabic colour term, the position of each tile that was named with high consensus (achieved the D_{75} criterion) in CIE (International Commission on Illumination) u' v' coordinates along with the location of the putative universal foci taken from Heider (1972). The universal foci are labelled to provide landmarks to help interpret the graph. It can be seen that, for each term, the location of the high-consensus tiles falls close to the appropriate universal foci.

4. Discussion

The results from the two tasks converge to suggest that *ahmar* "red", *akhdar* "green", *asfer* "yellow", *azrock* "blue", *asswed* "black", *abiyadh* "white", *banafsagee* "purple", *boartoogaalee* "orange", *bonee* "brown", *wardee* "pink" and *rassasee* "grey" have the strongest

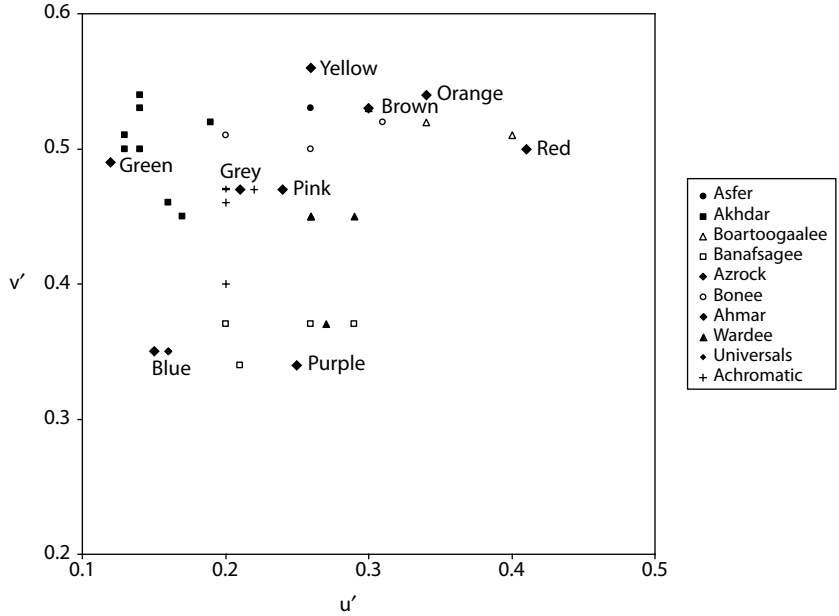

Figure 2. Location of Arabic adult's colour naming with agreement level 75% and above in the CIE (1976) chromaticity diagram (u′ v′). *Asswed* "black", *abiyadh* "white", *ahmar* "red", *akhdar* "green", *asfer* "yellow", *azrock* "blue", *bonee* "brown", *banafsagee* "purple", *wardee* "pink", *boartoogaalee* "orange"

claim to basic status. Arabic therefore corresponds perfectly with Berlin and Kay's (1969) stage VII of colour term evolution. These eleven terms were the most frequently offered terms in the elicitation task with scores of almost 70% or more for both samples, except for *rassasee* "grey" which scored about 50% in both samples. The rank orders of the terms on both main measures were very similar, with just minor variations in their positions. The tokens of Kay and McDaniel's (1978) primary categories – *ahmar*, *akhdar*, *asfer*, *azrock*, *asswed* and *abiyadh* – were the six most frequent terms, and they were offered by over 80% of the samples. *Banafsagee*, *boartoogaalee*, *bonee*, *wardee* and *rassasee* were the next most frequent terms, and they are the Arabic derived categories.

All of the measures from the naming task also suggest that the eleven terms just given are probably BCTs in Arabic. They had high frequency of use and high dominance scores, and their referents were similar to the appropriate universal focus. *Zeatee* "oil green" and *samawee* "light blue" had the next highest scores on most measures, and these two terms may merit further investigation.

Our conclusions are necessarily limited to educated urban dwellers in Saudi Arabia, and it may be, as Borg (2007) suggests, that other Arabic speaking groups may have fewer BCTs.

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Red herrings in a sea of data

Exploring colour terms with the SCOTS Corpus

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The Scottish Corpus of Texts & Speech (SCOTS) is a multimedia corpus of Scottish texts, containing a wide range of written and spoken genres from 1945 to the present day. One application of the resource is the study of the use in context of lexical items. This paper explores ways of exploiting SCOTS to investigate the literal, metaphorical and idiomatic uses of colour terms in contemporary Scots. This involves using the integrated analysis tools to consider the collocational patterning of these terms. Other complementary online resources, such as the *Dictionary of the Scots Language*, are drawn on where appropriate to aid in the interrogation of the complex body of material in the corpus. The paper also outlines the issues involved in using a minority-language corpus for linguistic research.

1. Introduction

On a flagpole or a sports field, Scotland expresses her identity in blue. But arguably it is in the red area of the colour spectrum where the strongest associations are to be found. Red hair has been associated with the Scots at least since Roman times, and is still one stamp of a stereotypical Scot, as portrayed, for example, in cartoons. Scottish wildlife calls to mind majestic red deer, scampering rusty-red squirrels, and red grouse hiding in the mauve heathery moorland. Even the built environment is characterized by red, as with the classic red sandstone tenements of Glasgow.

What does this mean for language? Does the close association between red and the physical environment correspond to a special place for *red* in Scottish language? The purpose of this paper is to explore the use of the term *red*, and its variant forms, in the Scots language, drawing particularly on the Scottish Corpus of Texts & Speech (SCOTS) resource. It also serves as an introduction to the SCOTS resource, which is freely available online and offers a useful perspective on the continuum of Germanic language varieties spoken in Scotland, and as such a valuable point of comparison with existing corpora of standard English. Anders Steinvall, in his corpus-based work on

colour terms in standard English, has found that *red* has a privileged status among chromatic colour terms, indeed that it occurs "more than three times as often in compounds and classifying phrases than any other chromatic term" (Steinvall 2002: 113). The strong associations of Scotland with red suggest that compounds with *red* will be still more important in the SCOTS corpus.

2. Scots and Scottish English

Like English, Scots derives from the Anglo-Saxon and Scandinavian languages spoken across mainland Britain in the early Middle Ages. Social and linguistic factors, however, such as its fluctuating status in society over the centuries, and contact with other languages such as Dutch, French, Latin and Gaelic, led it to develop differently. Today, there are a number of related but distinct spoken varieties across Scotland, such as the Doric of the North-East, urban varieties of Scots in Glasgow and Edinburgh, and insular Scots in Shetland and Orkney. There is currently no standard written form, as the vast range of variant spellings in the SCOTS corpus illustrates. Following Aitken & McArthur (1979), among others, the SCOTS project views Scots as one end-point of a linguistic continuum, with Scottish English as the other. Scottish English is the variety of English used in Scotland, similar to standard English but with some distinctive features of lexis, grammar and, especially, pronunciation.

3. Dictionary evidence of the use of *red* in Scots

Before turning to the evidence of the present-day languages of Scotland offered in the SCOTS corpus, it is helpful to consider the dictionary evidence of the use of *red* in Scots. The online *Dictionary of the Scots Language* (DSL) shows, in line with Steinvall's comments for standard English, that *red* is part of a large number of compounds in varieties of Scots: the main entry for *reid* (a variant of *red*) in the *Scottish National Dictionary* component of the dictionary, which covers the period from 1700 to the present day, lists eighty such compounds. Steinvall's further finding that *red* in English is used in compounds "particularly in the domains of plants and animals" (Steinvall 2002: 113) also appears to hold true for Scots, at least as far as dictionary evidence goes. A sample of these compounds, picking out those related to flora, fauna and physical features, is reproduced in Tables 1 and 2. Most of these examples are uses of *red/reid* which seem to be particular to Scots, at least as far as a comparison with the *Oxford English Dictionary* (OED) is concerned. It is possible, of course, that English dialect dictionaries may provide another perspective.

Table 1. *Red* in compounds denoting flora and fauna, from *Dictionary of the Scots Language,* www.dsl.ac.uk, listed under entry 'reid'

red-arsie, -ersie, the name vulgarly given to a large bee that is red behind
reid-back, the ladybird
red beltie, a bee with red striped markings
red-bog, a red-coloured substance, phs. a species of alga
red curldoddy, red clover, *Trifolium pratense*
red-doup, a bee with red markings behind, an Italian bee
red-end, a bee with red markings behind
rid flook, a flounder, prob. the dab
red foul, the red grouse, *Lagopus scoticu*s
red-glove, a variety of gooseberry
red hawk, the kestrel, *Falco tinnunculus*, from the reddish tint of its plumage
red-legged horseman, the redshank, *Tringa totanus*
red professor, an angling fly
red sauch, a variety of willow, *Salix purpurea*

Table 2. *Red* in compounds denoting physical features, from *Dictionary of the Scots Language*, www.dsl.ac.uk, listed under entry 'reid'

red-avised, having a ruddy complexion, red-faced; red-haired
red brae, red-close, rid lane, red loan(in), red road(ie), the gullet; [NB. *Red lane* appears in OED with the same signification]
red seuch, ***-sheuch***, the gullet or stomach
red-heidit, as in Eng. *red-headed*, having red hair, hence, in popular belief, of an excitable impetuous nature
red-kuted, having red ankles
re(i)d-neb, -nib, a red nose, used as a nickname
re(i)d shank, lit., a red leg, used *fig.* a nick-name for a highlander, esp. a kilted highland soldier, because of his bare legs

In a number of expressions, as the DSL lexicographers note, *red* is used with an intensive function. These are listed in Table 3. In some cases, a metonymical connection with the expression's origins is still evident, as for example with *reid-mad*.

The *Oxford English Dictionary* provides little evidence of similar usage in standard English. It notes the common expression *see red*, meaning to get angry or lose control, and also identifies *red-mad/red-wood* (see Table 3), meaning furious or completely mad, as being Scottish in use, from Old English *wede* "mad". In *red-hot*, used figuratively to mean "outstanding", *red* can also be seen to have an intensive role; here again the metonymic origin is clear.

Table 3. *Red* used with an intensive function in compounds, from *Dictionary of the Scots Language*, www.dsl.ac.uk, listed under entry 'reid'

reid horn mad, furious, in a state of uncontrolled passion
reid-hunger, ravenous hunger. Hence *reid hungered*, ravenously hungry
reid-mad, furiously angry, demented; very enthusiastic in an unbalanced way
reid-nakit, stark naked
red rantin, frenzied, wild
re(i)d-wud, -wood, -weed, stark staring mad, furious, beside oneself with rage, distraction, etc., mentally unbalanced

4. The SCOTS corpus

As in many other areas of linguistics, there has been a turn in recent years to explore what electronic language corpora can offer the study of colour terms. Corpora are large, electronically searchable, collections of texts or text extracts, which have been designed and compiled for the purposes of linguistic research (see Anderson & Corbett 2009). The great value of corpora is that they allow researchers to go beyond their own intuition, by considering a very large quantity of data which has not been analyzed and 'packaged' by lexicographers or other language specialists. This means that it is possible to build up a picture of the relative extent of usage of words or expressions, and patterns of use, taking account of factors like language change over time, social background of speakers/writers, and genre.

Mainstream corpora of standard English have already been quite thoroughly analysed for colour data, often in conjunction with evidence from dictionaries and thesauruses. For example, Steinvall (2002) bases his descriptive corpus study of colour terms on the Bank of English corpus, which contains UK, US and Australian English. Kerttula (2002) takes a historical perspective on colour terms, using the British National Corpus and other present-day sources, alongside diachronic data from the *Historical Thesaurus of the OED* (Kay, Roberts, Samuels & Wotherspoon 2009). Niemeier (1998) investigates metonymy and metaphor in a selection of basic colour terms, basing her study on the British National Corpus, collocation data from the Bank of English, Roget's thesaurus and various English dictionaries.

In 2007, a team in the Department of English Language at the University of Glasgow completed work on the Scottish Corpus of Texts & Speech (SCOTS). It is now therefore possible to carry out similar explorations of Scots and Scottish English, and to compare the picture of the use of *red* which this corpus offers. SCOTS is a general corpus containing texts in Scots and Scottish English: that is, it is geographically-specific, but includes a wide range of texts and genres, of both written and spoken language, with accompanying metadata concerning textual context and demographic information about language users. At four million words, it is small compared to the

most widely used corpora of standard English, such as the British National Corpus and the Bank of English, but for a corpus of a minority language it is sizeable, and the proportion of spontaneous, conversational, spoken language it contains is large. The corpus is free to use, and can be browsed, searched and analyzed online.

Colour terms in English pose few problems for retrieval in a corpus such as the British National Corpus or the Bank of English because they do not inflect. The limited number of derivations, such as *reddish*, *redness*, *redden*, *redder*, *reddest*, are also quite straightforward to find, through the use of wildcards and truncation (e.g. *red**, where the asterisk indicates any number of additional characters, including zero), although some manual editing may be necessary to eliminate from the results other words beginning with *red-*, such as *redecorate*, *redeem*, *redo*.

Corpora of non-standard language, such as Scots, raise different issues from corpora of standard language, such as English. While inflection is not an issue for Scots either, the issue of retrieval is much more acute for non-standard languages in which spelling variants are common. The SCOTS corpus is not semantically tagged or tagged for spelling variants, and so there is no way of automatically identifying all of the variants of *red*. The *red herrings* in the title of this paper are swimming in a sea of data, potentially alongside *reid herrins*, *rudd harrengs*, *rid harrings*, and other combinations. It is difficult to cast the net wide enough to capture all of the instances we may be interested in. In information technology terms, this represents a problem of *recall*.

A second issue is that of *precision* of retrieval, that is, as far as possible, netting only those instances which are of interest, and not capturing unwanted examples too. Resolving this problem requires disambiguation. At present, manual analysis is the only way of discarding the instances of *Reid* where it is a common surname and *reed* used as a variant spelling of *to read (a book)*. Work on the automatic identification of spelling variants in SCOTS is ongoing.

5. *Red* in SCOTS

The *Dictionary of the Scots Language* lists a number of variant spellings of the headwords *red* (in the *Dictionary of the Older Scottish Tongue* data, covering the Older Scots period) and *reid* (in the Modern Scots data from the *Scottish National Dictionary*). Table 4 gives the raw frequency of these variants in the current version of the SCOTS corpus (dataset 15, April 2009).

As will be evident, not all of the variants listed by the *Dictionary of the Scots Language* are attested in the SCOTS corpus. There are many possible reasons for this. For example, it is no surprise not to find occurrences of the Older Scots variants in a corpus of present-day texts, though given the idiosyncratic spelling systems adopted by some authors, it could not be assumed that such word forms would not appear. Other variants are typical of dialectal varieties which are not thoroughly represented in

Table 4. Frequencies of occurrence of *red* and variants in SCOTS

Variant	Occurrences in SCOTS
Rade	0
Raid	0
Read	0
Reade	0
Red	570
Rede	0
Reed	48
Reedd	0
Reede	0
Reid	174
Reide	0
Reyd	0
Rid	58
Ride	0
Ried	0
Rud	0
Rudd	0
Ryid	0
Total	**850**

SCOTS. It is likely that the transcription practice adopted by the project will also have had an effect, since, in order to maximize the searchability of the corpus, spoken texts were transcribed conservatively, adopting standard spellings by default. Finally, the corpus is relatively small and therefore it may simply be a matter of chance that rarer forms are not attested.

A table showing the occurrence of other colour terms in the red area of the spectrum can be found in the Appendix. This shows raw and normalized figures for these colour terms in the SCOTS corpus, alongside comparable figures for the Bank of English corpus, based on Steinvall's study (2002). The figures for the SCOTS data account only for these words used as colour terms: that is, they do not include *plum* where it denotes the fruit, *ruby* for the gemstone, and so on. It is quite evident from the data that SCOTS is a much smaller corpus than the Bank of English. The fact that it also contains a range of language varieties complicates matters further. As a result, the low figures may be unreliable. The data suggest, however, that SCOTS contains a larger proportion of the basic colour term *red*, and indeed other colour terms close to red. This is likely to be due to the inclusion in the corpus of a significant number of spoken texts involving young children.

6. Delving deeper: quantitative to qualitative

Frequency is only part of the picture. It is also important to consider patterns of usage. The online SCOTS corpus has a number of integrated features which can help here.

One way into a deeper appreciation of the data in the SCOTS corpus is through the 'Collocate Clouds' feature developed by the project computing manager, Dave Beavan. This facility offers an immediate picture of the use of a word-form, which highlights areas which may repay further investigation through a concordance. A cloud for the word-form *red* can be found in Figure 1. The cloud shows the one hundred words which collocate most frequently with the node word, *red*, within a span of five words to each side. These are presented in a weighted display, in which font size increases with frequency, and font brightness increases with the strength of collocation between the node and each word (using a measure of Mutual Information).

The cloud for *red* gives a good initial impression of the use of the word-form. It is easy to understand why it frequently appears in the vicinity of words like *apples*, *Square*, *pepper*, *rose*. Items like *F1113* indicate speaker identification codes in transcribed spoken documents, which are treated here as word-forms. The presence of several of these in the cloud indicates that this word occurs frequently in the spoken texts in the corpus.

The homonymous senses of the word-form *reed* in Scots are evident from the cloud in Figure 2. Intuition allows us to identify the items which most likely collocate with *reed* as a colour term (*ribbon*, *frock*, *coat*) and, conversely, with *reed* as a type of

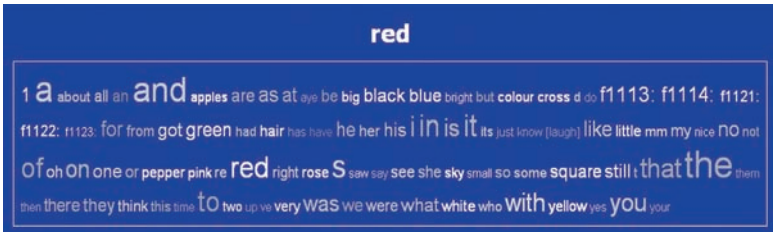

Figure 1. Collocate cloud for *red* in the SCOTS corpus

Figure 2. Collocate cloud for *reed* in the SCOTS corpus

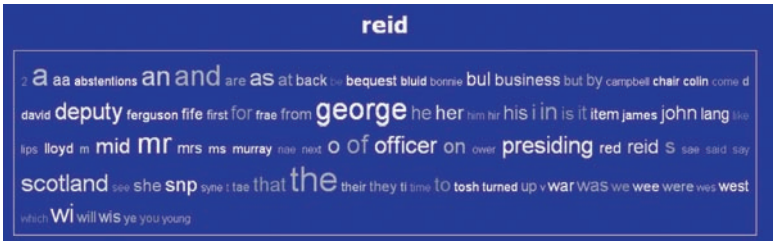

Figure 3. Collocate cloud for *reid* in the SCOTS corpus

stalk or cane (*bushes*, *snapping*, *lang* (= long)). *Reed* and *red* can also be seen to collocate frequently and significantly with other colour terms (*crimson*, *red*, *green*, *blue*), and indeed with themselves – *red red rose* is not a surprise in a corpus which reflects the continuing influence of Robert Burns on Scots.

In the cloud for *reid*, in Figure 3, the most frequent collocates appear to result from its common use as a Scottish surname (for more on onomastics in Scotland, see Bramwell 2011). In fact, it is the name of George Reid, at the time Deputy Presiding Officer of the Scottish Parliament, which is emerging in the cloud. The clouds allow us to begin to disambiguate word-forms: the fact that *reid* occurs frequently in the vicinity of proper names and titles, and also with some other colour terms, suggests that it is likely to have at least two quite separate uses.

A final cloud, presented in Figure 4, has been created from a version of the SCOTS corpus in which all of the colour-related instances of variants of *red* (and only the colour-related instances) have been grouped together under the macro term *redreidridreed*. The cloud therefore effectively shows the frequent and significant lexical collocates of realizations of the concept *red*.

Collocate clouds are of course only a starting point, which allow the researcher to identify possible lines of enquiry. To investigate the use of these variants in any depth we must go beyond the cloud. Using the resource's integrated tools, it is simple to jump from a cloud into a concordance view of an item, to see it in its immediate co-text, with the frequent and significant collocates highlighted.

Figure 4. Collocate cloud for colour uses of *red, reid, rid* and *reed* in the SCOTS corpus

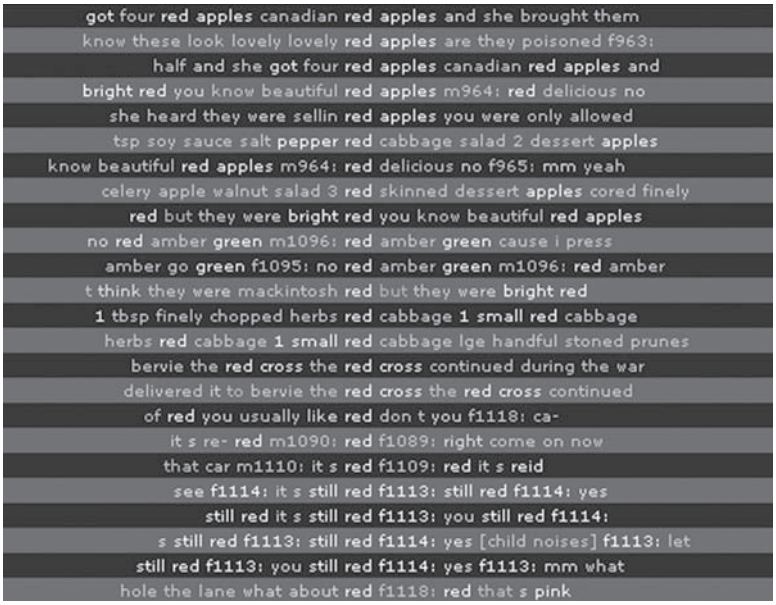

Figure 5. Section of concordance view of *red* in the SCOTS corpus

Concordance line	Textual genre
1. Was quite right. It is a bit of a **red herring** to keep talking about serious	Parliament report
2. Described the demographic issue as a **red herring.** He drew the line between	Parliament report
3. Eurekas! Interjections fling **red herring** Into the works. They may	Poetry
4. I hope that I did not throw in a **red herring** by talking about discounts. The	Parliament report
5. Again. Well she'd soon net that **red herring!** "I always think mature	Prose fiction
6. Ill not clear it. The tribunal is a **red herring** of democracy. At the meeting	Parliament report
7. Might be an absolute waste of time, a **red herring** and impractical	Parliament report
8. The merchant got im tae buy some **reid herrins.** He said Willie could	Prose, non-fiction
9. In thir tales isnae juist a **rid herrin.** Ou hae aaready seen that the	Academic prose

Figure 6. Concordance of *red herring* (including variant spellings and inflections) in SCOTS

This concordance view allows a detailed analysis of the compounds and phrases in which the node word occurs. Examples of these follow in the next section, grouped into rough categories according to the type of relationship between the noun and the colour term. It is important to note that it is individual instances which are categorized (that is, *tokens*), rather than decontextualized phrases (*types*). This allows for cases where the same compound has different meanings in context. For example, among several instances of *red herring* (including variant spellings) used metaphorically, there is one instance which is literal, denoting a herring which has taken on a red colour from the curing process. A grammatical distinction is evident here too, as all of the metaphorical examples are singular, and the literal one is plural. Further corpus data would show if this is indeed a reliable pattern. Figure 6 shows all instances of the expression, indicating textual genre in each case.

7. *Red* in compounds

The relationship between *red* (and variants) and the nouns it qualifies in compounds is not constant across the corpus data. Indeed, it is possible to identify examples of a number of categories, the boundaries between which are not always sharply defined. At one extreme some compounds are purely combinatorial or descriptive: that is, the meaning of *red* is not context-dependent or specialized. Examples are *red skirt*, *red ball* (in snooker), *red pencil*, *reed string*, *reid jaikit* (= jacket), *rid tractour* (= tractor), *reid flowers*. At the other extreme, some instances form part of highly idiomatic, non-combinatorial, expressions, whether these are conventional, as in *red herring*, or one-off, as in *red meat politics*, the meaning of which can only be established by considering the wider context of the text.

In between these two groups, compounds exemplify degrees of idiomaticity. Some can be described by traditional headings such as metaphor and metonymy. These include *red tops* (i.e. tabloid newpapers), *red tape*, *rid-bluidit* (= red-blooded), *reid brae* (i.e. the gullet, see the definition from *Dictionary of the Scots Language* in Table 2), *red mist*, *red face*, *red neck*. A further advantage of a corpus with a wide range of searchable metadata categories, such as SCOTS, is that it is possible to investigate potential correlations between use of language and sociolinguistic factors, such as gender, age, region, and social background, and also textual factors, such as genre and register. In the case of *red face* and the particularly Scottish *red neck* and *riddie* (as in the corpus example *Somebody's got a riddie*, meaning that someone is visibly embarrassed), the demographic and textual metadata suggest that a difference in both the generation of the speaker/writer and the mode (speech or writing) are factors behind the choice of expression. In particular, there is evidence of only younger speakers using *red neck* with the sense of "embarrassment", and of *red face* being more common in written than spoken texts.

A further group of examples is neither metaphorical nor purely descriptive, but represents another type of idiomatic relationship between the colour term and the qualified noun. A *red apple* is unarguably red, indeed often a very focal red, and also stands in contrast to a green apple. *Red currants* are quite a "reddy-red", and also stand in contrast to *blackcurrants*. *Red lentils*, on the other hand, are red, but an orangey-red rather than a focal red. *Red/reid squirrels* are opposed to *grey squirrels* and, more recently, *black squirrels*, and are more of a rusty-brown colour. Some *red/reed wine* is closer to focal red than other types; all *red wine* is closer to focal red than *red sandstone* or a *red squirrel* are. These are examples of *red* being used for type modification. Steinvall explains that "the purpose of modification is to create a subclass of the noun, thus restricting its reference", and remarks that usually only the most basic colour terms are used for type modification (Steinvall 2002: 59). In line with this, *red* in the SCOTS corpus is found in various instances of type modification, especially natural things particular to or characteristic of Scotland – *red deer*, *red sandstone*, *red hair*. The corpus evidence supports the dictionary evidence that these compounds are especially common in the domains of plants and animals.

8. Conclusion

Corpora provide a useful complement to dictionary evidence in the linguistic investigation of colour terms, as previously demonstrated by Steinvall (2002) and Kerttula (2002), among others. In particular, corpora offer evidence concerning both frequency and usage, which allows for both quantitative and qualitative analysis. New types of visualization, such as those which the SCOTS corpus offers online, extend the approaches which can be taken to corpus data. At the same time, caveats are necessary when dealing with corpora of non-standard languages as is the case here. Such corpora present particular challenges to linguistic analysis, as they tend to be smaller than corpora of standard language, with the result that individual lexical items can be infrequent and it is difficult to generalize reliably from findings. Any skew in the balance of a small corpus is likely to be of greater significance than in a large corpus, such as the British National Corpus or Bank of English. The issue of multiple spelling variants in languages without a standard written form also poses problems for the retrieval of data.

In relation to varieties of Scots, this exploration of a small set of colour terms in the SCOTS corpus has shown a number of things. First, the overall picture of *red* in varieties of Scots is very similar to standard English. *Red* and its variants are used in both compositional and idiomatic expressions and are common in metaphorical usage, having similar associations with danger, warnings, embarrassment and politics. SCOTS contains instances of several idioms which are particularly Scottish, including some which survive in fiction and poetry and are deliberately archaizing (e.g. *reid brae*), and creative expressions such as *red neck* and *riddie* which are related to the more widespread *red face*.

However, the SCOTS evidence suggests that varieties of Scots have lost many of the idioms involving *red* which were peculiar to Scots in the past. It is possible that these survive but are very rare, or indeed that they were always very rare and the dictionary evidence, with little concern for frequency, simply hides this fact. Further evidence of older usage is now available, in the Glasgow Corpus of Modern Scottish Writing (CMSW), completed in 2010, which contains texts spanning the period 1700–1945. Although completed too late for this investigation, CMSW will in future provide valuable evidence of how the use of colour terms has changed over time.

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Appendix

Colour term	Frequency of occurrence in SCOTS	Normalized frequency in SCOTS (per 10,000 words)	Frequency of occurrence in Bank of English	Normalized frequency in Bank of English (per 10,000 words)
Red	570	1.42	38912	1.20
Pink	225	0.56	8924	0.28
Orange	105	0.26	3553	0.11
Scarlet	28	0.07	1208	0.04
Crimson	19	0.05	878	0.03
Rose	7	0.02	632	0.02
Maroon	3	0.01	518	0.02
Mauve	6	0.01	501	0.02
Peach	3	0.01	302	0.01
Magenta	1	<0.01	194	0.01
Rust	3	0.01	174	0.01
Plum	0	0	134	<0.01
Tangerine	3	0.01	111	<0.01
Vermilion	0	0	98	<0.01
Fuchsia	0	0	93	<0.01
Carmine	1	<0.01	80	<0.01
Ruby	3	0.01	not available	not available
Russet	3	0.01	not available	not available
Reddish	0	0	568	0.02
Pinkish	2	<0.01	198	0.01
Orangish	0	0	3	<0.01
Maroonish	0	0	1	<0.01
Rosy	14	0.03	1104	0.03
Pinky	0	0	113	<0.01
Rusty	0	0	94	<0.01
Reddy	0	0	17	<0.01
Plummy	0	0	10	<0.01
Mauvey	0	0	4	<0.01
Maroony	0	0	1	<0.01
Redder	0	0	113	<0.01
Reddest	0	0	25	<0.01
Pinker	1	<0.01	25	<0.01
Pinkest	0	0	1	<0.01
Oranger	0	0	0	0
Orangest	0	0	1	<0.01

Occurrences of colour terms in the red area of the spectrum in SCOTS, with comparative data from the Bank of English (Steinvall 2002).

Towards a diachrony of Maltese basic colour terms

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*... *la perception de la couleur n'est pas entièrement elucidée quand on en a precisé les domaines physiques et physiologiques. Il y a une histoire humaine de la perception.* [colour perception cannot be fully explained merely by a precise specification of the relevant physical and physiological domains; perception is itself a product of human history.] (Ignace Meyerson 1957: 7)

The vernacular of the Maltese archipelago displays a twelve-term colour paradigm comprising ⟨abjad⟩ "white", ⟨iswed⟩ "black", ⟨aħmar⟩ "red", ⟨aħdar⟩ "green", ⟨isfar⟩ "yellow", ⟨ċelesti⟩ "sky blue", ⟨blu⟩ "dark blue", ⟨kannella⟩ "brown", ⟨roża⟩ "pink", ⟨griż⟩ "grey", ⟨oranġjo⟩ "orange" and ⟨vjola⟩ "violet". The dual systemic split of the blue category is a striking feature of Maltese, inviting comparison with the situation obtaining in Italian and other Mediterranean languages. The hybrid (basically Arabic/Italian) composition of the Maltese colour system presents the linguistic researcher with an intriguing cultural synthesis reached by an erstwhile medieval vernacular of Arabic spoken by a small island community exposed to complex linguistic and cultural currents endemic in its regional and local history. The case of Maltese – a Europeanized Arabic vernacular – highlights the crucial role of external influences on cognitive processes monitoring the acquisition of colour categories, and evokes the need for a linguistic model incorporating an elaborate cultural dimension restricting universalist claims commonly associated with the Berlin and Kay paradigm.*

* Maltese terms are presented in this paper as graphemes (denoted by angular brackets). Since written Maltese does not indicate vocalic length, this convention indicates a difference in linguistic level from the presentation of Arabic words (in italics), in which vocalic length is indicated by means of a macron (as in ā).

1. Preliminaries

The present essay reviewing salient diachronic and areal aspects relevant to the development of the basic colour paradigm of Maltese is intended as a contribution to the lexical semantics of a hybrid idiom with a relatively small speaker community.[1] Colour systems of small language communities present the researcher with a distinctive evolutionary typology dominated by permanent contact with languages of wider communication mediating cultural content in a globalizing modality.

The language of the Maltese archipelago is, in genetic terms, a unique variety of colloquial Arabic[2] whose beginnings hark back to the late ninth century, when these strategically located islands were occupied by Arabic- and Berber-speaking military contingents from North Africa and Sicily.[3] Malta's earlier linguistic profile is chronologically difficult to reconstruct with accuracy, but is known to have certainly included long-term exposure, at different times, to Phoenician, Punic, Greek and Latin (Mayr 1909: 111). The question of putative lexical and other residues from these respective ancient linguistic strata in present-day Maltese has yet to be thoroughly studied by contemporary scholarship.[4]

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1. This is an abridged version of a more detailed historical probe into the stratification of the Maltese chromatic lexicon. Lexemes cited from this language are here given in the standard orthography to facilitate reference to Maltese dictionaries (see the bibliography under Aquilina and Serracino-Inglott). Maltese ⟨ċ⟩ and ⟨ġ⟩ represent the sounds [tʃ] and [dʒ] respectively, and ⟨ħ⟩ stands for a voiceless pharyngeal fricative. The digraph ⟨għ⟩, continuing the Old Arabic (OA) voiced velar and pharyngeal fricatives [ʁ] and [ʕ], is most often realized as secondary length of the adjacent stressed vowel. The symbol ⟨ż⟩ stands for the voiced alveolar fricative [z]; without the dot, this letter indicates the Italian affricate [ts] in loans from this language. Maltese ⟨q⟩ renders the voiceless glottal stop [ʔ], and ⟨x⟩ the voiceless alveopalatal fricative [ʃ]. For further detail on the phonetic realization of Maltese graphemes, see Borg (1997: 280–2). The Maltese sound system has lost the OA velarization feature in consonants (here marked by means of a subscript dot); thus the Arabic sounds such as [ṣ], [ḍ] and others are continued by plain equivalents. Likewise the distinction between voiceless velar and pharyngealized fricatives (OA [ḫ] and [x]) has been discarded; the fusion usually yields in Maltese a voiceless pharyngeal spirant [ḥ].

2. Maltese is currently spoken by a population of about 410,000 and by at least as many emigrants resident in various parts of the British Commonwealth (Australia, Canada and so on). Dialectologists ordinarily classify it along with the peripheral varieties of colloquial Arabic surviving outside the pale of the Arab countries (Fischer & Jastrow 1980: 33), comprising a set of highly distinctive and mutually incomprehensible vernaculars spoken by non-Arabs, mainly in S. E. Anatolia, Cyprus, Central Asia (Uzbekistan and Afghanistan) and Central Africa (Chad). The Arabic vernaculars of Spain and Sicily also belonged in this class; Arabic-based pidgins fall into a class of their own.

3. On the Berber lexical component in contemporary Maltese, see Colin (1957), Aquilina (1976) and Footnote 14 below.

4. For a tentative study of ancient Semitic residues in Maltese, see Borg (2009).

The Maltese colour paradigm is, in a very concrete cultural sense, at the opposite extreme of the Bedouin colour system described in Borg (1999b). The former encodes the colour discourse of a long-settled and thoroughly westernized speech community. The Bedouin colour system (as retained by tent-dwelling tribesmen in the Negev and Sinai) still reflects the indisputable circumstance of its having been modelled after their desert ecology. Linguistic researchers of colour rarely have the opportunity of probing in detail different colour systems co-existing within the same language area, though Maltese lies, of course, strictly outside the pale of Arabic acrolectal space. It is here taken as axiomatic that systematic study of lexico-semantic paradigms along the historical axis stands to gain appreciably in empirical rigour when pertinent areal and cultural dimensions are brought to bear on the synchronic data. Thus, while reviewing salient sociocultural factors relevant to the evolutionary path selected by Maltese in its acquisition of colour terms, this research attempts to clarify its speaker community's inclusion in linguistic and cultural networks extending across the Mediterranean.

Direct contact with native Arabic in Malta probably came to an end in the thirteenth century with the expulsion of the island's Muslim community; hence the special chronological dimension of Maltese, which represents, in essence, a medieval variety of Arabic that has survived to this day. The subsequent cultural and linguistic history of the Maltese islands must take within its purview the numerous and complex influences radiating from the adjacent mainland to the north, that is from South Italy and Sicily, and the constant impact of Mediterranean cultural and linguistic currents concomitant with Malta's eventful social, political, and maritime history.[5] This diachronic study of colour terms in Maltese illustrates among other things the extensive 'referential space' entailed in historical research of this essentially oriental idiom – now a language of Europe.

In linguistic terms, the historical profile of Maltese entailed about 800 years of autonomous development in close interaction, first with colloquial and literary Italian and later with English. Beginning with the administration of the Maltese Islands by the Order of the Knights Hospitallers of St. John (1530–1798), Italian became the preferred language of culture. This situation lasted throughout most of the period of British colonial rule (1800–1964), coming to an end in the Second World War when English finally replaced Italian.[6]

5. On the Mediterranean impact on the Maltese lexification of colour, see Section 2. On its influence on the general lexicon, see Borg (1996a).

6. Aware of the subsequent bedouinization of N. African Arabic by the Banū Hilāl and other Arabian nomads, Colin (1931: 7) has stated: "Peut-être même sera-t-on amené un jour à envisager, pour la période pré-hilalienne, la possibilité de l'existence d'un bloc linguistique «arabe d'Occident» ayant englobé, avec les populations citadines de l'Espagne musulmane, celles du Maġrib, de Malte et de Sicile". [It is even possible that one might, at some point, have to visualize, for the period preceding the migration of the Banū Hilāl [to N.Africa], the existence of a well-defined linguistic region coterminous with 'Western Arabic' comprising, along with the urban populations of Muslim Spain, those of the Maghreb, Malta, and Sicily.]

Within the ambit of the 'Age and Area Hypothesis' as propounded by Bartoli (1873–1946; 1906; 1925; 1945), Maltese represents a noteworthy exemplar of the so-called *area isolata* (relic area) in relation to both the Italian and Arabic language areas.[7] Thus the Maltese wordstock is a useful and, as yet, largely untapped source in the linguistic task of contrasting the centre with the periphery vis-à-vis the Arabic and Romance dialect areas.

On account of the prolonged isolation of Maltese from the sources of native Arabic – and despite the considerable inroads into its structure effectuated by foreign language contact – the rich, lineally inherited lexical stratum of this peripheral variety of Arabic still remains a useful reference point for the diachronic study of mainstream varieties of this language, particularly in the reconstruction of early Maghribī Arabic, given the numerous formal continuities of Maltese with the Arabic vernaculars of medieval Sicily and, especially, Al-Andalus.

As will be noted below, for instance, the oldest stratum in the Maltese colour paradigm retains virtually intact the Old Arabic (OA) five-term system. Lexical corpora assembled for comparative purposes specifically from contemporary diaspora vernaculars of Arabic can be valuable in the diachronic study of specific semantic paradigms in this language and in Semitic, since they can render possible among other things the chronological ordering of lexical isoglosses. Furthermore, correspondences obtaining between the wordstocks of relatively isolated or mutually distant points on a linguistic map (let us say, Malta or Cyprus and mainstream Arabic) cannot be attributed to mere chance but ordinarily signal direct or indirect historical and cultural continuities.

Of special interest in this specific regard is Malta's history of contact with Middle Eastern varieties of Arabic, introducing into its Maghribī profile a linguistic component of Levantine provenance (Stumme 1904: 83) along with a considerable older layer of lexical Aramaisms (Borg 2009). As will be suggested below, Maltese has, through its affiliations with the periphery of the Eastern Mediterranean (Borg 1996b), retained a remarkably suggestive lexical trace intimating an evolutionary link to the emergence of the blue category in ancient Arabic (see Section 6).[8]

2. The basic colour terms of Maltese

Following Berlin and Kay (1969) rather literally, Briffa (2007) attributes to standard Maltese *eleven* basic colour terms; in fact, as already noted in Borg (1999a: vi), the

7. Drawing on original insights popularized by the Indo-Europeanist Johannes Schmidt (1843–1901) and the Romanist Wilhelm Meyer-Lübke (1861–1936), Bartoli etched a theoretical framework, systematizing for historical linguists the interactive correlations obtaining between areal configuration and temporal sequence in linguistic evolution, exemplified on the basis of the Romance dialect map.

8. On the various linguistic peripheries relevant to Maltese, compare Borg (2004: 55, Footnote 101).

basic colour paradigm of Maltese lexifies *twelve* categories including two functionally distinct terms for BLUE (see Table 1).[9]

As already noted, the Arabic component in the Maltese colour paradigm continues (with minor phonetic changes) the OA five-term colour system as posited in Fischer (1965) and retained in most varieties of colloquial Arabic, corresponding to the first five categories posited in the Berlin and Kay evolutionary sequence. The other colour names listed in Table 1 are of Italian provenance and encode the later categories (that is, Berlin and Kay's Stage V onwards).

Retention in Maltese of the basic five-term system attested in the earliest known linguistic stratum of Old Arabic signals continuity with a much older Near Eastern cultural synthesis reached already in Biblical Hebrew with its own five-term categorization of the colour spectrum: *lābān* "white", *šāḥōr* "black", *ʿādōm* "red", *yārōq* "green", *ṣāhōb* "yellow, bright" (Brenner 1982). It invites comparison with several five-term colour systems existing in certain sheltered speech communities, such as that of the Cypriot Arabic Maronites (Borg 2004: 84). The Neo-Aramaic speakers of Ṭūr ʿAbdīn in S. E. Anatolia (Asia Minor) also display a five-term colour paradigm (*ḥeworo* "white", *komo* "black", *semoqo* "red", *yaroqo* "green", *šaʿūθo* "yellow" (author's observation).

The lexification in Maltese of the later categories of the Berlin and Kay sequence attests to the salient impact of foreign language contact as a catalyst of

Table 1. The basic colour terms of Maltese with their etymologies. German glosses are from Fischer (1965: 243, 273, 335, 306, 358). Ar = Arabic; It = Italian; OIt = Old Italian

⟨**abjad**⟩ "white" < Ar *ʾabyaḍ* "hell leuchtend, weiß [bright, white]".

⟨**iswed**⟩ "black" < Ar *ʾaswad* "schwarz, dunkel, finster [black, dark]".

⟨**aħmar**⟩ "red, light brown" < Ar *ʾaḥmar* "rot, braun [red, brown]".

⟨**aħdar**⟩ "green" < Ar *ʾaxḍar* "dunkelfarbig, blau, grün [dark-coloured, blue, green]".

⟨**isfar**⟩ "yellow, pale" < Ar *ʾaṣfar* "alle Farbtöne vom hellsten Gelb und Beige bis Orange und gelblich Dunkelbraun [all shades from brightest yellow and beige to orange and yellowish dark brown]".

⟨**ċelesti**⟩ "sky blue" < It *celeste* [sky blue].

⟨**blu**⟩ "dark blue" < It *blu*/Eng *blue*.

⟨**kannella**⟩ "brown" < It *cannella* "cinnamon".

⟨**roża**⟩ "pink" < It *rosa*.

⟨**griż**⟩ "grey" < OIt *griso*.

⟨**oranġjo**⟩ "orange" < It *arancione*/Eng *orange*.

⟨**vjola**⟩ "violet" < It *viola*.

9. This trait brings Maltese in line with two Slavic languages: Polish and Russian; cf. *niebieski/goluboy*, Polish and Russian respectively for 'light blue'; *granatowy/sinij* Polish and Russian for 'dark blue'. Dual lexification of BLUE appears to be not uncommon in certain Mediterranean languages (see Section 5 below).

change, and foregrounds above all the cultural role of *extraneous* structural pressures in the acquisition of these systemically marked lexemes. The integration – mainly from Italian – of these colour categories in Maltese is patently not the sole product of an autonomous internal process after separation from the Arabic-speaking world, since cognates of three Maltese colour words (continuing, specifically, Italian *kannella* "cinnamon", *rosa* "rose", and *griso* "grey"[10] for BROWN, PINK and GREY respectively) also occur in Modern Greek. Demotic Greek has *kaneli* (κανέλι) "light brown", *roz* (ροζ) "pink", and *grizo* (γρίζο) "grey" (paralleled by Cypriot Greek [kanel'li], [roz], and [ˈgrizzo] respectively) (author's observation).

The parallel between Maltese and Greek here suggests that lexification of these three categories was the outcome of a regional pattern disseminated by colonial Italian. Similarly, the lexification of more than a single blue category in this language finds parallels in other parts of the Mediterranean region, for example in Italian. There are also other signs of foreign influence.

It is significant that within mainstream Arabic itself, the expansion of the basic colour inventory inherited from Old Arabic to the maximal set of eleven terms, exemplified for Cairo, Damascus and Jerusalem in Table 2, has clearly also transpired in part under

Table 2. Basic color systems in three urban Arabic vernaculars (Borg 2007). Sources for the Cairo vernacular are Stewart (1999: 106) and Badawi and Hinds (1986); for Damascus, Stowasser and Ani (1964), and for Jerusalem, the author's own observation

Cairo	Damascus	Jerusalem	Translation
ʾabyaḍ	*ʾabyaḍ*	*ʾabyaḍ*	white
ʾaswad	*ʾaswad*	*ʾaswad*	black
ʾaḥmar	*ʾaḥmar*	*ʾaḥmar*	red
ʾaxḍar	*ʾaxḍar*	*ʾaxḍar*	green
ʾasfar	*ʾasfar*	*ʾasfar*	yellow
ʾazra'	*ʾazra'*	*ʾazra'*	blue
bunni	*bunni*	*bunni*	brown
ramādi "grey" [ashen]	*rmādi*	*ramādi*	grey
zahri "pink" [flower-colour]	*zahər* (invariable)	*zahri*	pink
burtʾāni	*bərtʾāni*	*burtʾāni*	orange
banafsigi "violet" [name of flower]	*ʿannābi* "purple"	*lēlaki* [or] *banafsaĝi* "violet"	[violet or purple]

10. Standard Italian has *grigio* for 'grey'. Cognates of **griso* are well known from Northern Romance (French, Provençal and Catalan *gris*), Spanish and Portuguese (both have *gris*). For further detail, see Meyer-Lübke (1935: 330).

the globalizing influence of foreign language contact, for example *lēlaki* "violet" from Persian *nīlak* "blueish" (from Sanskrit *nīla-*); *burtʾāni* "orange" from *Portugal*, and so on.

As can be inferred from Table 2, there is a notable degree of convergence among Eastern Arabic vernaculars in their selection of the later categories, that is beyond Stage IV of the Berlin and Kay evolutionary sequence. Actually, the extraneous, centrifugal impact on the colour nomenclature can here also be observed in later acquisitions encoding Arabic linguistic forms, since the standard OA morphophonemic *afʿal* canonic form for colour adjectives, and those of its feminine and plural equivalents, are conspicuously absent in later colour categories: *bunni* "brown" (from Arabic *bunn* "coffee beans"); *ramādi* "grey" (from Arabic *ramād* "ashes"); and *zahri* "pink" (from Arabic *zahr* "flowers, blossoms").

The semantic content of basic colour terms in Maltese has been largely aligned with Standard Average European (SAE) norms (Whorf 1941). Thus the terms ⟨abjad⟩ and ⟨iswed⟩ ordinarily stand simply for "white" and "black" but idiomatic usage yields noteworthy instances of semantic innovation, such as ⟨baḥar abjad⟩ meaning literally "white ([that is] calm) sea" (Serracino-Inglott 1975–84:I.4).[11] Aquilina (1987–90:I.63) records the verbal cognate ⟨bajjad⟩, literally "whiten", in the meaning "polish (brass)", evoking a "brightness" value, and ⟨tbajjad⟩ "fade (colour of cloth)".

Maltese ⟨aħmar⟩ "red" encodes both focal red and macro-red (including the brown hue of baked or roasted food),[12] and ⟨aħdar⟩ "green" evokes "grass green" and freshness, without the darker nuances (blue or black) of its older form or the link with succulence and moisture (cf. Cairene *ʾaxḍar* "wet" (Badawi & Hinds 1986: 254)). The verbal equivalent ⟨ħdar⟩ "to turn green" can refer to a sickly pale complexion, but the common metaphorical expression ⟨qalb ħadra⟩, literally "a green heart", characterizes a cruel person.

Maltese ⟨isfar⟩ "yellow", optimally exemplified by the colour of egg yolk, can also designate a pale complexion: ⟨wiċċu isfar mewt⟩, literally "his face is as yellow as death", "he's deathly pale". Applied to certain natural surfaces, such as leather, ⟨isfar⟩ encodes light brown (for example, tan shoes). Maltese "yellow" can also convey brightness in the collocation ⟨isfar lellux⟩[13] "bright yellow"; note here the verbal cognate ⟨lellex,

11. Arrow brackets in citations from Maltese enclose orthographical representations.

12. A macro-red category has also been noted in European usage: "Il est à remarquer que les paysans ne reconnaissent que le rouge, dont le domain pour eux embrasse le rose et l'orange, et toutes les nuances comprises entre ces couleurs; – le jaune, mais seulement certaines nuances; quand il est pâle, ils l'appellent blanc; quand il est un peu foncé, c'est du rouge" (Karr 1851: 107–108). [One should note that country folk only perceive a red category whose domain, from their viewpoint, comprises pink and orange, including all the hues intervening between these colours, as well as certain shades of yellow. However, they call pale yellow 'white.']

13. Cf. Ar *lāllūšah* 'calendula' (a plant with bright red, yellow and orange flowers) (Dozy 1881:II.516) with its verbal cognate ⟨lellex, ilellex⟩ "shine, glitter" from Berber *lallūš* (Colin 1931: 12).

ilellex⟩ "to shine, glitter", also attested for Zaïre in Colin (1957) with the gloss "avoir une couleur éclatante" [have a bright colour].

3. The non-basic colour system of Maltese

Briffa (2007) correctly observes that the non-basic chromatic vocabulary of contemporary Maltese has been profoundly influenced by the nomenclature of modern colour technology (mostly English). The inventory of non-technical usage, however, still displays a residual element of lineally inherited terms harking back to an Arabic stratum. This tends to vary across the Maltese speech community because rural speakers generally retain a richer stock of lineally inherited non-basic colour terms than the urban community, often archaisms restricted to specific collocations: ⟨ixjeb⟩ "white (of hair)"; ⟨idgħam⟩, feminine ⟨dagħma⟩, plural ⟨dagħam⟩ "dark", usually modifying the basic colours red and black (see Table 3), and so on. The traditional Maltese word stock of non-basic colour terms is well reflected in Vassalli's *Lexicon Melitense-Latino-Italum* of 1796. Most of these colour terms are still known to contemporary rural Maltese speakers who are familiar with the terminology encoding natural colours referring mainly to animal pelts: ⟨ixqar⟩ "brindled (horse, goat)" (Aquilina 1987–90:II.1582).

The cultural dimension implicit in the semantics of non-basic colour terms tends to be overlooked in Berlin and Kay's research paradigm. Maltese ⟨iblaq⟩ "of mixed colour (light and dark)", for instance, does not merely refer to a static condition, but also to observable colour changes in fruit undergoing a process of maturation: ⟨dulliegħa belqa⟩ "a water-melon that has just begun to ripen (that is, is turning red inside)" (Aquilina 1987–90:I.134). Maltese here retains a distinctive formal trait of the OA word stock, a great part of which lexified the natural colours of the desert ecology. Prolix lexification of ecological hues in Arabic is today best exemplified by speakers of Bedouin vernaculars (Borg 1999b: 133–9).

4. Formal aspects of Maltese colour terms

Linguistic colour research rarely incorporates information on the formal behaviour of colour terms, articulating their distinct status as a grammatical subsystem in the language concerned. Like their OA counterparts, Maltese colour terms display a fairly elaborate grammatical profile comprising adjectival, verbal and nominal reflexes of colour concepts. Despite its prolonged period of autonomous evolution and the external impact of foreign language contact, Maltese has extensively retained the formal apparatus encoding the inflectional and derivational morphology of Arabic. Observe, for instance, the grammatical productivity of the Maltese root morpheme *ḥmr* "red":

Table 3. Non-basic color terms in 18th-century Maltese (after Vassalli 1796). Numbers in round brackets refer to pages in Vassalli (1796). Ar = Arabic; f. = feminine; pl. = plural

⟨**iblaq**⟩, f. ⟨belqa⟩, pl. ⟨boloq⟩ "mixtus colore; nigricans, cineraceus, leucophaeus; coloris pomorum quum ad maturitatem veniunt; fosco, grigio, vajo, cinerizio" [variegated, shading into black, ash-coloured, light grey, of the colour of apples as they ripen; dark, grey] (35). < Ar *ablaq, balqā', bulq* "variegated, piebald".

⟨**idgħam**⟩, f. ⟨dagħma⟩, pl. ⟨dagħam⟩ "obscurus; valde niger, valde ruber; nerissimo, rossissimo" [dark, intensely black, intensely red], e.g. ⟨aħmar idgħam/dagħmien(i)⟩ "Perfecte russus, valde ruber, coccineus" [intensely red, scarlet]; ⟨iswed idgħam/dagħmien⟩ "Perfecte niger, nigerrimus" [completely black] (143) equivalent to Ar *'adġam, daġmā', duġm* "having a darker colour around the nose than the rest of the body (horse)".

⟨**iżraq**⟩, f. ⟨żerqa⟩, pl. ⟨żoroq/żoraq⟩ "glaucus, caesius, caeruleus; di color mischio tra 'l verde e 'l verde ceruleo, celeste" [blueish grey, light blue, greenish blue, dusky, a variable colour between grass-green and blueish green] (673) < Ar *'azraq, zarqā', zurq*.

⟨**ikħal**⟩, f. ⟨kaħla⟩, pl. ⟨koħol⟩ "caeruleus; turchino, azzurro" [dark blue, variable colour between dark and light blue] (368) < Ar *'akḥal, kaḥlā', kuḥl*.

⟨**ixqar**⟩, f. ⟨xaqra⟩, pl. ⟨xoqor⟩ "rufus; rossigno" [red/reddish (hair)] (304) < Ar *'ašqar, šaqrā', šuqr*.

⟨**ismar**⟩, f. ⟨samra⟩, pl. ⟨somor⟩ "sub-niger" [dark-skinned] (301, 592) < Ar *'asmar*, *samrā', sumr*.

⟨**ixheb**⟩, f. ⟨xehba⟩, pl. ⟨xeheb⟩ "Zyziphinus, luteo-ruber; di colore tra il giallo ed il rosso simile al color del giuggiolo e del zibibo" [the colour of jujube fruit, between yellow and red (orange?), variable colour between yellow and red approximating that of the jujube fruit and of currants] (304) < Ar *'ašhab, šahbā', šuhb* "weißgrau, weiß, hellgrau" [greyish white, white, light grey] (Fischer 1965: "Wortindices", *passim*).

⟨**għosfri**⟩, f. ⟨għosfrija⟩, pl. ⟨għosfrin⟩ "luteus color" [yellow approximating orange] (363) < Ar *'usfur* "safflower, yellow dye".

⟨**qannbi**⟩ "color seminis cannabini" [the colour of hemp seeds] (404) < Ar *qannab* "hemp".

⟨**xejbien(i)**⟩ "di color quasi giuggiolino" [approximating the colour of the jujube fruit] < Ar *'ašyab/šā'ib*.

⟨**brinġieli**⟩ "color fructus melongenae sc. violaceus; paonazzo, violetto" [the colour of the eggplant, i.e. violet; bluish violet (like the peacock's tail), violet] (57) equivalent to Ar *bāðinğānī* [the colour of eggplant].

⟨**dibsi**⟩ "coloris mixti" [of an indistinct hue] (163) < Ar *dibs* "treacle, honey".

a. a stative verb: ⟨ħmar⟩ "to become red; to blush".
b. the causative equivalent: ⟨ħammar⟩ "to redden".
c. an adjective: ⟨aħmar⟩ "red", f. ⟨ħamra⟩, pl. ⟨ħomor⟩.
d. an approximative adjectival form: ⟨ħamrani⟩ "reddish".
e. an abstract noun: ⟨ħmura⟩ "redness".

Causative verb forms are, however, available exclusively for the root morphemes *byḍ* "white", *swd* "black", *ḥmr* "red", and *ḥḍr* "green" (from OA *byḍ*, *swd, ḥmr*, and *xḍr*); this trait invites comparison with the analogous restriction in English which limits the

derivation of causatives to the first three terms in the Berlin and Kay evolutionary sequence: *white* gives *whiten, black* gives *blacken* and *red* gives *redden.*

As already noted, reflexes of OA colour adjectives are also elaborately inflected for gender and number in Maltese:

> ⟨abjad⟩, f. ⟨bajda⟩, pl. ⟨bojod⟩ "white"; ⟨iswed⟩, f. ⟨sewda⟩, pl. ⟨suwed⟩ "black"; ⟨aħmar⟩, f. ⟨ħamra⟩, pl. ⟨ħomor⟩ "red"; ⟨aħdar⟩, f. ⟨ħadra⟩, pl. ⟨ħodor⟩ "green"; ⟨isfar⟩, f. ⟨safra⟩, pl. ⟨sofor⟩ "yellow".

The derivational potential operating within the Maltese colour system has been exemplified in Briffa (2007), which demonstrates among other things that the Arabic lexical component in the Maltese colour paradigm often proliferates, under its own creative impulse, derivational forms non-existent in Arabic itself, for instance new *nisba* (suffixed) terms in the realm of abstract nouns: ⟨bjudija⟩ "whiteness", ⟨swidija⟩ "blackness", and so on (Briffa 2007: 72).

An interesting OA pragmatic trait which continued in the Maltese colour paradigm (cf. Borg 2007: 267) is the minimal grammaticalization implemented (that is, mere juxtaposition) in collocations of {colour word + noun} encoding comparisons: ⟨aħmar demm⟩ (literally, red + blood) "blood red" (signifying "as red as blood"); ⟨abjad karti⟩ (literally, white + paper) "pure white" (signifying "as white as paper") and others. This type of Maltese collocation appears to be rare outside discourse on colour, but examples exist: ⟨ħelu manna⟩ (literally, sweet + manna) "very sweet" (signifying "as sweet as manna"); ⟨morr velenu⟩ (literally, bitter + poison) "very bitter" (signifying "as bitter as poison").

5. The evolution of BLUE in Arabic and Maltese

Maltese has inherited from Old Arabic two root morphemes designating the colour BLUE, *żrq* and *kħl*, both of which are, in the standard language, collocationally restricted and, consequently, non-basic: Maltese ⟨iżraq⟩, f. ⟨żerqa⟩, pl. ⟨żoroq⟩, ⟨għajnejn żoroq⟩ "blue eyes" (from Ar *azraq*, f. *zarqāʾ*, pl. *zurq*); Maltese ⟨ikħal⟩, ⟨sema ikħal⟩ "blue sky" (from Ar *kaḥl* "sky, firmament") (Hava 1982: 646). This analysis differs from that in Briffa (2007: 77) where ⟨ikħal⟩ is assigned basic status; the usages just cited, however, clearly show that both Maltese ⟨iżraq⟩ and ⟨ikħal⟩ are salient colour terms in a non-basic modality. Vassalli's *Lexicon Melitense-Latino-Italum* (1796: 673, 368) defined them as follows:

> Maltese ⟨iżraq⟩ "glaucus, caesius, caeruleus; di colore mischio tra 'l verde e 'l verde di colore celeste, azzurra, cerulea" [blueish grey, light blue, greenish blue, dusky, a variable colour between grass-green and blueish green]; Maltese ⟨ikħal⟩ "caeruleus; turchino, azzurro" [dark blue, variable colour between dark and light blue].

Though both terms are here equated with Italian *azzurro*, the gloss *turchino* for ⟨ikħal⟩ would seem to intimate "dark blue"; thus, whereas these terms can, like Latin *caeruleus*,

refer to lighter shades of blue, Maltese ⟨ikħal⟩ can also extend its domain towards darker shades of this colour. For Vassalli, ⟨iżraq⟩ runs into green; in the contemporary language, ⟨ikħal⟩ also overlaps with GREEN, as, for example, in *wara x-xita l-għelieqi jikħlu* "after a rainfall, the crops look green" (Aquilina 1987–90:II.604).

Contemporary standard Maltese ordinarily encodes light and dark shades of BLUE by means of two basic terms taken over from Italian: ⟨ċelesti⟩ "light blue" and ⟨blu⟩ "dark blue" respectively. There has been, however, a long-standing revivalist trend among Maltese writers going back to the late nineteenth century, promoting the lineally Semitic lexical heritage in preference to loanwords (even when these are well-integrated in the spoken register); thus the basic categorization of BLUE in Maltese is liable to remain a moot point in a formal analysis. In view of the existence in Maltese of the aforementioned lineally inherited Arabic-based terms for BLUE, its lexification of this semantic slot with Romance linguistic forms is, to say the least, intriguing. Relegation of the reflex continuing Arabic *azraq* "blue" in Maltese to the non-basic component of the colour inventory is particularly striking when it is recalled that this lexeme has – possibly under the impact of literary usage – emerged as the virtually pandialectal Arabic designation for "blue":[14]

a. Palestinian Arabic: *ʿazraq* "blau" [blue] (Bauer 1957: 62).
b. Damascus: *ʿazraq* "blue" (Stowasser & Ani 1964: 25).
c. Cairo: *ʿazra'* "blue; grey (horse); dove grey"; *ʿazra ṣīni* "china blue" (Badawi & Hinds 1986: 369).
d. Lebanon: *zaytūn ʿazraq* "olives pas mûres, encore vertes" [unripe olives, still green] (Feghali 1935: 155).
e. Dathīna: *ʿazraq* "bleu, mais ce thème implique aussi l'idée de gris ou de noir; Grauschimmel" [blue, but this topic also implies the idea of grey or of black; grey mould] (Landberg 1920–42:III.1836).

It will be suggested below that the fate of the Arabic lexemes *azraq* and *akḥal* in the history of Maltese is not fortuitous, but a direct outcome of sociocultural factors. Throughout most of its history, the population of the Maltese Islands is known to have been fairly small, comprising mainly peasant folk in small rural settlements. In his 1954 study of colour terms in the Slavic languages, Herne insightfully remarked that rural speech communities have, generally, little practical use for blue.

Prototypical notions of blue in the Mediterranean language area can derive from "sky blue" and "sea blue"; observe the Cypriot Greek equivalents *galážžo* and *θalassí* (cf. Gk *thalassa* (θαλασσα) "sea").[15] In fact, as already noted above, Modern Greek also

14. Among the Bedouin, the reflex of OA *azraq* usually means "black" (Borg 1999b).

15. An interesting semantic point arising with respect to Demotic *galazios* (γαλάζιος) "sky blue" is its derivation from *gala* (γάλα) "milk". The association of light blue with milk finds parallels in Cairene *labani* "pale blue; milky (of colour)" (Badawi & Hinds 1986), and in Omdurman *axadar labani* "hellblau" [light blue] (Reichmuth 1981: 56) (equivalent to Ar *laban* "milk,

shares with Maltese a dual categorization of the blue continuum: Gk *galazios* (γαλαζιος) "light blue" and *mple* (μπλε) "dark blue". This categorization appears to be normative in Greek literary usage according to the definitions of these two terms proferred in the *Lexiko tēs koinēs Neoellēnikēs* (*Dictionary of Common Modern Greek*) (1998: 293, 887).

It is worth noting here that Davies, Corbett and Margalef (1995) have also noted two salient terms for BLUE in Catalan though, apparently, encapsulated within a single category. Thus the question arises as to whether dual categorization of BLUE may not simply be a Mediterranean trend. At all events, the internal split of the blue continuum into two categories in Maltese probably mirrors an analogous situation in contemporary colloquial Italian where terms for BLUE (*azzurro*, *blu* and others) appear to function as autonomous categories.[16]

The late lexification of a fully fledged BLUE category in standard Maltese, and its derivation from Italian, are probably best explained with reference to prolonged and close contact with the Italian vernaculars. Summing up the dialectal data relative to the categorization of BLUE in the *Sprach- und Sachatlas Italiens und der Südschweiz* (*AIS*) (Jaberg & Jud 1928–40), Kristol notes (1980: 142–144):

1. The complete absence of an equivalent for *blue*, for example in the Italian dialects of Canzo (Como province), Gavorrano and Pitigliano (Grosseto province), and Serrone (Rome province).
2. The incidence in several Italian dialects of a GRUE category (that is, GREEN together with BLUE).

It would seem fairly plausible to adopt for Maltese BLUE the historical typology that Kristol postulates for the Italian language area with its "extreme dialectal fragmentation and excellent preservation of local dialects" (1980: 139). This author attributes the absence of a basic blue category in these Italian vernaculars to a regressive shift entailing loss of the Latin term for blue (*caeruleus*). In fact no reflex of this term occurs in the basic colour paradigms of the Romance languages: Spanish, Portuguese *azul*; Italian *azzurro/blu/celeste*; French *bleu* and so on.[17] Echoing Gladstone, Lyons highlights the uncertain status of the blue category in Ancient Greek:

yoghourt"). In Moroccan Arabic, the term *ləbni* (cf. *lbən* "petit lait" [whey]) is defined as "de couleur bleu ciel pâle; blanc grisâtre légèrement bleuté, plus foncé que la nuance *sukri* [of a pale sky-blue colour; slightly blue greyish white, darker than sugar-colour, i.e. white with a light bluish tint] (Premare 1993–9:XI.25). Thus here again cross-linguistic cultural isoglosses in relation to colour semantics point to the agency of regional factors.

16. The categorization of the BLUE continuum by contemporary Italian speakers is the topic of ongoing research by Mari Uusküla of the Estonian Language Academy (Talinn).

17. This might be taken to suggest that Latin *caeruleus* was non-basic. Such a possibility has been intimated in Lyons (1999: 67): "Whether Classical Latin had a word for BK-blue is somewhat more problematical" [i.e. than *luteus* as a level-1 word for "bright, reddish or orange-yellow" A. B.].

> It is not at all clear, however, that Ancient Greek had a word for the sixth color in the BK-hierarchy: blue. In fact, there are serious, and perhaps insoluble, problems relating to Ancient Greek words that denote colors in the blue-purple area of the spectrum. At least three, and possibly four, words have to be considered as basic level-1 color terms: *halourgos* (usually translated "purple"), *kuaneos* (... usually translated "dark blue"), *orphninos* ("violet"?) and possibly *glaukos*. (1999: 63; cf. Jensen 1965)

The comparable development of Ancient Greek *glaukos* (γλαυκος) in a direction later paralleled by that of Classical Arabic *azraq* is addressed in the following section.

6. From brightness to hue in relation to BLUE in Arabic and Maltese

MacLaury (1992) expounded the notion that modern colour systems evolved from earlier lexico-semantic paradigms, the terms of which encoded bright versus dark contrasts rather than hue differentiation. In his later study, *Color and Cognition in Mesoamerica* (1997), this author stated:

> People who attend strongly to similarity may be inclined to categorize brightness, whereas those who attend strongly to distinctiveness mainly categorize hue. Thus, brightness categories will tend to precede hue categories in evolutionary order. The physiological basis may be that neural channels conveying luminance respond faster than those conveying hue sensations; thus brightness is the first impression when experiencing color. It takes greater acuity to sort out the second impression of hue. (MacLaury 1997: 44)

A striking aspect of the semantic shift from 'brightness' to 'hue' residually reflected in the present-day Maltese lexicon relates specifically to the internal history of the BLUE category in Semitic. Classical Arabic encodes BLUE by means of the term *azraqu* which, as Fischer (1965: 48) has shown, did not allude to chroma (saturation) in the oldest lexical stratum of Arabic (that is, in pre-Islamic poetry), but designated the glittering or gleaming of a sharp point, a star, or other such object. In other words, it conveyed a sensation of brightness combined with movement:

> Die ermittelte Bedeutung "blinkend, glitzernd, schillernd" hat sich als primäre Benennung an allen altarabischen Belegstellen bestätigt. Es kann noch das Bezeichnungsmerkmal hinzugefügt werden, daß nur von solchen Dingen gesagt wird, an denen das Glitzern und Schillern punktartig auftritt, wie bei Sternen, Lanzenspitzen und Augen. (Fischer 1965: 54)[18]

18. The meaning patterns extrapolated from all the references to *azraqu* in Old Arabic poetry endorse this term as a basic designation for "flashing, sparkling, and shimmering". A further characteristic trait of this usage is its exclusive applicability to objects in which glittering and shimmering appear as a point source, for instance in stars, spearheads and eyes.

Recognizing the far-reaching impact of the Greek *koinē* in the Near East and elsewhere, Fischer (1965: 50, 238) insightfully refers to a parallel semantic shift within ancient Arabic and hellenistic Greek which may well account for the strikingly analogous evolutionary paths selected by OA *azraqu* and Ancient Greek *glaukos*.[19]

Significantly, in this regard, closely related meanings associated with brightness rather than hue for the root morpheme *zrq* also show up in the modern Arabic vernaculars. Thus Yemeni Arabic has the cognates *zāriq* "sparks (of fire)" and *zārigah* "sunray(s)...radiating through a window" (Piamenta 1990–1991:I.199). Observe also the semantic patterns *ʿazraq* "multicoloured, shining" (Piamenta 1990–1991:I.199) and Lebanese *zarqaṭ* "prendre des couleurs" [to take on colour] (Denizeau 1960: 218).

From the Maltese standpoint, the preceding remarks on the evolution of BLUE from an earlier brightness category in Old Arabic merit attention in relation to an odd lexical archaism in the language: the root morpheme {żrnq} yielding Maltese ⟨żernaq⟩ "to dawn" with its cognate noun ⟨żerniq⟩, with a long vowel [i:], "first light", which invite comparison with a number of Neo-Aramaic cognates with closely related meanings:

a. Koy Sanjaq (Iraqi Kurdistan) *zarəq* "rise (sun)" (Mutzafi 2004: 254).
b. Mandaic (Iran) *zarrūq* "glänzend" [gleaming] (Macuch 1989).
c. Ṭuroyo (S. E. Anatolia) *zaliqo* "Sonnenstrahl" [sunbeam] (Ritter 1979: 595).

Aquilina (1987–1990:II.1611) plausibly relates ⟨żernaq⟩ to Maltese *żrq* as in *żeraq* "to flash (eyes)", but fails to bring to bear comparative data from Arabic and other Semitic languages calculated to highlight the diachronic significance of the Maltese lexeme specifically in relation to the colour lexicon.

The remarkably conservative character of the Maltese lexicon truly stands out in this connexion, since the semantic pattern of "sprinkling (liquids)" and radiating "light contrasts (in relation to eyes)" both co-occur as far back as Assyrian: Assyrian *zarāqu* "sprinkle (liquids)", *zuriqtu* "irrigation", *zuruqqu*/*zirīqu* "primitive apparatus for drawing water for irrigation", *zarriqu* "with speckled eyes (of a demon)"[20] (*CAD* XXI: 65, 69, 167, 134).

The aforecited data from Arabic and other Semitic languages suggest that the original meaning of the proto-Semitic root morpheme **zrq* was "to sprinkle, throw (water

19. Fischer (1965) discusses the closely parallel semantic development of Ancient Greek *γλαυκός*, glossed in Liddell and Scott (1996: 350–1) as "originally without any notion of colour, gleaming; later, of colour, blueish green or grey, of the olive...elder, grapes, vine leaves, frequently of the eye, light blue, grey, etc". The putative influence of Greek on the OA color system – conceivably through the mediation of Aramaic (cf. Syriac *zārqā* "bläulich" [bluish]; Brockelmann 1928) – cannot be ruled out given the mediation of Greek language culture in Arab-dominated Syria and Palestine (Mango 2002: 214).

20. For this meaning, compare Akkadian *bitramu* "multicoloured (of eyes)", *barmu* "multicoloured, variegated", *burmu* "coloured part", *bitrumu* "very colourful of bird, piebald of mule" (*CAD* II.49). Note that the ancient Semitic collocational association of {zrq} with 'eyes' has filtered down to Maltese.

and, by analogy, light)". The Aramaic-based Maltese root morpheme {żrnq} here interestingly retains explicit traces of this primeval stage, conveying the analogical meaning relating to "light" apparently unattested for its Aramaic cognate in the available lexicographic sources. Consequently, the Maltese Aramaism here supplies the 'missing link' between the semantic field of Aramaic *zrnq* and that of Assyrian *zrq*.

The significance for Semitic lexicology and lexicography of this residual semantic trait in Maltese is notably enhanced by the additional incidence of the metathesized cognate root **rzq* from **zrq* encoding a semantic pattern most closely reflected in the aforecited terms from Assyrian. Consider Maltese ⟨merżuq⟩ "ray of light", and ⟨merżaq, jmerżaq⟩ "radiatim & cum copia emitto lucem; eiicio lac e mammis, aquam; far raggi; schizzare, mandar fuori con impeto liquore" [radiate a strong light; spurt out/exude milk from the breasts, water; emit rays; splash, eject fluid with force] (Vassalli 1796: 472).[21] Ancient Hebrew and numerous dialectal Arabic cognates lexified with the root {zrq} convey closely related meanings:

a. Biblical Hebrew *zarāq* "streuen, Staub" [to spread, dust] (Gesenius & Buhl 1954: 208).
b. Syriac *zraq* "to scatter, sprinkle, disperse" (Payne Smith 1903: 121).
c. Jewish Aramaic *zraq* "to throw, sprinkle" (Sokoloff 1990: 182).
d. Yemeni Arabic *zaraq* "to throw" (Piamenta 1990–1991:I.199).
e. Dathīna *zarraq* "to throw" (Landberg 1920–42:III.1835).
f. Lebanese Arabic *zaraq* "jaillir avec force d'un orifice" [to gush out of an orifice with force]; *zarzaq* "tomber de haut ou descendre dans une conduite depuis un endroit en faisant du bruit (eau)" [to fall from a height or to flow noisily (water) down a pipe]; *zarrāqa* "roseau creux muni d'un piston; on le remplit d'eau et, en appuyant sur le piston, on asperge (jeu d'enfant)" [a hollow reed provided with a plunger; it is filled with water and, on pressing down the plunger, it sprays out (a children's game)] (Denizeau 1960: 218).
g. Palestian Arabic *zaraq* "se glisser (*ʿala*)" [to glide] (Denizeau 1960).

It is worth noting that in certain contemporary Arabic vernaculars, including Maltese, cognates lexified with this root display a semantic pattern not far removed from "forceful emission of light or water" and/or some aspect of "movement":

a. Maltese ⟨żerżaq⟩ "slide down".
b. Gulf Arabic *zarrag/k* "cause to slide" (Holes 2001: 221).
c. Cairo *zarra'* "slip" (Badawi & Hinds 1986: 369).
d. Iraqi Arabic *zirag* "to dash, hurry, go quickly" (Clarity et al. 1964–7:II.203).

21. Vassalli (1796) is here cited in the modern orthography. It is remarkable that Maltese retains the range of meanings found only in fragmentary fashion in different varieties of ancient Semitic!

All things considered, the historical treatment noted above for the Maltese Aramaism ⟨żrnq⟩ invites comparison with that evidenced in several vernaculars of Eastern Arabic referred to in Borg (2007: 270), where certain diachronically basic color terms of Aramaic provenance (that is, *ḥwr* "white", *šḥr* "black", *smq* "red", and *yrq* "green") have survived on the margins of the Arabic colour paradigm.

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Rosa Schätze – Pink zum kaufen

Stylistic confusion, subjective perception and semantic uncertainty of a loaned colour term

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Over the past decades, English has had a strong influence on the German language, including the introduction of new words, among them the colour term *pink*. A first study (Frenzel 2006) investigated German speakers' perception of *rosa/pink* as two separate colours rather than different shades of the same colour. The results suggested that *pink* was causing a shift in the semantic scope of the German colour term *rosa*. In order to further investigate this change in progress, a corpus of six popular magazines has been compiled since 2006. To objectively determine the application of the two colour terms and their status in German, instances of *pink* and *rosa* were selected on the basis of visual support from illustrative material in the magazines. The interpretation of the corpus takes semantic, connotative, contextual, and, particularly, stylistic considerations into account to ascertain the level of basicness of *pink* in the German language.

1. Introduction

German is a language rich in loanwords from English (Carstensen & Busse 1996), including the colour term *pink*. *Pink* denotes a very clear colour range for English native speakers, whilst it has a more restricted range for German native speakers. A first study (Frenzel 2006) investigated the perception of the two terms *pink* and *rosa* by German speakers. From this study it became apparent that the colours described by the German term *rosa* correspond to English *pink/pale pink*, and the colour term *pink* in German to *dark*, *strong*, *vivid* or *shocking pink* in English. The results showed that the terms were perceived as referring to two separate colours rather than to shades of the same colour. Following the introduction of *pink*, the semantic scope of German *rosa* has been restricted and no longer corresponds as closely to *pink's* denotational range in English.

Since *pink* seems to be already established in the German language, the question of its status arises. It has been shown (Frenzel 2006; Kaufmann 2006) that *pink* is definitely not a basic colour term (BCT) in German, but that there might be a change in progress. In order to investigate further the status, behaviour and perception of these two colour terms in German, a corpus of six popular magazines has been compiled since 2006. This paper presents the results of the corpus-based study.

2. History and previous investigations

2.1 *Rosa*

The colour term *rosa* derives from the colour of a flower, the dogrose, and was first used only with reference to the plant itself (*rosenfarb* "rose coloured", *rosenrot* "rose red"). However, in the second half of the eighteenth century these adjectives were no longer sufficient to describe this pale shade of red. Therefore, the Latin plant name 'rosa' started to be used instead. At first the usage was restricted to compound nouns such as *Rosakleid* "pink dress", but later it also developed an attributive function (cf. *Etymologisches Wörterbuch des Deutschen* 1993). *Rosa* is described in dictionaries as a pale red or with reference to typical objects (cf. Duden 1999). It also developed metaphorical extensions with the meaning of "unrealistic", "optimistic" (e.g. *to view the world through 'rosa' glasses*). Meanwhile *rosa* has become a BCT according to the criteria of Crawford (1982; cf. also Frenzel 2006: 32, 82).

2.2 *Pink*

The colour term *pink* derives from an English plant name, the blossoms of the Dianthus. The flower has been called pink since the sixteenth century (Barnhart 1988).[1] In the *Concise Oxford Dictionary* (1999), *pink* is described as being "a colour intermediate between red and white", a definition which corresponds closely to that of *rosa* in the German dictionaries. The basic status of this colour term in English has been established in several studies (Boynton & Olson 1990; Johansson & Hofland 1989).

Pink was first recorded in German as a noun in 1966 (Carstensen & Busse 1996). One year later it was found as an adjective, but mainly in combination with *-farben* "-coloured". It is described in dictionaries as a "strong" or "loud" shade of *rosa* or as a

1. The flower received the name *pink* from the Dutch loanword *pinck*. However, its etymology is not entirely clear since there are two possible meanings of the original Dutch word (http://www.OED.com).

"slightly gaudy" *rosa* (Carstensen & Busse 1996.; Duden 1999.).[2] This description suggests a difference between the English and the German term *pink*. The differentiation between the colour terms in German is displayed in recent bilingual dictionaries, where English *pink* is translated as *rosa* and German *pink* as *shocking pink* (*Pons Großwörterbuch* 1999).

The semantic and structural aspects of these two colour terms were part of a corpus-based study conducted by Kaufmann (2006). The investigation was object-related in order to determine prototypical objects of reference and prototypical effects. The main findings concerning *pink* and *rosa* are summarized in Table 1.

In general, Kaufmann's study confirms the restriction of the original denotational range of *rosa*, and furthermore shows that *pink* is not as firmly established in the German language as *rosa*. Thus, it is not a BCT in German as it is in English.

In order to determine the perception of German speakers concerning these two colour terms, a cognitively oriented questionnaire was set up (Frenzel 2006). The questionnaire included production, association and identification tests. This study clearly shows a stable distinction between *pink* and *rosa* among speakers across age and gender groups, and also shows that *pink* has a higher salience than comparable non-basic colour terms, some of which have been present in the German language longer than this English loanword (Frenzel 2006: 58). It was shown that *pink* is applied with more ease and consistency in colour naming tasks and also displays more varied associations than the other non-basic colour terms used in this study.

Table 1. Overview of Kaufmann's results (2006)

	Objects of Reference				
	Natural	***Artificial***	**Connotational**	**Morphological**	**Syntactical**
Rosa	flowers, food, animals	clothes, cosmetics, interior design, toys	optimistic, positive, old-fashioned	compound adjectives ("*rosarot*"); modifying compounds ("*blaßrosa*")	substantival, predicate, attribute
Pink	only flowers	*as above*	artificial, unnatural, dyed, modern, young, loud	most common: derivation with "*-farben*/*-farbig*" ("-coloured"); very low number of compounds ("*Pinktöne*")	substantival, predicate, rarely as attribute

2. Translations by the author.

In general, the informants' notion of *pink* largely agrees with the definitions found in dictionaries. This leads to the conclusion that the restriction of the denotational range of *rosa*, as well as the distinction between the two colour terms, is highly salient for native speakers of German despite *pink's* comparatively recent introduction into the German language.

3. *Pink* and *rosa* in magazines

3.1 A corpus study

Even though the status of *pink* has been established in the studies mentioned above, there is a change in progress which has become evident, for example, from the deviation of standard language from non-standard speech (Kaufmann 2006: 325). Therefore, a corpus has been compiled with the aim of investigating whether the application of these two colour terms to actual colour representations corresponds to the distinction speakers make. The main focus in the corpus is on visual evidence: only those articles where the colour terms *pink* and *rosa* directly refer to pictures have been incorporated. The compilation of the corpus started in 2006. It consists of the six popular magazines listed in Table 2.

The choice of popular magazines over literary texts is supported by the fact that they reflect everyday language use better and provide a means of verifying the actual application of the colour terms. However, the corpus is still growing; this study is based on its status in February 2008. It is important to note that, due to the focus on visual evidence, relevant areas of the language and the use of the two colour terms are not necessarily equally well represented.

3.2 Methodology

In order to perform a meaningful statistical analysis, the following criteria were established for the selection of corpus samples:

Table 2. Magazines included in the corpus

No.	Name
1	Freizeit Woche
2	Woche der Frau
3	Auf einen Blick
4	Freizeit Revue
5	a – die Aktuelle
6	Frau im Trend

1. the use of the colour terms with respect to their representation in the picture in order to determine their actual application
2. categories of objects of application so as to determine possible differences between the two colour terms
3. evidence of inflectional endings and other syntactical considerations to determine the degree of integration and the individual status of the two colour terms
4. the type and kind of adjectives used to describe and modify the two colour terms in order to determine collocations and associations as well as an implied colour scale.

It is crucial to identify 'wrong' or deviating applications in order to understand whether the distinction established in the studies mentioned above is present in the corpus and therefore established within the language. However, stylistic and contextual considerations have to be taken into account, as well as the fact that the use of a colour term other than *pink* or *rosa* might be motivated by an attempt to avoid repetition. Evidence of hyponymy relations is also significant, since this could provide insight about the status of independence of *pink* from *rosa*.[3] Furthermore, the presence of 'scale perception' is also investigated: if there was evidence that each colour term has several different shades, i.e. it denotes its own colour space, it would prove that the terms are more independent of each other than a hyponymy relation would suggest.

In addition to this, the co-texts of the colour terms are examined to investigate collocations, so as to determine the extent to which the two colour terms differ and where they converge semantically. Finally, the degree of integration of the colour terms into the German language is investigated through a comparison of their frequency of use and their objects of application and to bring into consideration morphological and syntactical aspects.

4. Results

4.1 Overall frequency

As regards the overall use of the colour terms *pink* and *rosa* in the corpus, they do not seem to differ greatly. The simplex *rosa* takes up 44% of all the 339 colour term instances, whereas *pink* appears in 36% of the instances. Other non-basic colour terms were used so infrequently that their number in the corpus is negligible.

Nevertheless, there are two other colour terms, *rosarot* "rose red" and *rosé*, which have to be taken into account as they are used quite frequently. As far as *rosarot* is concerned, it could be interpreted at first sight as a mixed colour because of its two

3. If, for example, *rosa* is used exclusively when a picture displays a colour shade that speakers would identify as *pink* and not vice versa, it shows that the two terms are perceived as hyperonym and hyponym respectively.

colour term components, but it is mostly used as a synonym for *rosa* (Kaufmann 2006; Frenzel 2006). Furthermore, it is recommended as an alternative for *rosa* by the Duden grammar (2005: 351), in case difficulties with the inflection arise. As for *rosé*, it is a non-basic colour term describing the same colour as *rosa*.[4] There is no evidence of applications that differ in any way from those of *rosa*. It is mostly used as a synonym for *rosa* (for what seem to be mainly stylistic reasons), and from evidence found in the corpus it is nowadays restricted to certain denotational areas like wine or is used as a fashion word. Taking these facts into account, *rosarot* and *rosé* can be included in the instances of *rosa*, in which case that term's overall frequency changes from 44% to 64% as compared to 36% for *pink*. However, the difference in frequency is still not as high as one might expect, considering the relatively recent introduction of *pink* into the German language.

4.2 Objects of application

The objects of application found in the corpus can be classified into four main categories: plants and flowers; decoration and interior design; fashion; other as shown in Figure 1. The last category includes objects such as champagne or salmon, which are subsumed under one category since their use is very rare in the corpus (only one or two instances per object).

Figure 1 also shows that *Rosa* clearly has a higher frequency in all the categories due to its longer and firmer establishment in the German language. Speakers are more secure in its application, and, since the restriction of its denotational range is relatively recent, it is still used more generally. However, *pink* is used almost as frequently as *rosa*

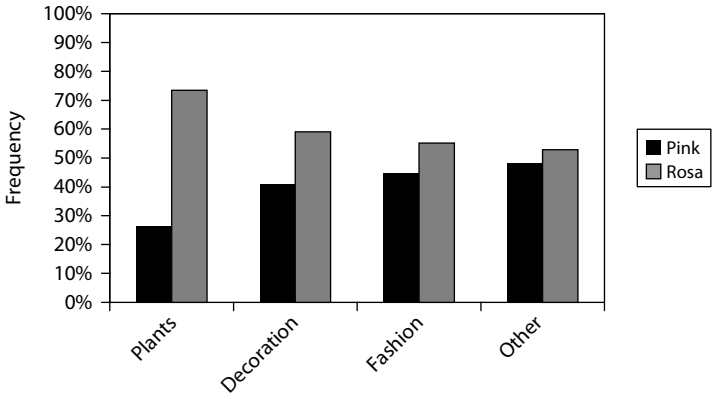

Figure 1. Objects of application

4. A remnant from French from the time *rosa* was established in German as a colour term (*Etymologisches Wörterbuch des Deutschen* 1993).

for fashion as well as decoration and interior design, with a difference of only 10% and 19% respectively. The greater disparity between the application of the two terms in the plants domain can be explained by the fact that *pink* denotes in German a very intense and strong colour which is rather infrequent in nature (see also Kaufmann 2006). In general, both terms have a quite restricted range of objects of application; this could be due to the nature of the corpus itself as there are generally more artefacts than natural objects in newspaper corpora (Altmann 1999: 4).

4.3 'Wrong' applications

As can be seen in Figure 2, *rosa* is clearly the more frequently used colour term across most of the magazines. Magazine 6 constitutes the only exception, being more modern than the other five and targeting a younger audience (in terms of layout and topics).

Figure 3 shows the frequency of 'wrong' applications. An application is considered 'wrong' when the use of a colour term for a picture deviates from the use taken as reference. The number of 'wrong' applications is relatively high (10% of the entire corpus), considering how clear and sure speakers were in their differentiation between the two terms (Frenzel 2006). Nonetheless, in most cases the two colour terms are used as expected, with a clear distinction between *pink* and *rosa* as well as restricted denotational ranges.

A more detailed analysis of the 'wrong' applications revealed four possible causes for the deviations in use:

1. colour representation on the printed page
2. stylistic form of the article
3. author's confusion and uncertainty
4. imperfect translation.

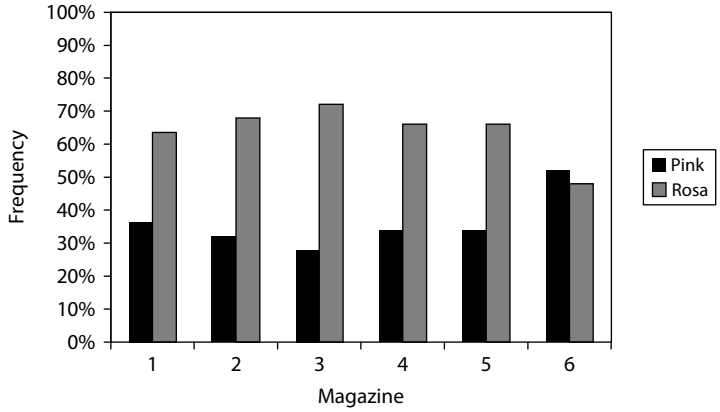

Figure 2. *Pink* and *rosa* in individual magazines (percentages refer to each magazine, not to the whole corpus)

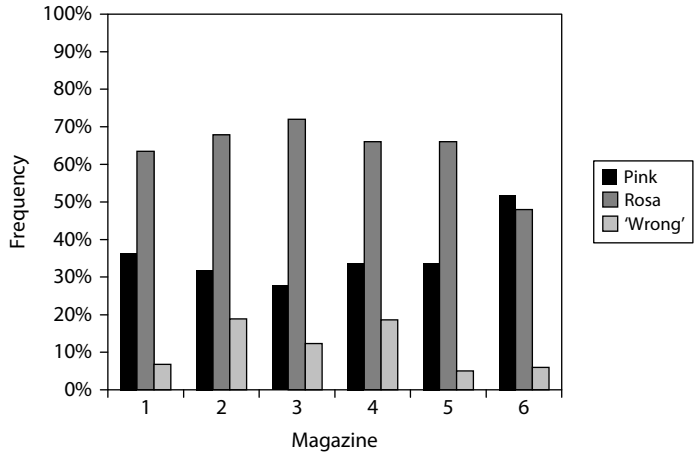

Figure 3. 'Wrong' applications in each magazine

Colour representation is a well-known problem: defining standards for the reproduction of the desired colour in various media is still a very challenging and open research topic for many different disciplines. It becomes apparent that lack of standardization is the cause of some deviations, when, for example, a picture is used twice in the same article but the printed colour differs from picture to picture.

Authors often rely on stylistic concepts such as synonyms and metaphors to avoid repetition, which can lead to inconsistency in the colour terms used, for example when various objects in a picture are described as *pink* and then *knallrosa* is used as a variation, or, as in the example taken as the title for this essay "Rosa Schätze – Pink zum kaufen" (Rosa treasures - Pink for purchase), where *rosa* and *pink* refer to the same picture (*Die Aktuelle* 2006: 11.57).[5] Translations from English into German and quotations of English sayings such as "Sie trug 'Pretty Pink'" ('she wore "pretty pink"' (*Freizeit Woche* 2006: 40.78)), are not considered a problem here, since only three instances were found.

Confusion and uncertainty as to which colour term to employ, however, appears to be the most frequent cause of the many instances of 'wrong' applications. It often seems as if the colour terms are used randomly, or as if the writer does not pay attention to which term was used before. Obviously the motivation of the choice of colour term is difficult to determine since it is also possible that the author's perception differs from that determined in previous studies. This uncertainty is also reflected in the apparently random (or possibly reflecting the author's choice) writing of the colour term *pink* with a capital letter or not.

5. *Knall* means "bang"; it is used to express a strong and vivid shade.

4.4 Hyponymy relations

The characteristic of a hyponym is that it can be included in the category of its hyperonym. For instance, the term *olive* can be included in *green*, i.e. everything *olive* can be called *green*. Due to the longer presence of *rosa* in the German language and its recent denotational range restriction, the hyponymy relation between *rosa* and *pink* is of interest so as to establish the extent to which *pink* is independent of *rosa*. Assuming *rosa* as the hyperonym of *pink*, all 'wrong' applications should select *rosa* instead of *pink*. The results show that this assumption is true for most of the deviations, with only a single instance being recorded where *pink* is described as a shade of *rosa*. This result indicates that *rosa* is viewed as the hyperonym. In contrast to this, *pink* is used instead of *rosa* 24% of the time, a surprisingly high frequency, suggesting that the hyponymy relation between *pink* and *rosa* is not fully established and that *pink* is not necessarily considered to be a shade of *rosa* (Frenzel 2006: 49). Further investigation would be useful to ascertain this relation more precisely.

4.5 Scale perception

Scale perception refers to all instances in the corpus where a scale of different shades is assigned to the respective colour terms, which suggests a perception of the two colour terms as independent.[6] Overall, 10% of items in the whole corpus assign colour shades to *rosa*, and thus imply a colour scale, but only 3.5% do so for *pink*. This low result is not conclusive enough to prove an independent status for *pink*. The restriction of the denotational range of *rosa*, on the other hand, is proved since 44% of the instances where a colour scale is implied refer to pale and soft shades. This also provides further evidence for the distinction made between the two colour terms, sometimes even indicating a well-defined location at opposite ends of a scale, e.g. "they glow in a dark *rosa* almost *pink*" (*Freizeit Woche* 2006: 15.17).

4.6 Collocations

A collocation of a colour term consists of a combination of the colour term and the object of application within a certain context. If it can be established that a collocation is stable across objects and contexts, it can be assumed that it has been established alongside the colour term.

It is striking that the two colour terms occur in the corpus exclusively with positive connotations. This is partly due to the focus on visual evidence, since the articles frequently describe design proposals. This particular focus of the corpus on visual evidence is also the reason why the collocations are not as diverse as those found in the study of Kaufmann (2006). For instance, "girl" and "girlish" may be inherent in "female", but "small" and "cute" could not be established here.

6. For example *pale rosa* or *strong shade of pink*. Compare **dark lime green*: a modification of this non-basic term is not possible because it describes a very specific shade of green.

Table 3. Summary of collocations

	rosa		**pink**
frequent	"delicate"/"gentle" (7%)		"strong" (3%)
less frequent	"pale", "light", "fresh"	"romantic", "happy", "female"	"shining" "fashionable", "young"
seldom	"soothing", "nice", "baby colour" (0.9%)		"shrill", "sensual"

As shown in Table 3, the two colour terms have overlapping collocations ("romantic", "happy" and "female"), showing that they are semantically closely related, which is of course due to the recent division of the denotational range of *rosa*. Nonetheless, the perception of *rosa* as "soft" and *pink* as "strong" not only proves the discernable perception difference of the two colour terms, but also stresses the division of the colour space and the different range where each can be applied. These findings agree with the previous studies (Frenzel 2006, Kaufmann 2006) in which the brilliancy, luminosity and brightness of the shades denoted by *pink* are often either explicitly stressed or are in the co-texts.

4.7 Integration into the German language

In order to assess the integration of the two colour terms into German, morphological and syntactical aspects were investigated; high productivity indicates strong integration.

As shown in Table 4, the derivation with *-farben*/*-farbig* "coloured" is the most frequent word formation process for both terms. The number of instances is the same for both terms, although *rosa* has a higher overall frequency. The comparatively high frequency of this derivation for *pink* is due to insecurity concerning its inflection.

Table 4. Morphological processes

	Compounds		
	adjectives	**modifying**	**nouns**
Rosa	– *farben*/*-farbig* (9%) – *rot* (~6%)	Paler shades e.g. *blaß-*, *zart-*, *hell-* ("pale-, gentle-, light-")	– ton/-töne ("shades") (2%)
Pink	– *farben*/*-farbig* (9%)	none	– ton/-töne, -palette, -nuancen ("shades, range, nuances") (1.5%)

Inflectional insecurity is also the reason why compound adjectives are the most frequent word formation for *rosa*. These consist mostly of *rosarot*, which is used as a synonym since the adjective part *rot*, one of the oldest BCTs, can be easily inflected. This solution is not applied for *pink* because the combination with *rot* or other colour terms does not exist.

Other *rosa* compounds are formed with modifying adjectives, thus indicating the exact shade of *rosa*. In most cases, such compounds point towards the paler shades of *rosa's* original denotational range, e.g. "*blaßrosa* Tulpen" ("pale rosa tulips") (*Freizeit Woche* 2007: 11.17). There is not a single instance of compounds with modifying adjectives for *pink* to be found in the corpus. This is probably due to the fact that *pink* has had a very narrow denotational range in German since it was introduced into the language. *Rosa*, in contrast, still has some access to the original colour space, hence the need to clarify its exact shades.

Compounds formed with nouns are slightly more frequent for *rosa* than for *pink*. It is interesting to note that those for *rosa* are restricted to *Rosaton/-töne* ("shades"), whereas those for *pink* also include *Pinkpalette* and *Pinknuancen* ("pink range" and "nuances of pink"). The reason could be that *pink* is a younger colour term and therefore more creative and productive than *rosa*, whose compound forms are more conventionalized.

As far as syntactical characteristics are concerned (see Table 5), the uses found in the corpus mostly agree with the study of Kaufmann (2006). Both colour terms are used as substantives, predicates and attributes. Nominalization is realized via grammatical transposition with an article or the preposition *in*, e.g. "Ein Blütentraum *in* Pink und Rosa" ("A blossom dream in pink and rosa") (*Freizeit Revue* 2007: 38.76). Inflection is often realized with *-farben/-farbig* "coloured" or, in the case of *rosa*, the simplex term is left uninflected. *Pink*, in contrast, displays several instances of inflected use, e.g. "Sexy im *pinken* Kleid" ("sexy in the pink dress") (*Freizeit Revue* 2007: 29.88). While this was claimed only for non-standard speech (Kaufmann 2006: 325), apparently the inflectional use of *pink* is becoming more established.

In terms of Berlin and Kay's (1969) criteria for BCTs, both *pink* and *rosa* clearly comply with the first criterion, each being monolexemic. *Rosa* also satisfies the second criterion (it should not be a hyponym), since it is clearly differentiated from *rot*,

Table 5. Syntactical characteristics

	Syntactical	
	Nominalization	**inflection**
rosa	grammatical transposition (18%)	uninflected simplex *-farben/-farbig* only
pink	grammatical transposition (15%)	inflected simplex with added *-e* *-farben/-farbig*

whereas this is questionable for *pink*. It seems to be differentiated from *rosa* most of the time, but there are still occasions where it is treated as a hyponym. Nevertheless, it cannot be clearly included in *rosa*. Considering criterion three (its application should not be contextually restricted), both colour terms are applied to diverse objects, although *pink* displays a contextual restriction in several areas.

The criterion of psychological salience is a much debated concept, which is why Crawford (1982) suggests the presence of the colour term in the idiolects of all speakers as an alternative. This has been demonstrated for both colour terms in a previous study (Frenzel 2006). Finally, the criterion of stability of reference across occasions of use (Crawford 1982: 342) is problematic for *pink*, as was shown with regard to 'wrong' applications.

5. Conclusion

The status of the two colour terms in the German language is influenced by their age, frequency of use, and syntactical and morphological characteristics. Both are relatively young, with *rosa* having entered the language in the eighteenth cenury and *pink* in the 1960s. Furthermore, frequency of use reveals that *pink* has not been well integrated into German: the less established a colour term is in a language, the more restrictions it has in its usage. In contrast to *red*, which, as one of the first BCTs, has a complete inflectional paradigm and is also comparable, *pink* and *rosa* are restricted in their inflection, are non-comparable and do not have a (officially acknowledged) derivation with *-e* or *-lich*. On the one hand, *rosa* is more restricted than BCTs already established in German for a longer time but does not have any restrictions on its syntactical uses. *Pink*, on the other hand, cannot be inflected (in standard speech). Consequently, there is a large number of nominalizations and derivations with *-farben/-farbig* "coloured". There are also fewer word formation processes and no comparisons to be found in the corpus, which leads to the conclusion that *pink* is not as firmly established in the language.

In conclusion, *rosa* could be classified as a secondary BCT, due to the above restrictions. *Pink* is definitely not a BCT, but the deviation of the inflection of non-standard speech from standard speech would suggest a change in progress. It remains to be seen and investigated which direction the development of this colour term in German will take.

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Kashubian colour vocabulary

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The aim of this paper is to present the colour lexicon, including both basic and non-basic terms, found in Kashubian (or Cassubian), a West Slavic language spoken by a relatively small community inhabiting the coast of the Baltic Sea (the Pomorskie Province in Poland). The results of the five-minute elicitation list task show that Kashubian basic colour terms include words for white, black, red, green, yellow, blue, brown, grey and pink. As regards the terms for purple and orange, due to language contact (Kashubian people are bilingual), many informants use the Polish words naming these colours; however, these words may – as the results of the task indicate – be treated as non-basic terms. Besides, it is worth considering whether Kashubian, like Russian and Ukrainian, has evolved a second basic term for blue.

1. Introduction

The aim of this paper is to present the Kashubian colour lexicon, including both basic and non-basic terms. We will discuss the results of the five-minute elicitation list task, the purpose of which was to measure the salience of colour terms.[1] We will also concentrate on the entries concerning colour words included in Kashubian dictionaries.

Kashubian (or Cassubian) is a West Slavic language spoken by a relatively small community inhabiting the coast of the Baltic Sea in Poland (the Pomorskie Province). According to Latoszek (1992: 2), the number of Kashubian people amounts to 330,000, or approximately 500,000 when half-Kashubians are included (compare

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Popowska-Taborska 1997: 317; Stone 1996: 49; Treder 2002a: 41–42).[2] However, not all of them can speak the Kashubian language: it is estimated that about sixty per cent of Kashubian people speak it. Kashubian speakers are bilingual: in many cases, the situation is diglossic; for example, with Polish as the language of instruction at school, numerous Kashubian speakers cannot write in their language (Treder 2002b: 47). The first texts written in Kashubian were religious texts translated from German and published in the sixteenth century (see Treder 2005 for details).

In 2005, Kashubian was officially recognized by the Polish authorities as a regional language. What can now be observed is the revival of the Kashubian language and culture, which is manifested by, among other things, a changing attitude to the language. Kashubian is now taught at some schools (for details see, among others, Breza 2001; Joć 2001); moreover, Kashubian studies were opened at the University of Gdańsk in the academic year 2009 – 2010.

2. Candidate basic colour terms in Kashubian

In this study, we will make use of the division into basic and non-basic colour terms proposed by Berlin and Kay. Having analyzed the colour terms found in almost one hundred languages, Berlin and Kay (1969: 2–4, 104) put forward the following general hypotheses concerning colour systems:

1. There exists a universal maximum of eleven basic colour categories, which can be represented by their foci: white, black, red, green, yellow, blue, brown, purple, pink, orange and grey.[3]
2. The size of the basic colour vocabulary of a language varies from two to eleven terms.[4] However, it was suggested that there are restrictions concerning the order of acquisition of the categories and their terms: they develop in a predictable order, which was presented as an evolutionary sequence of seven stages (Berlin & Kay 1969: 4):[5]

2. According to the 2002 Polish National Census, the number of people who officially declared Kashubian nationality was 5,062 and the number of people who claimed that they used Kashubian on a daily basis amounted to 52,665. Information sourced from http://www.stat.gov.pl/gus/5840_749_PLK_HTML.htm, accessed 15.06.2009.

3. This list of foci which featured in the 1969 sequence has since been revised to include macro-colour categories such as GRUE (a single category consisting of GREEN + BLUE) which commonly appear in the early stages of category acquisition. Single-hue categories appear later as macro-categories subdivide. For an early revision of this aspect of the hypothesis, see Kay (1975).

4. It is now widely accepted that some languages have twelve basic terms; for example, Russian has two basic blue terms (see, for example, Paramei 2005).

5. The suggested 1969 stages are presented first, with the major later revisions added in brackets. Several possible trajectories (variational details in category acquisition) are now recognized, but the revisions mentioned here are concerned with the most common route only (see Trajectory A, Kay & Maffi 1999: 750, Figure 2).

Stage I: white and black (later macro-white and macro-black)
Stage II: addition of red (later, separation of macro-red and white)
Stage III: addition of green or yellow (later, separation of grue and black)
Stage IV: green *and* yellow (later, separation of yellow and red)
Stage V: addition of blue (later, separation of blue and green)
Stage VI: brown
Stage VII: pink, purple, orange and grey (later pink, purple and orange, with grey as a wild-card occurring at any stage from III to VII).[6]

For a society which has mostly single-hue categories, the equivalents of the following English terms are called 'primary' basic colour terms: *white, black, red, green, yellow* and *blue*. The remaining five are referred to as 'secondary' basic terms (see, for example, Kay & McDaniel 1978: 626–627, 633; Corbett & Davies 1997: 198).

Polish has eleven basic colour terms: *biały* "white", *czarny* "black", *czerwony* "red", *zielony* "green", *żółty* "yellow", *niebieski* "blue", *brązowy* "brown", *fioletowy* "purple", *pomarańczowy* "orange", *różowy* "pink" and *szary* "grey" (see, among others, Pawłowski 2006; Stanulewicz 2006; Tokarski 2004; Waszakowa 2000). It is reasonable to expect that Kashubian, as a West Slavic language related to Polish, should enjoy a similar number of basic terms. An overview of dictionaries (Ramułt 2003; Sychta 1967–76, analyzed by Handke 2001; Trepczyk 1994) and teaching materials (Kwiatkòwskô & Bòbrowsczi 2000; 2003) allows us to make a list of the following possible candidates: *biôłi*, *czôrny*, *czerwòny*, *zelony*, *żôłti*, *mòdri*, *bruny*, *lilewi*, *różewi*, *apfelzynowi* and *szari*. Table 1 presents these terms accompanied by their Polish and English equivalents.

Table 1. Kashubian candidates for basic colour terms accompanied by their Polish and English equivalents

Kashubian terms	Polish basic colour terms	English basic colour terms
biôłi	*biały*	*white*
czôrny	*czarny*	*black*
czerwòny	*czerwony*	*red*
zelony	*zielony*	*green*
żôłti	*żółty*	*yellow*
mòdri	*niebieski*	*blue*
bruny	*brązowy*	*brown*
lilewi	*fioletowy*	*purple*
różewi	*różowy*	*pink*
apfelzynowi	*pomarańczowy*	*orange*
szari	*szary*	*grey*

6. Kay and Maffi's sequence consists of five stages only (Kay & Maffi 1999: 748, Figure 1).

It can be easily inferred from Table 1 that some terms found in Kashubian are historically related to Polish terms: the first five primary basics (*biôłi*, *czôrny*, *czerwòny*, *zelony* and *żôłti*) and two secondary basics (*różewi* and *szari*). The term for orange, *apfelzynowi*, is a borrowing from German (*Apfelsine* "orange"). The remaining terms, that is *mòdri*, *bruny* and *lilewi*, are related to Polish non-basic colour adjectives: *modry* "blue" (considered obsolete), *brunatny* "brown", and *liliowy* "lilac" respectively. However, these morphological relationships should not be surprising as Slavic languages happen to use historically – hence morphologically – related colour terms (see Table 2).

On examination of Table 2, it appears that Kashubian shares more primary basic colour terms with Czech than with Polish, due to their common word for blue: Kashubian *mòdri* and Czech *modrý*.

It should be borne in mind that some of the terms listed in Table 1 can have secondary meanings as well. For instance, apart from meaning "white", *biôłi* can also function as an equivalent of English *clean*, *light* or *grey*(*-haired*); and *czôrny* "black" can also mean "dark" and "dirty" (Handke 2001: 24–25).

Let us now recall Berlin and Kay's four criteria which a colour term is likely to fulfil in order to be a basic term (1969: 6):

1. It is *monolexemic*; that is its meaning is not predictable from the meaning of its parts.
2. Its meaning is not included in that of any other color term.
3. Its application is not be restricted to a narrow class of objects.
4. It is psychologically salient for informants.

Table 2. Basic colour terms in selected Slavic languages and Kashubian candidate basic terms (Czech, Russian and Ukrainian terms are taken from Waszakowa 2000: 23–24; see also Hippisley 2001). Question marks indicate the uncertain basic status of the term

Category	Polish	Czech	Russian	Ukrainian	Kashubian
WHITE	*biały*	*bílý*	*belyj*	*bilyj*	*biôłi*
BLACK	*czarny*	*černý*	*černyj*	*čornyj*	*czôrny*
RED	*czerwony*	*červený*	*krasnyj*	*červonyj*	*czerwòny*
GREEN	*zielony*	*zelený*	*zelenyj*	*zelenyj*	*zelony*
YELLOW	*żółty*	*žlutý*	*želtyj*	*žovtyj*	*żôłti*
BLUE	*niebieski*	*modrý*	*goluboj sinij*	*blakytnyj synij*	*mòdri*
BROWN	*brązowy*	*hnědý*	*koričnevyj*	*koričnevyj brunatnyj*	*bruny*
PURPLE	*fioletowy*	*fialový*	*fioletovyj*	*fioletovyj*?	*lilewi*
PINK	*różowy*	*růžový*	*rozovyj*	*roževyj*?	*różewi*
ORANGE	*pomarańczowy*	*oranžový*	*oranževyj*	*oranževyj*?	*apfelzynowi*
GREY	*szary*	*šedý*	*seryj*	*siryj*	*szari*

Berlin and Kay (1969: 6–7) also propose four auxiliary criteria for any cases which remain in doubt after the application of the first four criteria. They are as follows:

5. The doubtful form should have the same distributional potential as the previously established basic terms.
6. Colour terms that are also the name of an object characteristically having that colour are suspect.
7. Recent foreign loan words may be suspect.
8. In cases where lexemic status is difficult to assess, morphological complexity is given some weight as a secondary criterion.

Taking into consideration the four main criteria proposed by Berlin and Kay, we can safely state that each of the Kashubian terms listed in Table 1 fulfils three of them, namely numbers 1, 2 and 3. The meanings of the terms cannot be predicted from the meanings of their parts, they do not name shades of basic categories, and they can all be used to describe various objects.

The Kashubian terms seem to fulfil all of the secondary criteria, albeit with one exception. The adjective *apfelzynowi* "orange" differs as to its origin from the other terms, and it fails to fulfil Criterion 6. It can be noted that the English adjective *orange* and its Polish equivalent *pomarańczowy* also fail to fulfil Criterion 6. As far as Criterion 7 is concerned, both terms (*apfelzynowi* and *pomarańczowy*) fulfil it as they are not recent loans.

3. Psychological salience of Kashubian colour terms

Let us concentrate here on Criterion 4, which concerns the psychological salience of colour terms. In order to check whether the Kashubian terms listed in Table 1 are salient for Kashubian speakers, a behavioural test called the *elicitation list task* was carried out in 2006 with thirty-two informants (twenty-one women and eleven men), aged twenty to seventy (Stanulewicz 2009). The procedure was as follows: the participants wrote down all the colour terms which came to their minds in five minutes, and after each minute the person administering the task asked them to draw a line and continue below it.[7]

7. Psychological and linguistic tests which can be used to measure the salience of colour terms are presented by Corbett and Davies (1997). Berlin and Kay (1969: 6) also used the elicitation list task, assuming that informants tended to write the most salient terms at the beginning of the exercise. The division of the task into minutes was proposed by Morgan and Corbett (1989, reported in Corbett & Davies 1997: 204). In different studies, the number of informants used has varied considerably; for example, twenty-five informants in the World Colour Survey (Kay, Berlin, Maffi & Merrifield 1997), thirty-one Russian speakers (Morgan & Corbett 1989, reported in Corbett & Davies 1997: 203–205), thirty-four Ukrainian and twenty-eight Belarusian speakers (Hippisley 2001), and eighty Polish speakers (Stanulewicz 2006).

The Kashubian speakers who participated in the elicitation list task fell into two groups. One group, consisting of eleven people, attended a course of literary Kashubian conducted at the University of Gdańsk by Professor Marek Cybulski, and the task was administered by one of the present authors. The other group included mainly friends and relatives of students of the University of Gdańsk who volunteered to carry out the task in their home towns and villages. The informants in the former group were mainly in the age range of twenty-one to twenty-seven, whereas the informants in the latter group were older, mainly in the thirty-six to fifty range. It should be noted that the informants – with a few exceptions – had serious problems with Kashubian spelling, which reflects the fact that, for most of them, Kashubian had never been the language of instruction at school (see Treder 2002b). Moreover, in publications issued at various periods, different Kashubian spelling conventions are used, which may also cause confusion.

The number of elicited terms amounted to seventy-four. It should be borne in mind, however, that the full list of the elicited terms contained a number of Polish terms, which is inevitable in the case of bilingualism,[8] as well as terms referring to degrees of brightness. Table 3 contains the twenty-three top colour terms elicited within the five minutes of the task, while Table 4 concentrates on the first minute of the task. Table 5 lists the mean ranks of each colour term which reached the threshold of twenty per cent during the five minutes of the task and, finally, Table 6 presents the terms provided by each informant in the first position on their lists.

Our first observation concerns the order of the first seven colour terms listed in Tables 3, 4 and 5: the ranking lists of the words elicited in the task are almost an ideal reflection of the evolutionary sequence proposed by Berlin and Kay in 1969 (1969: 4, Figure 2).

Let us now concentrate on the frequency of the candidate Kashubian basic colour terms listed in Table 1. As the results found in Table 3 suggest, over fifty per cent of the informants gave the following colour terms: *biôłi*, *czôrny*, *czerwòny*, *zelony*, *żôłti*, *bruny*, *mòdri*, *szari* and *różewi*: it could be stated that these terms are familiar to most Kashubian speakers. Tables 4, 5 and 6, presenting respectively the results of the task after the first minute, the mean ranks of the top colour terms, and terms with the highest position, clearly point to the first seven words, which apparently form a group of the most salient colour terms.

8. Borrowing frequently occurs in such cases; for example, apart from terms of native origin, bilingual Welsh people also use English colour terms (Lazar-Meyn 1991). As Polish and Kashubian are genetically and geographically close languages, Polish colour vocabulary can be expected to exert a considerable influence on the Kashubian system of colour terms.

Table 3. The twenty-three top Kashubian colour terms elicited within five minutes (N = 32) (Stanulewicz 2009: 134)

Rank	Term	Number of occurrences	Percentage of responses
1–2	*biôłi* "white"	32	100
1–2	*czôrny* "black"	32	100
3	*zelony* "green"	31	96.875
4–5	*czerwòny* "red"	29	90.625
4–5	*żółti* "yellow"	29	90.625
6	*bruny* "brown"	28	87.5
7	*mòdri* "blue"	24	75
8	*szari* "grey"	19	59.375
9–10	*różewi* "pink"	18	56.25
9–10	*niebiesczi* "blue" (< Polish *niebieski*)	18	56.25
11–12	*strzébrzny/srébrzny* "silver"	14	43.75
11–12	*złoti* "gold"	14	43.75
13	*pòmarańczowi* "orange" (< Polish *pomarańczowy*)	13	40.625
14	*fioletowi* "purple" (< Polish *fioletowy*)	12	37.5
15	*beżowi* "beige" (< Polish *beżowy*)	8	25
16–17	*lilewi* "purple"	7	21.875
16–17	*granatowi* "navy blue" (< Polish *granatowy*)	7	21.875
18	*cemnozelony* "dark green"	5	15.625
19–23	*bordowi* "claret, bordeaux" (< Polish *bordowy*)	4	12.5
19–23	*bùri* "dark grey"	4	12.5
19–23	*cytrónowi* "lemon"	4	12.5
19–23	*krémòwi* "cream"	4	12.5
19–23	*seledinowi* "celadon" (< Polish *seledynowy*)	4	12.5

What comes as a surprise is the relatively low position of *mòdri* "blue" in Tables 3 and 6: it is placed lower than *bruny* "brown". However, *mòdri* enjoys a higher rank than the terms for BROWN and YELLOW when we take the mean rank into consideration. The fact that *mòdri* was given by only seventy-five per cent of the informants may be explained by language contact: some informants gave the term *niebieszczi*, which means "heavenly, pertaining to the sky", and the related Polish word *niebieski* means "blue".[9]

9. Interestingly enough, some informants supplied both terms, *mòdri* and *niebieszczi*, which might suggest that these terms are used to refer to different shades of blue.

Table 4. The fourteen top Kashubian colour terms elicited in the first minute (N = 32) (Stanulewicz 2009: 136)

Rank	Term	Number of occurrences	Percentage of responses
1	*côrny* "black"	29	90.625
2	*biôłi* "white"	27	84.375
3–4	*zelony* "green"	24	75
3–4	*żôłti* "yellow"	24	75
5	*czerwòny* "red"	22	68.75
6–7	*mòdri* "blue"	20	62.5
6–7	*bruny* "brown"	20	62.5
8	*niebiesczi* "blue" (< Polish *niebieski*)	12	37.5
9	*szari* "grey"	7	21.875
10	*różewi* "pink"	6	18.75
11–13	*fioletowi* "purple" (< Polish *fioletowy*)	4	12.5
11–13	*strzébrzny/srébrzny* "silver"	4	12.5
11–13	*złoti* "gold"	4	12.5
14	*pòmarańczowi* "orange" (< Polish *pomarańczowy*)	3	9.375

Table 5. The mean ranks of the top seventeen Kashubian colour terms

Rank	Term	Mean rank
1	*czôrny* "black"	2.875
2	*biôłi* "white"	3.0313
3	*czerwòny* "red"	4.0667
4	*zelony* "green"	4.9032
5	*mòdri* "blue"	4.9583
6	*żôłti* "yellow"	5.4193
7	*bruny* "brown"	6.2592
8	*niebiesczi* "blue" (< Polish *niebieski*)	7.1667
9	*fioletowi* "purple" (< Polish *fioletowy*)	9.3636
10	*szari* "grey"	9.3889
11	*lilewi* "purple"	9.5
12	*różewi* "pink"	9.5556
13	*złoti* "gold"	11
14	*strzébrzny/srébrzny* "silver"	11.6
15	*pòmarańczowi* "orange" (< Polish *pomarańczowy*)	11.7333
16	*beżowi* "beige" (< Polish *beżowy*)	12
17	*granatowi* "navy blue" (< Polish *granatowy*)	13.2858

Table 6. The Kashubian colour terms with the highest ranking

Rank	Term	Number of occurrences
1	*biôłi* "white"	13
2	*czôrny* "black"	8
3	*bruny* "brown"	3
4–6	*czerwòny* "red"	2
4–6	*żôłti* "yellow"	2
4–6	*mòdri* "blue"	2
7–8	*zelony* "green"	1
7–8	*niebiesczi* "blue" (< Polish *niebieski*)	1

The relatively high rankings of *niebiesczi* in Tables 3, 4 and 5, as well as its presence in Table 6, may point to the extension of the meaning of this term: in Polish too, *niebieski* originally meant only "heavenly, pertaining to the sky". Moreover, it is worth considering whether Kashubian is developing a second basic term for BLUE, just as Russian and Ukrainian have done (see, among others, Morgan & Corbett 1989; Corbett & Davies 1997; Hippisley 2001; Paramei 2005).

Instead of the term *lilewi* "purple", the informants frequently provided its Polish equivalent, *fioletowy*. However, if we consider the mean rankings of these two terms in Table 5, it appears that they are on a par with each other.

As far as the term for ORANGE is concerned, *apfelzynowi* fails to fulfil the criterion of salience. The informants frequently supplied the Polish adjective *pomarańczowy* (with spellings reflecting the Kashubian pronunciation of this word). In addition, two other terms appeared: *brunewi* and *òranżewi*, but both of them exhibited the same low frequency as *apfelzynowi*. If we ignore the use of Polish *pomarańczowy*, Kashubian seems not to have any basic term for ORANGE. This claim could be supported by the existence of the expression *żôłti jak marchew* "as yellow as carrots". The colour of the most common variety of modern carrot in Poland can be described as reddish, orange, or between yellow and red. We could here recall the Polish simile *rudy jak marchewka* "red-haired as carrots". The portion of the colour spectrum referred to as *orange* in English and *pomarańczowy* in Polish might have been subsumed under *żôłti* in Kashubian.

Summing up, the set of colour terms which were the most salient to the Kashubian informants includes the following adjectives: *biôłi* "white", *czôrny* "black", *zelony* "green", *czerwòny* "red", *żôłti* "yellow", *bruny* "brown", *mòdri* "blue", *szari* "grey" and *różewi* "pink" as well as *niebiesczi* "blue", considered not to be a colour term in correct literary Kashubian.

4. Kashubian non-basic colour terms

Let us now concentrate on the non-basic terms provided in the task and found in the dictionaries compiled by Ramułt (2003), and Sychta (1967–1976), the latter analyzed by Handke (2001). In the previous section, we have already presented the most salient non-basic colour terms elicited from the informants.

Table 7 contains the colour terms found in the dictionaries mentioned above. It is worth stressing that some of these words originate from nouns referring to objects, substances and phenomena associated with particular colours, for example *piwònijowi* "peony-coloured" (from *piwònijô* "peony"), *trôwiasti* "grass-coloured" (from *trôwa* "grass"), *lenisti* "flaxen" (from *len* "flax"), *òrzechòwi* "nut-coloured" (from *òrzech* "nut"), *piwiasti* "beer-coloured" (from *piwò* "beer"), *wrzosowi* "heather-coloured" (from *wrzos* "heather"), *łososowi* "salmon-coloured" (from *łosos* "salmon"),

Table 7. Kashubian non-basic colour terms found in the dictionaries compiled by Ramułt (2003), and Sychta (1967–1976) in Handke (2001)

Category	Non-basic terms
WHITE	*maslany* "butter-coloured, cream" *méwiasti* "seagull-coloured" *mléczny* "milk-white" *sëwi* "white/grey(-haired)" *strzébrzny/srébrzny* "silver"
BLACK	–
RED	*ògnisti* "fiery" *piwònijowi* "peony-red" *rudi* "red(-haired)"
GREEN	*trôwiasti* "grass-green"
YELLOW	*lenisti* "flaxen" *lniany* "flaxen" *piwiasti* "beer-coloured" *wòskòwi* "wax-coloured" *złoti* "golden"
BLUE	–
BROWN	*òrzechòwi* "nut-brown"
PURPLE	*wrzosowi* "heather-coloured"
PINK	*łososowi* "salmon-pink"
ORANGE	–
GREY	*bùri* "dark grey" *mëszati* "mouse-coloured" *pòpielati* "light grey" *pichòwati* "dust, grey"

mëszati "mouse-coloured" (from *mësz* "mouse") and *pichowati* "dust-coloured, grey" (from *pich* "dust"). As can be easily seen, some terms may be considered ambiguous, for example *maslany* "butter", classified as a shade of white, could also be considered to denote a shade of yellow, while *sëwi* "grey/white(-haired)" and *strzébrzny*/*srébrzny* "silver" might equally well be considered to indicate shades of grey.

Let us return to the results of the elicitation list task. Apart from the terms presented in Tables 3, 4 and 7, the informants provided a number of other colour terms which are listed in Table 8. Polish terms – unless verified by the Polish-Kashubian dictionary compiled by Trepczyk (1994) – are ignored. We have also decided not to include compounds like *cemnomòdri* "dark blue", derivatives like *mòdrawi* "bluish" or diminutive forms like *bielechny* "white".

Apart from the adjectives mentioned above, it is also necessary to make two lists of colour terms that indicate a degree of brightness and refer to colour combinations.

Table 8. Kashubian non-basic colour terms elicited from the informants (but excluding the elicited terms listed in Table 7)

Category	Non-basic terms
WHITE	*krémòwi* "cream" *perlowi* "pearly"
BLACK	*grafitowi* "graphite-coloured"
RED	*amarantowi* "amaranth-coloured" *bordo* "claret, bordeaux-coloured" *ceglasti* "brick-red" *czerwòny lësati* "red(-haired)" *pùrpùrowi* "purplish red" *wiszniowy* "cherry-red"
GREEN	(*tùrkùsowi* "turquoise")
YELLOW	*bùrsztinowi* "amber-yellow" *cytrónowi* "lemon-yellow" *miodowi* "honey-coloured" *piôskowi* "sandy yellow" *złocësti* "golden"
BLUE	*mòrsczi* "aquamarine" *tùrkùsowi* "turquoise"
BROWN	*kasztanowi* "chestnut" *kawowi* "coffee-coloured"
PURPLE	*sliwkòwi* "plum-coloured"
PINK	–
ORANGE	*brunewi* "orange" *òranżewi* "orange"
GREY	*bieławi* "grey"

The first group includes the following adjectives: *bladi* "pale", *jasny* "fair, light", *mroczny* "dark, cloudy", and the adverb *cemno* "dark" used to form compound colour adjectives, for example *cemnomòdri* "dark blue", *cemnozelony* "dark green" (Sychta 1967–1976, in Handke 2001: 37). The second group comprises the following terms: *bestri* "colourful, conspicuous, pied, freckled", *piegòwati* "pied", *plachcòwati* "pied", *pestri/pstri* "colourful, pied", *pstrokati* "dappled" and *srokati* "dappled".

5. Nouns, verbs, adjectives and adverbs related to the basic colour adjectives

The aim of this section is to present lexical items morphologically related to the Kashubian basic colour adjectives. The linguistic material comes from two dictionaries: the Kashubian-Polish dictionary compiled by Ramułt (2003) and the Polish-Kashubian dictionary compiled by Trepczyk (1994).

The basic adjectives can also serve to form other adjectives and adverbs. Selected lexical items belonging to these two classes are listed in Table 10. There are also nouns originating from adjectival derivatives of the *-ish* type, for example *mòdrawòsc* "bluishness" from *mòdrawi* "bluish".

It is also possible to find a number of other Kashubian derivatives and compounds in which the colour term refers to a selected feature of the referent, for example *białka/biôłka* "woman, wife",[10] *bielës* "man/boy with blond hair", *bielëska* "woman/girl with blond hair", *czerzwiónka* "red cow", *żółtk* "yolk", *mòdrôk* "cornflower" and *mòdrokwiat* "cornflower".

6. A final word

Kashubian colour terms have not yet been examined in detail. What requires further study is Polish influence in the BLUE, PURPLE and ORANGE areas. It would also be

Table 9. Selected nouns and verbs related to Kashubian colour adjectives

Nouns	Verbs
biôłosc "white" (n.), "whiteness"	*bielec* "be/become white"
czôrnosc "black" (n.), "blackness"	*bielëc* "make white, whiten"
czerzwionosc "red" (n.), "redness"	*czôrniec* "become black"
zelonosc "greenness" (n.)	*czerzwieniec* "become red, redden"
żółtosc "yellowness" (n.)	*zeleniec* "become green"
mòdrosc "blue" (n.), "blueness"	*żółtknąc* "become yellow"
	mòdrzec "become blue"

10. The origin of *biôłka* (Polish *biała*) is the white coif worn in the past by married women: it is the abbreviated form of Polish *białogłowa* "white head", an old term for a woman.

Table 10. Selected adjectives and adverbs derived from Kashubian colour adjectives

Colour adjective	Other adjectives: diminutives (dim.) and adjectives of the *-ish* type	Adverbs
biôłi "white"	*bielechny* "white" (dim.) *biôławi* "whitish, grey"	*biôło* *biôławò* (< *biôławi*)
czôrny "black"	*czôrnuszi* "black" (dim.) *czôrnuszinczi* "black" (dim.) *czôrnuszëneczczi* "black" (dim.)	*czôrno*
czerwòny "red"	*czerwenasti* "reddish"	*czerzwiono*
zelony "green"	*zelonawi* "greenish"	*zelono* *zelonawò* (< *zelonawi*)
żółti "yellow"	*żółtawi* "yellowish"	*żółto* *żółtawò* (< *żółtawi*)
mòdri "blue"	*mòdrawi* "bluish"	*mòdro* *mòdrawò* (< *mòdrawi*)
bruny "brown"	*brunawi* "brownish"	–
różewi "pink"	*różawi* "pinkish"	*różewò*
szari "grey"	–	*szaro*
lilewi "purple"	–	*lilewo*

beneficial to check whether corpus studies corroborate the findings presented in this paper; however, at present, no Kashubian corpora are available. Another field to be investigated is the set of Kashubian fixed phrases containing colour words.

We cherish the hope that this study has cast some light on Kashubian colour vocabulary and that it will encourage a lively academic discussion, and research which provides further insights into this field.

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Colour terms

Evolution via expansion of taxonomic constraints

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Russian attributive constructions with colour terms are analyzed using the *Russian National Corpus*. We focus on recently emerging colour terms and their development through to the early twenty-first century. Terms are considered in a construction-based framework, as syntactic-semantic rule pairs, with the emphasis on dynamics in their taxonomic combinability. This is exemplified by constructions denoting the BROWN category: names for objects, having similar referential meaning, collocate exclusively with one of the contending colour terms, *buryj* (older) or *koričnevyj* (newer). We argue that constraints on the usage of a colour term reflect a taxonomic boundary between two classes: the older term applies to *natural objects* whereas its new rival initially applies to *artefacts*, later expanding to natural objects. This finding indicates that discourse functioning of emerging colour terms is driven by the cognitive concept of 'naturalness'. Combinability with nouns from both taxonomic classes is suggested as a supplementary linguistic criterion of colour term basicness.

1. Introduction

The colour lexicon has been intensively studied since the seminal work of Berlin and Kay (1969) in which they put forward the broad hypothesis that all languages have a restricted number of semantic universals denoting colour, from two to eleven, named by basic colour terms (BCTs).[1] It should be emphasized that the Berlin and Kay (B&K) approach investigates colour semantics by means of psycholinguistic methods of naming and mapping; that is, it delineates the *referential*, context-free meaning of a colour

1. Berlin and Kay (1969) acknowledged that some languages might possess more than eleven BCTs, citing Russian and Hungarian. Extensive studies by the Surrey group (e.g. Davies & Corbett 1994) as well as our recent review provide evidence of the basic status of the two Russian terms for "blue", *sinij* and *goluboj* (Paramei 2007).

term in comparison with linguistic typological analysis that captures *attributive* or *descriptive* meaning.

The second B&K hypothesis refers to the evolutionary development of BCTs. It predicts that BCT systems unfold in *a partially fixed order* through seven stages, cumulatively gaining terms for: white and black (I) → red (II) → green or yellow (III) → green and yellow (IV) → blue (V) → brown (VI) → purple, pink, orange (VII), with grey being a 'wildcard' emerging at any stage between III and VII. Later studies led to refinements of the B&K model, to accommodate new empirical findings (for a review see Kay & Maffi 1999).

In the original B&K (1969) model and its later modifications the BCT sequence was derived from the analysis of contemporary data, which revealed the synchronic state of individual colour lexicons but held diachronic implications. As conjectured by Kay and Maffi (1999), the motivation driving the enrichment of a colour lexicon is the amount of information carried by the colours of objects as societies become technologically more complex. Deliberate manipulation in their manufacture, by using newly developed dyes and pigments, makes the colour of artefacts frequently the only feature by which they can be told apart. As a consequence, new lexemes denoting colour emerge. Due to their increasing functional load in linguistic communication the new terms are promoted in salience, with corresponding categories partitioning the psychological colour space more finely.

In view of this technological-control account of artefact colours, it is no surprise that, with the advent of the industrial revolution, the seventeenth and eighteenth centuries witnessed the emergence of many new colour terms. By the twentieth century some of these became basic. To name a few examples: Russian *koričnevyj* "brown", *oranževyj* "orange" and *fioletovyj* "purple" (Baxilina 1975); French *marron* "brown" (Forbes 1979, 2006); English *pink* (Kerttula 2002, 2007; Steinvall 2002, 2006); Hungarian *piros* "red" (Uusküla & Sutrop 2010).

The examples above support the B&K hypothesis of a multi-stage process of BCT emergence, and are also in accord with Kay and Maffi's (1999) conjecture that demands of communication are the driving force of colour-lexicon development. This explanatory scheme captures the stages (= synchronic states) of lexical evolution and, in addition, considers *extralinguistic factors* driving it, but in our view it is missing a significant factor – the linguistic mechanisms of a colour term's emergence. It is this factor, the *development in linguistic function* of colour terms, that we address in the present study.

2. Colour terms as words

In recent decades several studies set out to investigate the real-time development of colour inventories in individual languages. In the psycholinguistic approach, the

mapping procedure was employed after a two-decade lapse to capture ongoing changes in referential meaning of the colour terms (*French*: Forbes 1979, 2006).

Crucially, with time, colour terms may undergo changes in their connotations, a process that can be grasped solely by linguistic methods – by monitoring their *linguistic behaviour* (cf. Wierzbicka 1985). The latter implies variation in the colour terms' usage and collocation constraints which reveal changes in their semantic components, or in their attributive meaning (Lyons 1995: 206).

For exploring the development of colour term attributive meanings, in recent years a linguistic approach has been widely pursued using national language corpora; e.g. *French* Forbes (1979, 2006); *Russian* Rakhilina (2000, 2007); *English* Kerttula (2002), Steinvall (2002, 2006); *Ancient Indo-European languages* Normanskaya (2005); *Finnish* Kerttula (2007).

Our particular interest here is in those studies that focus on cases where a certain basic colour category is denoted by two colour terms, effectively referential synonyms, with one being older. Diachronically, different scenarios of the relationship between the two are possible:

a. An emerging colour term becomes basic, fully supplanting the old BCT, e.g. Old English *sweart* supplanted by Middle English *black* (Kerttula 2002: 321).
b. An emerging colour term contends with an old BCT and becomes basic, relegating the old to non-basic status, e.g. English *pink*, the competitor of *rose*, emerged as salient in the seventeenth century and became basic in the twentieth century, leaving *rose* for entrenched constructions (Steinvall 2006). The Hungarian *piros* "red", having emerged in the eighteenth century, surpassed the old *vörös* as the main colour term (Uusküla & Sutrop 2010).
c. An emerging colour term becomes basic on a par with the older BCT. Referentially they either are synonyms or greatly overlap but differ in their attributive use, e.g. *brun* and *marron* for "brown" in French (Forbes 1979, 2006); *sinij* and *goluboj* for "blue" in Russian (Paramei 2007). (In these examples the older term is given first.)

3. Colour terms as components of linguistic constructions

In the present study we used the *Russian National Corpus* (RNC) to investigate the development of Russian colour terms: their linguistic origin, morpho-syntactic patterns, semantic interpretation and, especially, their discourse functioning. Attributive constructions with these colour terms are analyzed from the *typological perspective* and monitored for possible regularities in their syntagmatic collocations, i.e. combinability with object names that differ taxonomically.

Linguistic constructions – pairings of form and meaning – are considered the linguistic means of referring to extralinguistic situations, e.g. *čërnyj kamen'* "black stone".[2]

2. For English translations of the Russian colour terms here and in what follows we used the lists suggested by Frumkina & Mikhejev (1996: 86) and Davies & Corbett (1994: 73–74).

According to *Construction Grammar Theory* (Fillmore, Kay & O'Connor 1988; Goldberg 2003), a construction is defined by its syntactic structure, grammatical characteristics of its components and, in addition, by taxonomic constraints on lexical variables. A change in taxonomic category of a certain lexeme may coerce a shift of the construction's meaning entirely, a phenomenon that underlies the essence of a metaphor (cf. Lakoff & Johnson 1980), e.g. *black stone* vs. *black humour*. In this example, two taxonomic meta-classes, of names for *concrete objects* vs. *abstract concepts*, are opposed.

In attributive constructions with colour terms, other taxonomic boundaries were established, namely opposing *animate* and *inanimate* objects as in, for example, the use of one or other of two basic terms for "green" in Samoan (Snow 1971). More recently, taxonomic boundaries of colour term use were explored *within the class of natural objects*, in an extensive international project including Polish, Ukrainian and Russian (Grzegorczykowa & Waszakowa 2000).

As part of this project, our analysis of Russian attributive constructions revealed that colour term usage is contingent on a taxonomic boundary of another kind – between names for *natural objects/surfaces* vs. *artefacts* (Rakhilina 2000, 2007). The rationale behind the significance of this semantic opposition is twofold. First, it may be sought in the fact that, in discourse, colour of many natural objects is affectively marked (e.g. eyes, hair or skin; cf. Rakhilina 2007).[3] Second, colour characteristics *per se* differ between natural objects and artefacts. The colour of artefacts, imparted by dyes or pigments, is circumscribed in hue and lightness, and, frequently, is high in saturation, e.g. *sinjaja rubaška* "dark blue shirt". In contrast, the colour of natural objects such as skin, animals, plants or surfaces is quite diffuse; it may refer to blended hue areas and/or to the desaturated (greyish) core of the psychological colour space, e.g. the Russian construction *sineje more* "dark blue sea" may denote colours ranging from green through grey to black. This range is very different from that of *sineje nebo* "dark blue sky" (which in Russian denotes the saturated blue of a cloudless sky), and both certainly differ from the colour of shirts.

In the present study we are especially interested in cases where the colour of denoted natural objects and artefacts is very alike but the Russian colour terms, as components of attributive constructions, differ. We investigate the usage of these contending colour terms in their relation to the taxonomic category of a noun, in particular their diachronic relationship.

3. In phraseological units related to natural objects, their named colour may in addition be semiotically loaded, i.e. refer to culture-specific concepts rather than to the objects' denotata, e.g. *zelënaja ljaguška* "green frog" or *seryj volk* "grey wolf" in Russian folklore (Rakhilina 2007: 367).

4. Modern Russian: Lexical development of colour terms

To monitor lexical development, we undertook a linguistic analysis of changes in frequently-used historically recent colour terms by employing the *Russian National Corpus* (RNC). This includes 160 million words (by August 2007 when the data were extracted) and contains entries from the eighteenth to twenty-first centuries. We focused on the following aspects: (1) categories/types of coloured objects whose names serve as colour term referents; (2) variety of descriptive meanings of colour terms; and (3) combinability with noun classes.

4.1 Objects as referents of new colour terms

Below we delineate four categories of coloured objects common for native Russians and serving as referents for emerging colour terms.[4] Within a category, each object name is listed according to the (diachronic) order of its occurrence as the colour term referent, and is accompanied by the corresponding adjectival form. Russian denominal adjectives, as a rule, are produced by adding the suffix '*-v*' or '*-n*' and (by convention) the (masculine, singular) ending '*-yj*'.

4.1.1 *Dyes and artefact fluids*

1. *Purpur* "crimson dye" > *purpurnyj* "crimson"
2. *Bordo* "Bordeaux" > *bordovyj* "wine red", "claret"
3. *Černila* "ink"[5] > *černil'nyj* "ink-coloured"

4.1.2 *Fruits and berries*

1. *Korica* "cinnamon" > *koričnevyj* "brown"
2. *Limon* "lemon" > *limonnyj* "lemon yellow"
3. *Višnya* "cherry" > *višnëvyj* "cherry-coloured"
4. *Olivka* "olive" > *olivkovyj* "olive-coloured"

4.1.3 *Gems and semi-precious stones*

1. *Lazur'* "pigment from lapis lazuli or azurite" > *lazurnyj* "sky-blue"
2. *Birjuza* "turquoise" > *birjuzovyj* "turquoise"
3. *Malaxit* "malachite" > *malaxitovyj* "malachite-coloured"

4. Note that the category list greatly overlaps with the one delineated by Kerttula (2002: 251) for English.

5. Traditionally in Russia, the ink, produced from galls, abnormal swellings on oak trees, has a dark violet colour. Until recently it was widely used at schools and public offices.

4.1.4 *Construction materials (very recent category)*
1. *Kirpič* "brick"[6] > *kirpičnyj* "brick-coloured"
2. *Asfal't* "asphalt concrete" > *asfal'tovyj* "asphalt-coloured"

4.2 Descriptive meanings of colour terms as denominal adjectives

From a diachronic perspective, an emerging Russian colour term derived from an object name enters initially as the pattern *cveta X* "colour of X" (d below) whereas a denominal adjective *X-yj* possesses other meanings (a-c):

a. "made of X/containing X"
b. "intended for X"
c. "where X is located"
d. "colour of X".

The "colour" meaning is established gradually; stages of this process can be pursued by real-language examples. In late twentieth-century Russian, according to the RNC, this early stage can be illustrated by the adjectival derivative of the noun *baklažan* "aubergine" vs. the pattern "colour of X":

1. *baklažannaja ikra* "aubergine paste" (a)
   but **baklažannaja mashina*
   mašina cveta baklažan "a car of the colour of aubergine" (d).

At a more advanced stage, a Russian colour term acquires the proper adjectival form *X-yj* (e) but its meaning continues to co-exist with the meanings (a-c); this is exemplified by the following:

2. *limonnyj pirog* "lemon pie" (a)
   limonnye oboi "lemon-coloured wallpaper" (e).
3. *višnevyj sok* "cherry juice" (a)
   višnevyj pidžak "cherry-red jacket" (e).

The emancipation of colour denotation from other meanings in Russian may be indicated by means of affix diversification, as in denominal adjectives from the noun *korica* "cinnamon". Having entered Russian in the seventeenth century, the adjective emerged in two forms, *koričnyj* and *koričnevyj*, both meaning "containing cinnamon" (a) and "brown" (e) (Baxilina 1975). However, by the twentieth century the form *koričnevyj* acquired the colour denotation as its only meaning (e):

4. *koričnevyj pol* "brown floor" (e).

6. In Russia, bricks are usually of a (matt) orange colour.

5. Usage constraints of the emerging Russian colour terms: Driven by the noun taxonomic class

When considering the development of emerging Russian colour terms, especially of very recent 'newcomers', our primary interest is in their functioning as components of attributive constructions. Below we examine several colour terms with respect to their collocations with nouns signifying certain classes of objects.

5.1 *Koričnevyj*: The Russian case of *"browns"*

Koričnevyj is considered to be the Russian term for "brown" (Berlin & Kay 1969; Frumkina & Mikhejev 1996; Rakhilina 2000, 2007). It has a high frequency of occurrence, ranking ten, and rather high morphological production, ranking fourteen (Corbett & Morgan 1988: 57).

Importantly, though in attributive constructions *koričnevyj* is broadly combinable with denoted objects, its usage is constrained solely to nouns from the taxonomic class of artefacts. For denoting natural objects and in conventional constructions, the older term *buryj* "(dust/greyish) brown" is used. The *koričnevyj* vs. *buryj* exclusive collocations are illustrated by the following examples:

5. *buryj medved'* "brown bear"
   buryj ugol' "brown coal"
   vs. *koričnevye botinki* "brown boots".

Buryj is rich in morphological derivations, ranking nine (Corbett & Morgan 1988: 57); its frequency rank, however, fell dramatically during a short period: from eleven (Corbett & Morgan 1988: 57) to 41.5 (Davies & Corbett 1994).

The taxonomic constraints on *koričnevyj*, as well as its frequency in the list task and derivational development – linguistic indices contributing to the measure of relative basicness (cf. Kerttula 2002: 336) – provide evidence that *koričnevyj* is not yet fully established as the basic term. In passing it is worth noting that the watershed in combinability of the two Russian browns – with natural objects vs. artefacts – is strikingly similar to that between the French older *brun* and recent *marron* (cf. Forbes 1979: 302, Table 1).

The above observation led to the following hypothesis: an emerging colour term initially expands over denotations of artefacts, whereas an older colour term with a similar referential meaning continues to denote natural objects. In the light of this hypothesis, we analyze development in combinability of several other relatively 'young' colour terms.

5.2 Linguistic behaviour of Russian highly frequent non-basic colour terms

5.2.1 *Birjuzovyj* "turquoise"

According to the RNC, the term *birjuzovyj* was already used in Russian in the mid-eighteenth century but originally meant only "made of turquoise" (in relation to "stone", "ring", "necklace", etc.). The mid-nineteenth century registered the usage of *birjuzovyj* predominantly in the sense of "turquoise-coloured", as related to the colour of a "collar" or "skirt" and, rarely, of "sky" or "sea". By the beginning of the twentieth century not only had the frequency of *birjuzovyj* usage increased significantly (by 50%) but also its combinability expanded – from nouns for artefacts (e.g. "fabric", "carpet") to those for "eyes" and natural surfaces (e.g. "water", "sky"). The data from the list task indicate that currently *birjuzovyj* is among the most frequently used Russian non-basic colour terms, ranking eighteen (Davies & Corbett 1994: 81).

5.2.2 *Bordovyj* "wine red", "claret"

The Russian term *bordovyj* originates from *Bordeaux* "claret". According to the RNC, as denoting the colour, it was first used as the form "red-*bordo* silk blanket" in Leo Tolstoy's *Resurrection* (1889). As the proper adjectival form *bordovyj*, it was used from the beginning of the twentieth century. For example, in the *bordovaja knižečka* "wine-red little book", the term is used metonymically to denote a document.[7] However, the term collocates exclusively with names for artefacts: the RNC reveals no combinations of it with nouns denoting natural objects. It is worth noting that, although taxonomically constrained, *bordovyj* is one of the most frequent non-BCTs, ranking fifteen, and, along with the basic term *fioletovyj* "purple", is a member of a family of several terms refining Russian nomenclature for the purple category (Davies & Corbett 1994: 81).

5.3 Linguistic behaviour of the Russian colour term 'new-comers'

5.3.1 *Černil'nyj* "ink-coloured"

In the nineteenth century the term *černil'nyj* was used solely with the 'non-colour' meaning, e.g. "ink spot/drop/pencil". In the twentieth century the RNC shows its first rare usages with a colour-descriptive meaning in literary, mostly poetic, texts or as part of compounds, e.g. *černil'no-sinij* ("ink-coloured, dark blue") related to "eyes/tongue/window" (V. Nabokov) or *černil'no-černyj/-fioletovyj* "ink-coloured, black/purple". By the end of the twentieth century the colour meaning of *černil'nyj* became more frequent, expanding to natural objects and surfaces "night/sky/darkness/water/bruises/clouds/storm clouds", but the usage is still marked and restricted to poetic texts.

7. In the Soviet Union, certificates or membership documents were frequently issued with jackets of this colour.

5.3.2 *Kirpičnyj* "brick-coloured"
The vast majority of modern usages of *kirpičnyj* registered in the RNC have the "made of X" meaning (a), as in "brick wall/building/gate", etc. With a colour-descriptive meaning the usage is constrained to the form *kirpičnogo cveta* "colour of brick" (d). However, on the Internet there are a few cases of *kirpičnyj* as a colour term (e), e.g. *kirpičnoe platje* "brick-coloured dress".

5.3.3 *Asfal'tovyj* "asphalt-coloured"
This very recent term appears in the RNC only in the conventional form *cveta mokrogo asfal'ta* "colour of wet asphalt", related to artefacts like "car/dress/suit/PC" and sometimes to "eyes/sky". On the Internet, in comparison, the advanced, adjectival form *asfal'tovyj cvet* "asphalt-coloured" is recorded, related to "car/PC peripherals/dinner jacket", etc., though the usage is with quotation marks; the only entry without marks is a description of eye shadows to yield "smokey eyes".

6. Conclusions

1. Delineating the exact mechanisms that underlie the evolution of a BCT inventory through the stages of the B&K model requires a more extensive analysis of colour lexicons of individual languages, and is a task for future studies. However, based on our examples of the linguistic behaviour of (relatively) new Russian colour terms, the process can be reconstructed as follows.

Lexically, a refinement of a colour category manifests itself through the emergence of a new colour term that complements the older one. New colour terms are derived from names of coloured objects and enter the language *gradually*. Initially the new term conforms to the pattern "colour of X". At the next stage it develops to the standard adjectival form "X-coloured" (in Russian usually X-*yj*). The 'colour' meaning may co-exist with other, non-colour meanings of the denominal adjective. At this stage, it may also function as a component of a compound name including a BCT, e.g. "X-black", "X-red", etc. The 'colour' meaning of the emerging term is then emancipated from other meanings and, ultimately, becomes the only one.

Analysis of Russian attributive constructions with colour terms indicates that the typical path of linguistic development of the emerging term is its initial collocation with a narrow taxonomic class of names for certain *artefacts*. The term then gradually expands to a much broader artefact zone and to *natural objects*, rivalling the older term in denoting a basic colour category. Further expansion of the contender term results in it supplanting the older one as a BCT, whereupon the older colour term becomes increasingly constrained in denoting certain natural objects, and in conventional constructions. Before becoming basic, the new colour term contender develops through all these stages – as is illustrated here by the two Russian terms for "brown", older *buryj* and more recent *koričnevyj*.

2. The regularities in the linguistic functioning of emerging colour terms indicate the significance of the cognitive boundary between natural and artefact colour. Along with bestowing manufactured objects with the chromatic distinctness needed for effective communication, dyes, pigments and lights apparently evoke new qualities of perceived colour, not seen in nature, that call out to be reflected linguistically. The cognitive significance of this boundary is unlikely to be an idiosyncratic feature of Russian colour naming since converging evidence, as mentioned above, comes from English, Estonian and French. This assumption requires further empirical investigation across languages, but the material presented here strongly suggests that 'naturalness' of the colour, as the cognitive concept behind the colour term denoting it, significantly determines the term's linguistic behaviour and, ultimately, whether it becomes basic.

Our findings on the constraints in taxonomic class combinability shed light on some linguistic mechanisms of colour term evolution. We suggest that the *combinability* of a colour term with names denoting *both artefacts* and *natural objects* may serve as a *complementary linguistic criterion* of basicness of the colour term in question.

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Preliminary research on Turkish basic colour terms with an emphasis on blue

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This paper describes and discusses list and naming experiments designed to ascertain whether Turkish *lacivert* "dark blue" is a Basic Colour Term (BCT). In addition to the standard sixty-five Color-aid tiles selected by Davies and Corbett (1995), seventeen additional tiles from the purple-blue region of colour space were used for these tasks. Measured against Urmas Sutrop's cognitive salience index (Sutrop 2001), *lacivert* attained high salience in the list task. However, the combined results suggest eleven Turkish BCTs (excluding *lacivert*): *yeşil* "green", *sarı* "yellow", *siyah* "black", *kırmızı* "red", *mavi* "blue", *beyaz* "white", *mor* "purple", *kahverengi* "brown", *pembe* "pink", *turuncu* "orange" and *gri* "grey". *Lacivert* remains a BCT candidate due to the additional tile used in the naming task, which emerged as dominant.

1. Introduction

The aim of this research is to establish the Turkish BCTs,[1] and to ascertain the position of *lacivert* "dark blue". *Lacivert* is a loanword from Persian, in which language it indicates the semi-precious stone lapis lazuli (Turkish *lacivert taşı* "*lacivert* stone").[2] By itself, however, *lacivert* designates an almost black, dark blue colour for which the closest English equivalent is 'navy blue'. Seventeen additional Color-aid tiles from the purple-blue region were used in the author's naming task in order to specify the status of *lacivert*.

1. The study is supported by the Estonian Science Foundation, grants no. 6744 and 8168. I would also like to thank Prof. Esin Örücü of the University of Glasgow for her helpful comments on this article, and Dr Carole Biggam of the same university for her time and patience in making this article readable. All mistakes from here on are, of course, my own. I am also grateful to Prof. Urmas Sutrop (Institute of the Estonian Language and University of Tartu) for providing me with the opportunity to undertake this research.

2. The reader should note that Turkish uses two symbols which can be confused by the non-Turkish reader. They are *i* and *ı* (the latter without a dot). The former is a long vowel sounding like the *ee* in English *seen*, while the latter represents what is often called a neutral vowel in English, as represented by the *e* in English *shorten*.

Emre Özgen and Ian R. L. Davies in their very valuable research conducted three experimentally based studies of Turkish colour terms. In the first experiment, eighty children (aged 8–14 years), 118 students (19–25) and thirty-five adults (20–38) completed a time-restricted (five minutes) written list task ("Write down as many colour terms as you can"). In reporting the list task results, the authors removed all general modifiers, for example *açık* "light" and *koyu* "dark", leaving only the simple forms of the colour terms (Özgen & Davies 1998: 925). This approach, to eliminate all modifiers, seems to continue throughout the article.

In the second experiment, "a subset of the child and adult samples" (altogether seventeen children and thirty-three adults) from the previous experiment took part in a colour naming task assessed by Davies and Corbett's general method for establishing BCTs (1995). Özgen and Davies report that "measures of salience and consensus derived from the two tasks converge to suggest that Turkish has 12 basic color terms" (1998: 919).

Besides the list and colour naming tasks for establishing Turkish BCTs, Özgen and Davies performed a third experiment in which 125 university students (109 females and 15 males), aged between nineteen and twenty-four, were tested during a class. They were asked to "write down as many kinds of *mavi* [blue] as they could think of" and, after finishing that list, to "write down whether *lacivert* was a kind of *mavi*". The results showed that 57% of subjects included *lacivert* "dark blue" in their lists of types of *mavi* "blue" and, furthermore, 85.5% regarded *lacivert* as a kind of *mavi* (Özgen & Davies 1998: 942). These results suggest that *lacivert* violates Berlin and Kay's non-inclusion criterion for basicness, which states that basic colour term signification is not included in that of any other colour term (Berlin & Kay 1969: 6).

I conducted my own two field tests to find out whether the position of *lacivert* "dark blue" as a twelfth Turkish BCT would be supported or refuted by the fieldwork results. I used eighty-two tiles (sixty-five standard plus seventeen additional purple-blue examples) in the colour naming task to more precisely establish the focus of *lacivert*. The subjects were all native Turkish speakers, and the interviews were conducted by a fluent or native speaker.

2. Method

The list and naming tasks, based on the fieldwork methods of Davies and Corbett (1995), were conducted in Ankara and Antalya on March 17–23 and July 12–26, 2007. The fieldwork consisted of two parts:

1. An oral list task, in which the subjects were asked to name as many colours as they knew.
2. A naming task, in which the subjects were asked to name sixty-five standard and seventeen additional Color-aid tiles.

The terms retrieved were written down by a fluent or native speaker of Turkish at the time, in the form provided by the native speaker subjects.

An intrinsic part of the field method is the testing of the subjects' colour vision, for which the *City University Colour Vision Test* (Fletcher 1998) was used, in order to determine whether the subjects had normal colour vision. In fact, four subjects did not pass the test and their answers were not included in the colour naming part of the data.

3. Subjects

The list task was completed by sixty subjects, thirty-one females (with a mean age of 28.7), and twenty-nine males (with a mean age of 35.6). The youngest subject was a 14-year old schoolgirl and the oldest a 79-year old former schoolteacher. Most subjects (33% of the males and 32% of the females) were young adults between the ages of 19 and 35. A second group, consisting of adults aged 36 to 65, had a 13% representation in both sexes. The least represented age groups were the elderly (5%) and teenagers (3%). No children were tested.

Most subjects (thirty-five in total, consisting of twenty females and fifteen males) had attained a high school diploma. It should be taken into account that the subjects were generally full-time university students in the middle of their university education. Nineteen subjects (eleven males and eight females) already had a university degree (B.A., M.A. or Ph.D.).[3]

All sixty subjects completed the oral list task, and fifty-six of them contributed to the naming task, after four subjects failed the *City University Colour Vision Test* (Fletcher 1998).

4. Stimuli

All subjects took part in the naming task, in which a set of sixty-five coloured tiles from the Color-aid Corporation 220 Standard Set was used, as suggested by Davies and Corbett (1995). The sixty-five tiles were originally chosen by Davies and Corbett because they "formed a coarse, but evenly spread sample of colour space" (1995: 27). This reduced set was used for the sake of expediency in that it facilitated the testing of a relatively large number of subjects in everyday situations, for example on the street, at home and at work. The tiles consisted of the Color-aid coloured paper glued to a 5 x 5 x 0.2 centimetre cardboard base.

3. It is likely that the presence of some colour terms in the results reflects the usage of the more educated sector of Turkish society. It has been suggested, for example, by Örücü (personal communication; see note 1 above) that some terms, for example *lila* "lilac" and *bordo* "burgundy," would be unfamiliar as colour terms in the rural areas of Turkey.

For ascertaining the position of *lacivert* "dark blue" in the Turkish colour term hierarchy, seventeen additional tiles were selected from the purple-blue region of colour space.[4] The additional tiles selected for the naming task covered the whole blue range of Color-aid tiles and most of the purple-blue region, along with three supplementary tiles to complete the selection.

Eighty-two tiles (sixty-five standard plus seventeen additional) were randomly shown to subjects, one after the other, on a neutral grey background in natural daylight.

5. Results

Altogether, 5,604 terms were named during both tasks, of which 562 were different terms. Out of 3,640 possible responses (65 tiles x 56 subjects = 3,640 terms), a little over 3,600 were actually given for the standard tiles, leaving less than one percent of 'don't know' answers. For the seventeen extra tiles, 951 responses out of a possible 952 (17 x 56 = 952) were given. Only one tile, B T4, was left unnamed.

5.1 The list task

According to the list task frequency in Table 1, the most widely used colour terms in Turkish are *yeşil* "green" (a frequency of 58 out of a possible 60), followed equally by *sarı* "yellow" and *siyah* "black" (frequency: 56), then *beyaz* "white" (54), *kırmızı* "red" (53), *mavi* "blue" (52), and, after a small drop in frequency, *mor* "purple" and *kahverengi* "brown" (48), *pembe* "pink" and *turuncu* "orange" (47). The next term, *gri* "grey" (43), has a frequency comparable to that of *lacivert* "dark blue" (41). Frequency is a crude measurement, but an effective criterion for finding out the most commonly used colour terms. The BCTs and the possible BCT candidate *lacivert* are followed by colour terms having a frequency percentage ranging from forty-three to twenty-eight percent, for example *lila* "lilac" and *bordo* "burgundy" (with a frequency of 26 each), *eflatun* "mauve" (frequency: 24), followed by *bej* "beige" and *turkuaz* "turquoise" with respective frequencies of 18 and 17.[5]

As shown in Table 1 below (the most salient Turkish colour terms according to the list task), frequency suddenly drops from sixty-eight percent for *lacivert* "dark blue" (a frequency of 41 out of 60) to forty-three percent for the terms *lila* "lilac" and *bordo* "burgundy" (26 out of 60). The fifty percent usage frequency (frequency: 30) draws a

4. The seventeen extra tiles used in the naming task were: BV T1, BV T2, BV S1, BVB T1, BVB T2, BVB T3, BVB S1, B T2, B T3, B T4, B S1, B S2, B S3, BG T2, Cobalt Blue, Navy Blue and Cyan Blue.

5. The older colour terms such as *ak* "white", *kara* "black", *al* "red", *boz* "grey" and *gök* "blue" were rarely used by informants; that is, they were named not more than once or twice in both list and naming tasks. The only exception was *kızıl* "red", which was named seven times in the list task.

rough line between the BCTs and the non-BCTs, but this is only one indicator of basicness. The frequency of *lacivert*, taken together with a mean position of 10.46, suggests that it is a twelfth Turkish BCT but this suspicion is only based on the analysis of the list task data, and so is not conclusive.

Table 1. The most salient Turkish colour terms in the list task (arranged in order of salience). Fr = frequency, Mp = mean position, Salience = cognitive salience index score

Term	Gloss	Fr	Rank	Mp	Rank	Salience	Rank
kırmızı	red	53	5	3.72	1	0.2375	1
mavi	blue	52	6	3.81	2	0.2275	2
yeşil	green	58	1	5.05	3	0.1914	3
sarı	yellow	56	2.5	6.04	4	0.1545	4
siyah	black	56	2.5	6.27	5	0.1489	5
beyaz	white	54	4	6.43	6	0.1400	6
mor	purple	48	7.5	8.90	7	0.0899	7
pembe	pink	47	9.5	9.04	8	0.0867	8
turuncu	orange	47	9.5	10.28	11	0.0762	9
kahverengi	brown	48	7.5	11.56	17	0.0692	10
lacivert	dark blue	41	12	10.46	12	0.0653	11
gri	grey	43	11	12.44	24	0.0576	12
lila	lilac	26	13.5	12.35	23	0.0351	13
eflatun	mauve	24	15	11.63	18	0.0344	14
bordo	burgundy	26	13.5	14.08	28	0.0308	15
bej	beige	18	16	15.11	34	0.0199	16
turkuaz	turquoise	17	17	14.53	30	0.0195	17
ela	hazel	9	20.5	10.56	13	0.0142	18
krem	cream	12	18	14.42	29	0.0139	19
haki	khaki	9	20.5	16.00	37.5	0.0094	20
yavruağzı	peach (a)	9	20.5	17.44	43	0.0086	21
açık mavi	light blue (b)	6	27.5	12.50	25	0.0080	22
fıstık yeşili	pistachio-green	8	22	17.00	42	0.0078	23
gök mavisi	sky-blue	7	24.5	15.00	32.5	0.0078	23
kızıl	red	7	24.5	16.00	37.5	0.0073	25
leylak	lilac	4	39	9.25	9	0.0072	26
açık pembe	light pink	5	32	12.00	21.5	0.0069	27
koyu yeşil	dark green	5	32	12.00	21.5	0.0069	27
açık yeşil	light green	4	39	9.75	10	0.0068	29
kavuniçi	light pinkish yellow (c)	6	27.5	15.33	35	0.0065	30
kiremit rengi	brownish orange (d)	6	27.5	15.67	36	0.0064	31
deniz mavisi	sea-blue	5	32	13.80	27	0.0060	32
koyu kırmızı	dark red	4	39	11.75	20	0.0057	33
fuşya	fuchsia	5	32	14.80	31	0.0056	34
vişneçürüğü	purple brown (e)	7	24.5	22.43	52	0.0052	35
füme	smokey	5	32	18.40	46	0.0045	36
fildişi	ivory	3	48.5	11.00	14.5	0.0045	36

Term	Gloss	Fr	Rank	Mp	Rank	Salience	Rank
menekşe	violet	3	48.5	11.00	14.5	0.0045	36
parlament mavisi	cobalt blue (f)	4	39	15.00	32.5	0.0044	39
gülkurusu	purplish pink (g)	3	48.5	11.33	16	0.0044	39
turanj	orange	3	48.5	11.67	19	0.0043	41
çimen yeşili	grass-green	5	32	19.80	50	0.0042	42
açık sarı	light yellow	4	39	16.25	39	0.0041	43
şampanya rengi	champagne coloured	5	32	21.40	51	0.0039	44
çağla yeşili	almond-green	4	39	17.75	44	0.0038	45
koyu mavi	dark blue	3	48.5	13.00	26	0.0038	45
açık kırmızı	light red	4	39	18.50	47	0.0036	47
buz mavisi	ice-blue	3	48.5	16.33	40.5	0.0030	48
kiremit	brownish orange (h)	3	48.5	16.33	40.5	0.0030	48
patlıcan moru	aubergine-purple	3	48.5	18.33	45	0.0027	50
açık kahve	light coffee	3	48.5	19.00	48.5	0.0026	51
gümüş rengi	silver coloured	3	48.5	19.00	48.5	0.0026	51
camgöbeği	pale bluish green (i)	3	48.5	28.00	53	0.0018	53
petrol mavisi	petroleum-blue	3	48.5	39.00	54	0.0013	54

Notes to Table 1

a. *Yavruağzı* means literally "baby-mouth" (Color-aid tile ORO T3). This tile was named *yavruağzı* by twenty-one percent of the subjects. Özgen and Davies (1998: 936) reported the same percentage, but more than thirty percent of their subjects preferred to use *pembe* "pink" for this tile.

b. The qualifiers *açık* "light", uçuk "very pale" and koyu "dark" can be used with any colour term, except those meaning 'black' and 'white'. They are only included here if used by the informants.

c. *Kavuniçi* means literally "flesh of the melon".

d. *Kiremit rengi* (literally "(roofing) tile-coloured") has been translated as "tile-red, brick-red" (*Redhouse* 2006: 469a), but the Color-aid tile most often named with this phrase was Sienna Brown (23%) and this tile was also named *kahverengi* "brown". The same tile was named brown or tan in English (Davies & Corbett 1995: 34). See also note (h) below.

e. *Vişneçürüğü* means literally "rotten morello (sour cherry)".

f. *Parliament blue* (spoken in Turkish as *parlament* or *parlement*) was used in the present tests only by young females not older than 33 years of age, and appears to occur in fashion and paint-related contexts. Color-aid tile BVB HUE was most often named with this term, but there was uncertainty among the informants as to its use elsewhere. The connection with a parliament is also uncertain. It has been translated here as "cobalt blue" which is a dark blue, but paler than that denoted by *lacivert*.

g. *Gülkurusu* means literally "dried rose", indicating the pale purple tinge on pink, caused by drying a pink rose.

h. *Kiremit* means literally "(roofing)-tile". It should be noted that *kiremit rengi* occurs at rank 31 in this list, and *rengi* means "colour of". It is possible that the presence of *rengi* elsewhere in the question put to informants caused some to regard this word as an 'understood' part of a colour phrase. See also note (d) above.

i. *Camgöbeği* refers to the colour of glass, specifically ancient glass, which is most often a pale turquoise colour.

A more precise indicator of basicness is Sutrop's cognitive salience index, which combines two list task parameters – frequency and mean position – independently of

the length of any particular list. It is therefore possible to compare different results as they do not depend on the length of the individual lists (Sutrop 2001: 263; see also Uusküla 2011). The most salient term has a cognitive salience index score of 1, and a term not mentioned at all has a score of 0. The formula for calculation of the score is: S = F/(N x mp).[6]

According to the cognitive salience index, the most salient terms in Turkish are the following twelve colour terms (see Figure 1): *kırmızı* "red", *mavi* "blue", *yeşil* "green", *sarı* "yellow", *siyah* "black", *beyaz* "white", *mor* "purple", *pembe* "pink", *turuncu* "orange", *kahverengi* "brown", *lacivert* "dark blue" and *gri* "grey".

Somewhat remarkably, *lacivert* (cognitive salience index score: 0.0653) holds the eleventh position instead of the BCT *gri* "grey" (0.0576), which many would have predicted to be in this position.

To compare the Turkish with the Russian results obtained by Davies and Corbett, I calculated the cognitive salience index scores from their data (Davies & Corbett 1994: 73). For example, *goluboj* "light blue" has a cognitive salience index score of 0.126, which is calculated by dividing its frequency (73) by the result of multiplying the number of subjects (77) by its mean position (7.50). According to the index, *goluboj* "light blue" is ranked fifth after *krasnyj* "red" (0.293), *sinij* "blue" (0.160), *želtyj* "yellow" (0.159) and *zelenyj* "green" (0.153).

Regrettably, Özgen and Davies (1998: 943) do not provide list task mean positions in their article, only the mean position ranking, so it is not possible to calculate cognitive salience index scores from their results and compare the two Turkish fieldwork datasets.

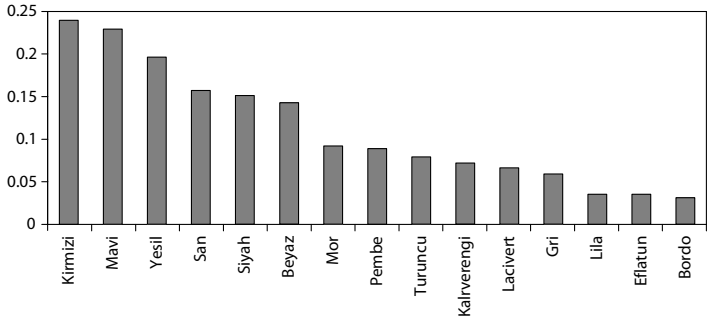

Figure 1. The most salient Turkish colour terms according to the cognitive salience index

6. In which S is the cognitive salience index score, F is the frequency of use in the list task, N is the number of subjects, and mp is the mean position.

5.2 The colour naming task

Table 2 gives the following information: *total frequency* refers to the number of times each term was used in the naming task; *dominance frequency* refers to the number of tiles for which each term was dominant;[7] *nmf* refers to the number of tiles for which each term was the most frequently used; and the *specificity index* (SI) refers to the result of the dominance frequency divided by the total frequency (Davies & Corbett 1994: 79). The most common terms are ranked by their total frequency. The term *hardal sarısı* "mustard-yellow" did not have the required total frequency and was left out of Table 2, but it was, nevertheless, the most frequently used term for Color-aid tile YOY-S2.

One of the most important indicators of basicness is the specificity index, which shows not only how many times a term was used, but also the degree of consensus. For example, *yeşil* "green" has the highest total frequency (241), but the ratio (SI) of dominance frequency (67) and total frequency is very low (0.278), resulting in *yeşil* ranking tenth and being placed higher only than *pembe* "pink", which has the lowest SI of all. Comparing it to *siyah* "black" (total frequency: 98; dominance frequency: 94) or to *beyaz* "white" (total frequency: 56; dominance frequency: 40) one can see how the SI shows the level of consensus among subjects. Ranked according to the specificity index, the eleven terms which attained dominance for sixty-five standard tiles are: *siyah* "black", *sarı* "yellow", *mavi* "blue", *beyaz* "white", *gri* "grey", *mor* "purple", *kırmızı* "red", *turuncu* "orange", *kahverengi* "brown", *yeşil* "green" and *pembe* "pink".

The most probable BCTs in Turkish, based on dominance in the tile naming task, are those already listed according to the specificity index but, ranked in order of dominance percentage, they are as follows: *siyah* "black" (equal to or surpassing a 90% dominance), *sarı* "yellow", *mavi* "blue", *mor* "purple", *kırmızı* "red" (equal to or surpassing a 75% dominance), *beyaz* "white", *gri* "grey", *turuncu* "orange", *kahverengi* "brown", *yeşil* "green", and *pembe* "pink" (equal to or surpassing a 50% dominance).

5.2.1 *Additional tile results for the blue region*

Standard tile BV HUE was named *lacivert* "dark blue" in twenty-two instances, which amounted to a thirty-nine percent consensus, but that was not enough to gain dominance (for which a frequency equal to or surpassing 28 was required). *Lacivert* was not, therefore, listed among the dominant terms because that requires a response involving a particular term from fifty percent or more of the subjects. The standard tile in question (BV HUE) could be considered exceptional as Özgen and Davies's results (1998: 937) show a staggering ninety-four percent consensus identifying it as *lacivert*, thus suggesting that the term has some claim to basicness.

My subjects were far less consistent in naming the BV HUE tile, giving it twenty-two different names, of which the most frequently occurring were: *lacivert* "dark blue"

7. A term is said to be dominant if at least half of the subjects use that term for a particular tile (Davies & Corbett 1994: 79).

Table 2. The most frequent colour terms in the naming task. Nmf = the number of tiles for which the term was most frequently used; SI = specificity index

Term	Gloss	Total frequency	Dominance frequency	Nmf	SI
yeşil	green	241	67	6	0.278
mor	purple	174	110	5	0.632
mavi	blue	152	109	3	0.717
kahverengi	brown	149	62	5	0.416
gri	grey	143	99	4	0.692
pembe	pink	135	31	7	0.230
kırmızı	red	130	80	3	0.615
açık yeşil	light green	119	–	4	–
turuncu	orange	114	70	5	0.614
sarı	yellow	105	82	2	0.781
koyu yeşil	dark green	99	–	3	–
siyah	black	98	94	2	0.959
koyu pembe	dark pink	63	–	1	–
açık pembe	light pink	59	–	1	–
beyaz	white	56	40	2	0.714
koyu mavi	dark blue	53	–	1	–
lila	lilac	51	–	2	–
eflatun	mauve	50	–	-	–
yavruağzı	peach	50	–	2	–
lacivert	dark blue	49	–	1	–
açık mavi	light blue	45	–	2	–
açık gri	light grey	38	–	-	–
kavuniçi	light pinkish yellow	37	–	-	–
koyu sarı	dark yellow	32	–	-	–
turkuaz	turquoise	32	–	-	–
açık mor	light purple	30	–	-	–
şampanya	champagne (-coloured)	30	–	-	–
açık sarı	light yellow	29	–	2	–
kiremit rengi	brownish orange	28	–	1	
koyu kahverengi	dark brown	28	–	-	–
bej	beige	27	–	1	–
	don't know	33			

(39%), *mor* "purple" (24%), *koyu mor* "dark purple" (7%), *eflatun* "mauve" (4%), *koyu mavi* "dark blue" (4%) and *mavi* "blue" (4%).

In comparison, additional tile B S3 was named *lacivert* "dark blue" by over half of the subjects (52%), consequently making it a dominant colour term. This could be interpreted as an indication that the most likely focus for *lacivert* "dark blue" is not among the sixty-five standard tiles used by Özgen and Davies (1998).

Four additional tiles, which gained dominance in the naming task, were described as *lacivert* "dark blue" (SI 0.758), *açık mavi* "light blue" (SI 0.718), *mavi* "blue" (SI 0.642) and *mor* "purple" (0.576). The last two BCTs also emerged as dominant among the standard tiles (see Table 2), but with lower specificity index scores. Among the additional tiles, the highest specificity index scores did not belong to BCTs, but, remarkably, to *lacivert* "dark blue" (with an overall ranking of third in terms of specificity), and *açık mavi* "light blue" (ranked fourth). The last term contains the modifier *açık* "light", violating Berlin and Kay's monolexemic criterion.

To conclude, *lacivert* "dark blue" has a high specificity index score even compared with Russian *goluboj* "light blue", which ranked eleventh on the specificity index (0.571) as calculated from the results of Davies and Corbett (1994: 79).

5.3 Combined analysis

The BCT criteria thresholds shown in Table 3 were selected on the basis of evident gaps in the frequency figures; for example, the list task frequency, as shown in Table 1, drops from 41 for *lacivert* "dark blue" to 26 for *lila* "lilac", and the mean position jumps from 6.43 for *beyaz* "white" to 8.90 for *mor* "purple". Similarly, the naming task frequency drops from 98 for *siyah* "black" to 63 for *koyu pembe* "dark pink" (Table 2). Dominance was interpreted as at least fifty percent consensus among the subjects, and only the dominant terms attained a specificity index score.

The most salient colour terms according to the sum of BCT criteria in Turkish are presented in Table 3. Meeting all five criteria are: *yeşil* "green", *sarı* "yellow", *siyah* "black", *kırmızı* "red" and *mavi* "blue". Next in line with four criteria fulfilled are: *beyaz* "white", *mor* "purple", *kahverengi* "brown", *pembe* "pink", *turuncu* "orange" and *gri* "grey". *Lacivert* "dark blue" is in twelfth place with one criterion threshold passed, namely list task frequency. Even taking into account the results for the additional tile B-S3, which increases the total criteria attained by *lacivert* to three, it still places *lacivert* in the position of a probable BCT candidate, but not a fully developed BCT.[8]

8. The *relative* basicness of colour terms is a well-known phenomenon. In other words, terms which are not totally convincing as BCTs in a language can be assessed as to their *degree* of basicness, although different languages are likely to require different criteria for such evaluations. For a suggested methodology for English colour terms, see Kerttula (2002).

Table 3. Sum of basic colour term criteria. Fr = frequency, Mp = mean position, DI = dominance index, SI = specificity index, * = dominance and specificity index scores based on the additional tiles (additional tile results appear in brackets in 'Sum of criteria')

		List task		Naming task			Sum of criteria
Term	**Gloss**	**Fr > 40**	**Mp < 7**	**Fr > 90**	**DI 1/2 > 1**	**SI > 0.2**	
yeşil	green	+	+	+	+	+	5
sarı	yellow	+	+	+	+	+	5
siyah	black	+	+	+	+	+	5
kırmızı	red	+	+	+	+	+	5
mavi	blue	+	+	+	+	+	5
beyaz	white	+	+	–	+	+	4
mor	purple	+	–	+	+	+	4
kahverengi	brown	+	–	+	+	+	4
pembe	pink	+	–	+	+	+	4
turuncu	orange	+	–	+	+	+	4
gri	grey	+	–	+	+	+	4
lacivert	dark blue	+	–	–	*	*	1 (3)
açık yeşil	light green	–	–	+	–	–	1
koyu yeşil	dark green	–	–	+	–	–	1
açık mavi	light blue	–	–	–	*	*	(2)

The terms with modifiers, for example *açık yeşil* "light green", *koyu yeşil* "dark green" and *açık mavi* "light blue" do not qualify as BCTs even though most of their values are high enough to suggest such a status. The first two passed only the naming task frequency criterion, while the third modified term, *açık mavi* "light blue", achieved dominance in the additional tiles.

6. Discussion

The position of *lacivert* "dark blue" as a probable candidate for basic status is fairly certain, but there has been some controversy over whether it should be considered the twelfth Turkish BCT. Özgen and Davies conclude their article by commenting that the safest conclusion is that Turkish has eleven BCTs: "Thus we have the unusual, but logically possible, case of a term being used with prevalence, consensus, and specificity, while at the same time being acknowledged as a subset of another term" (1998: 919). In contrast, Davies and Corbett's (1994) list and colour naming task results indicate that Russian has twelve BCTs, including *goluboj* "light blue", with Color-aid tile

BGB T3 attaining seventy-two percent consensus among subjects. The basicness of *goluboj* has also been convincingly argued by Paramei (2005).

The research done by Androulaki and colleagues (2006) on Modern Greek BCTs suggests that there are two terms for BLUE, including *γαλάζιο* (*galazio*) "light blue". After comparing the referents of three pairs of exceptional BLUE terms in Greek, Russian and Turkish, they claim that the main distinction between them is concerned with lightness:

> On average, *sinij* "dark blue" denotes darker colours than [blé] "blue", and *lacivert* "dark blue" is even darker. Comparing the Russian and Turkish terms to the landmark BLUE reveals that *goluboj* "light blue" has on average about the same lightness as BLUE but *mavi* on average is darker than BLUE.
>
> (Androulaki et al. 2006: 38)

This important role of lightness leads Androulaki and colleagues to suggest that "category formation involves the interaction of chromatic and achromatic mechanisms" (Androulaki et al. 2006: 39).

On the other hand, their research results in a reduced significance for the different stimuli employed (they used Munsell, Color-aid and NCS), and they report that "precise control over these variables [stimuli type, informants and illuminants] is not crucial in field studies aimed at establishing a language's BCTs" (Androulaki et al. 2006: 39). This can be seen as a small setback for this present research, as the most dominant tile for the Turkish *lacivert* "dark blue" was an additional tile attaining fifty-two percent consensus, while the standard tiles had a relatively low dominance of thirty-nine percent in the naming task.

Lacivert "dark blue" would have been considered basic by Özgen and Davies (1998), as it emerged as dominant in both list and colour naming tasks, were it not for the fact that, according to their third experiment, it violates Berlin and Kay's non-inclusion criterion. It is my belief that the position of *lacivert* remains that of a BCT candidate due to the low consensus in the colour naming task.

7. Conclusion

I consider the following eleven terms to be basic in Turkish: *yeşil* "green", *sarı* "yellow", *siyah* "black", *kırmızı* "red", *mavi* "blue", *beyaz* "white", *mor* "purple", *kahverengi* "brown", *pembe* "pink", *turuncu* "orange" and *gri* "grey".

As regards *lacivert* "dark blue", consensus in the colour naming task (either thirty-nine percent for BV HUE from a selection of sixty-five Color-aid tiles or fifty-two percent for tile B S3 from additional tiles) was unexpectedly low for it to be considered a fully-developed BCT. The low consensus in the colour naming task suggests that the claim for *lacivert* "dark blue" to be considered basic is not as firm as previously thought.

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Terms for red in Central Europe

An areal phenomenon in Hungarian and Czech

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In 1969 Brent Berlin and Paul Kay suggested that Hungarian may constitute an exception to their theory of universal BCCs by possessing 12 BCTs, including two basic reds. Recently some researchers have proposed that this is also true for Czech. These two genetically distant Central European languages were tested in large empirical-cognitive field studies in 2002, 2003 and 2007. The data collected show that both languages possess exactly 11 BCTs, including one basic term for red. However, it seems that the other term for red is culturally salient on a non-basic level. The puzzle of two salient terms for red could be best understood by drawing attention to the contextual impact on meaning, which is handled by examining syntagmatic and paradigmatic collocations. The case of the two colour terms may represent a unique areal phenomenon.

1. Introduction

In their classic study of 1969, Berlin and Kay proposed that Hungarian should be considered exceptional in having twelve BCTs instead of eleven, the number for most languages with a fully evolved colour system.[1] According to them, there were two BCTs denoting red, *piros* and *vörös* (usually translated into English as "light red" and "dark red"). Yet no thorough empirical tests with a sufficient number of native speakers had been conducted to support the claim. As has been discovered recently by applying different methods, there are exactly eleven BCTs in Hungarian, and only *piros* can be considered a basic term for red (see MacLaury, Almási & Kövecses 1997; Uusküla & Sutrop 2007; Uusküla 2008b). The research of MacLaury and his colleagues should be highly rated as they were the first to conduct field experiments with more than one native speaker of Hungarian (they had nine subjects, two men and seven

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women). They studied BCTs using Munsell colour stimuli and interpreted the results according to MacLaury's vantage theory (1997). They also asked nine female students about associations and collocations with *piros* and *vörös* (MacLaury et al. 1997: 76–77). They concluded that only *piros* can be regarded as a BCT and a general term for red (1997: 70).

Věra and Barbara Schmiedtová (2006) suggested that the Czech language also possesses twelve BCTs, including two basic terms for red – *rudý* and *červený*. Their study is based on an analysis of the Czech National Corpus and therefore does not incorporate field work. Until recently, no empirical field study with a large number of subjects had been carried out to establish the set and number of BCTs in Czech (cf. Uusküla 2008a).

The object of this article is to show that the question of two terms for red in Hungarian and Czech is complex and should be approached by considering a range of different factors.

2. Methods and data

The data were collected using the classical field method of Davies and Corbett (1994, 1995), with some additional suggestions made by Urmas Sutrop (2001, 2002).

All subjects completed three tasks:

1. A list task, where the subjects were asked to name as many colours as they knew.
2. The City University colour vision test was used to assess the subjects' ability to see colours (Fletcher 1980).
3. A colour-naming task involved sixty-five different colour squares shown to the subjects one at a time in sufficient daylight on a grey background. In 2003 fifteen additional tiles from the red-yellow and pink-purple region were shown to Hungarian subjects. The sequence of tiles was random for each subject. While indicating each colour tile, the experimenter asked the same question in Hungarian or Czech: "What do you call this colour?" All the answers were written down verbatim.

Three field trips were made to collect the data in order to be able to elicit the BCTs in the two languages, Hungarian and Czech, which were in contact for a long period of time. The two languages are genetically distinct. Hungarian belongs to the Finno-Ugric language family; Czech is an Indo-European language, classified in the Western branch of Slavonic languages.

The field work in Hungary was carried out in 2002 and 2003 in different regions: Budapest, Debrecen, Balassagyarmat, Győr, Pécs, etc. (Uusküla & Sutrop 2007, 2010). There was a total of 125 participants, sixty-six women and fifty-nine men, with a mean age of thirty-six years. In 2003 the naming task was conducted with fifteen additional tiles (sixty-five standard + fifteen additional = eighty tiles), with a sample group of

eighty-five subjects. The subjects were all native speakers of Hungarian with different dialectal backgrounds. The data for Czech colour terms were collected in Brno and Prague in the Czech Republic in 2007 (Uusküla 2008a). There was a total of fifty-two participants, thirty-three women and nineteen men, with a mean age of thirty-five years. The subjects were all native speakers of Czech, some having different dialect backgrounds. All interviews were conducted by the author in the native language of the subjects.

3. Hungarian and Czech BCTs with emphasis on red

Here the results are presented very briefly, concentrating on terms for red. Complete results have been published elsewhere (Uusküla & Sutrop 2007, 2010; Uusküla 2008a). The field work in Hungary yielded a total of 1148 different colour terms, while the field work in the Czech Republic provided 613 different colour terms. An analysis of the data clearly reveals that there is only one BCT for red both in Hungarian and in Czech. Both languages possess eleven standard BCTs; in Hungarian *fehér* "white", *fekete* "black", *piros* "red", *zöld* "green", *sárga* "yellow", *kék* "blue", *barna* "brown", *lila* "purple", *rózsaszín* "pink", *narancssárga* "orange" and *szürke* "grey"; and in Czech *bílá* "white", *černá* "black", *červená* "red", *žlutá* "yellow", *zelená* "green", *modrá* "blue", *hnědá* "brown", *oranžová* "orange", *fialová* "purple", *šedá* "grey" and *růžová* "pink". Here the Czech colour terms are written as feminine adjectives following Short (1993a: 526).

First, the Hungarian red terms will be briefly discussed. As the pilot interviews conducted in 2002 in Hungary with the standard sixty-five colour tiles did not show that *vörös* was a BCT, my colleague and I decided to complement the stimuli by adding fifteen extra tiles for the field work in 2003 in order to see if *vörös* would attain a basic status. The colour tiles added from the red spectrum were Life Red, ROR T1, RV S1, R S1, and R T1. In the list task, 123 subjects out of 125 mentioned the colour term *piros*, while only forty-three mentioned *vörös*: it was mentioned less often than some non-basic colour terms, e.g. *bordó* "bordeaux" (sixty-nine times), *citromsárga* "lemon yellow" (forty-nine times), *világoskék* "light blue" (forty-five times), and *sötétkék* "dark blue" (forty-four times). These results are similar to those of the elicitation task with ninety-eight native Hungarians carried out by Kiss and Forbes (2001: 194).

In addition to the frequency and mean position of a colour term, the cognitive salience index, which incorporates two parameters in the list task, was also calculated. The cognitive salience index was created by Urmas Sutrop (2001, 2002; see also Rätsep, 2011, Section 5.1). The index value was relatively high for *piros* (0.272) and low for *vörös* (0.019). The colour naming task results revealed that *vörös* could indicate red, dark red and/or light red, as it was randomly used to describe all red colour tiles (Uusküla & Sutrop 2010). In 2003 subjects were asked to name a total of eighty colour

tiles. Eighty-five subjects named eighty colour tiles, using the term *piros* on 210 occasions and *vörös* on nineteen occasions. In most cases, *piros* was applied to tiles RO (fifty-one times), ROR (forty-four times), ORO (twenty-two times), and R (sixteen times), while *vörös* was applied mostly to RO (five times) and ROR (three times). The colour of these tiles could be described as normal, not dark red (cf. Uusküla & Sutrop 2010). In short, there is only one red in Hungarian which fulfils the BCT criteria, namely *piros*. *Vörös* cannot be a BCT as its naming frequency was low in both list and colour naming tasks, and it was not part of the idiolects of all subjects. The concept of *vörös* seemed to be unclear, because there was no consensus among subjects as to what colour it actually referred to. MacLaury, Almási and Kövecses' findings indicated that *piros* could be regarded as a general name for red and *vörös* as a dark red (1997: 67–81). However, my field work results in Hungary showed that *vörös* does not indicate only dark red. Kiss and Forbes highlighted that twentieth-century political movements have influenced the usage of *vörös* (2001: 198). As various dictionaries state, *vörös* was and is still in use to indicate revolutionary left-wing parties and their symbols (see Kiss & Forbes 2001: 191–194 for entries of *piros* and *vörös* in different dictionaries).

The interviews in the Czech Republic were carried out with the standard set of sixty-five colour stimuli. The subjects named colour terms in both list and colour naming tasks in the feminine form, associating it with the noun *barva* "colour". In the list task, forty-five subjects out of fifty-two mentioned the colour term *červená*, while only nine mentioned *rudá*. In the colour naming task, *červená* was used on one hundred occasions, while *rudá* was elicited only three times from one male retired journalist, who used it to describe three purplish-red colour tiles (Uusküla 2008a: 24). In addition, the naming frequency for *rudá* in both tasks was extremely low, indicating that it rarely belonged to the subjects' idiolects. The data clearly reveals that only *červená* can be regarded as a BCT.

4. A note on etymology

The colour term *piros* derives from the stem *pír* "blush, ruddiness", and may be an onomatopoetic descriptive word with the denominal ending *-s* (Benkő, Kiss & Papp 1967: 206–208, 275). Synaesthetically, its sound refers to something burning or baking on an open fire. The colour term *piros* has no counterparts in other Uralic languages and it is therefore assumed that it might be a relatively new colour term. Originally *piros* indicated the colour of grilled meat or toasted bread; only later did it come to refer to the colour of blood (Benkő et al. 1967: 208). A native Hungarian is more likely to say "*a vér piros*" "blood is red" (not *vörös*) (De Bie-Kerékjártó 2003: 70). Some nouns and verbs derived from the stem *pír* are *pirosság* "redness", *pirul* "(to) blush", *pirkadat* "dawn", *pirít* "(to) toast, fry", *pirók* "finch", etc.

The root of the colour term *vörös* is probably *vér* "blood", and the form *véres* meant "bloody, covered with blood". Ancient Hungarians were a fisher-hunter tribe, used to

dealing with animal blood (Benkő et al. 1967: 1178; Sutrop 2002: 167). Over time the long vowel *é* in the first syllable was shortened to *e*, resulting in *veres*, which is still used synonymously with *vörös* in some Hungarian dialects. The Finno-Ugric word stem **wire* also denotes red in Finnic, Saami, Mordvin, Komi, Mari and Ugric languages (Hungarian, Khanty and Mansi) (Rédei 1998: 576; Futaky 1981: 49–50).

The Czech colour term *červený* is associated with the blood of the *Kermes vermilio* insect, which in ancient times was gathered to produce red dye for the dyeing of cloth (Machek 1957: 71). Its origin is Proto-Slavonic and the stem is found in numerous other contemporary Slavonic languages, e.g. Slovak *červený* "red", Polish *czerwony* "red", Upper Sorbian *čerwjeny* "red", Lower Sorbian *cerwjeny* "red" and Bulgarian *červen* "red". In English, the colour term *crimson* or *carmine* sometimes used to denote deep red also comes from *Kermes vermilio.*

The colour term *rudý* has its origins in the word indicating (iron) ore (Cz. *ruda* "ore") (Machek 1957: 426–427). The stem is Indo-European and widely used, e.g. English *red*, German *rot*, Lithuanian *raudona* and Latin *rufus*. The older colour term in Hungarian is *vörös*, while in Czech it is *červený*.

5. Collocations and connotations

It seems that the choice between two reds is conditioned more on the cognitive, emotional or collocational levels than on the basic one, depending on the particular context (cf. Lebedeva 1980–1981; Kiss & Forbes 2001; De Bie-Kerékjártó 2003; Kiss 2004; Schmiedtová & Schmiedtová 2006; Vaňková 2007; Uusküla 2008b; Uusküla & Sutrop 2010). Here it would be useful to refer to the semantic field theory of John Lyons (1995: 62), who states that the shared collocations could be discussed as paradigmatic collocations, while the collocations used with only one of the two words should be analysed as syntagmatic relationships between the colour word and its modifying noun (Lyons 1977: 230–269). It is not uncommon for the meaning of an expression to vary according to which of the two terms for red is used, e.g. *piros-fehér-zöld zászló* "Hungarian national tricolour", *vörös zászló* literally "red flag" – the flag of the former Soviet Union in Hungarian. (The same applies in Czech, where the collocation *rudý prapor* "red flag" describes the latter, whereas one of the colours included in the Czech national tricolour is *červená*.) Here the extensive field work of MacLaury and his colleagues (1997: 77) and Kiss & Forbes (2001: 194–197) should be acknowledged, as they asked their subjects about collocations and associations with *piros* and *vörös*. Henceforward, examples are taken from their work.

Some examples of Hungarian paradigmatic collocations are *piros/vörös rózsa* "red rose", *piros/vörös könyv* "red book", *piros/vörös toll* "red pen", *piros/vörös kabát* "red coat"; and in Czech *červené/rudé vlasy* "red hair", *červená/rudá tvář* "red cheek (the former referring to cold or health, and the latter to anger)", *červená/rudá růže* "red rose", etc. (Schmiedtová & Schmiedtová 2006; Vaňková 2007). However, in

Hungarian it is only possible to say *piros alma* "red apple", *piros cseresznye* "red cherry", *piros lámpa* "red lamp" and *piros pont* "red dot", but *vörös haj* "red hair", *vörös róka* "red fox", *vörös csillag* literally "red star" (a symbol of some former socialist countries), *vörös meggy* "red cherry", *Vörös tér* "Red Square", *vöröskáposzta* "red cabbage", *vörös bolygó* literally "red planet", Mars, *vöröskatona* "Red Soldier" and *vörös hadsereg* "Red Army".

In Czech the corresponding expressions are *červená květina* "red flower", *červené jablko* "red apple", *červené zelí* "red cabbage", *červená řepa* "beetroot", *červené rty* "red lips", *Červené pondělí* literally "Red Monday", Easter Monday, *rudý mak* "red poppy", *rudý bratr* literally "red brother", Red Indian, *rudý teror* "red terror", *Rudé náměstí* "Red Square", *rudoarmějec* "Red soldier", *Rudá armada* "Red Army", *rudá planeta* literally "red planet", Mars, etc.

It seems that the emotions causing someone to become red in the face also play an important role in the puzzle of two terms for red in Hungarian and Czech (see Vaňková 2007 for Czech). We can draw parallels between the two languages, as *piros* and *červená* are always connected to positive emotions, blushing, being healthy and so on, while *vörös* and *rudá* are connected with anger and other unpleasant emotions.

Based on the examples above, I propose the following groups:

1. expressions describing everyday objects, e.g. apple, cherry, flower, hair, lamp, etc.
2. terminological expressions (mainly connected to plant and animal names), e.g. red cabbage, beetroot, red fox, etc.
3. proper names
4. expressions motivated by an emotional state
5. metaphorical expressions.

It is always important to choose the right word to express oneself clearly without confusing one's conversation partner, as in most cases the two terms for red cannot be used interchangeably. Native speakers of Hungarian and Czech do it intuitively, whereas foreigners learning these languages have to be very careful to use the correct word for red in the appropriate context.

Considering the examples given above, it is possible to claim that Czech *rudý* corresponds to *vörös* in Hungarian, and yet this relationship is not as straightforward as it may seem. Beetroot in Czech is *červená řepa*; in Hungarian, however, it is *vörösrépa*, not **pirosrépa.* Red cabbage is, respectively, *červené zelí* and *vöröskáposzta*. There are expressions where these colour terms are used equivalently: Red Army is *Rudá armáda* and *vörös hadsereg* (spelled in accordance with local orthographic rules), Red soldier is *rudoarmějec* and *vöröskatona*, Planet Mars is *vörös bolygó* and *rudá planeta*, etc. It seems that collocations and associations play an important role in understanding the puzzle of the two terms for red.

6. The hypothesis: An areal phenomenon in Central Europe

I propose that the case of the two reds – one being basic and the other a culturally important salient non-BCT – may be an areal phenomenon. Hungarian and Czech share some grammatical and structural features, in addition to some evident parallels in the domains of semantics and vocabulary (cf. Skalička 1968; Futaky 1978; Thomas 2008). Helimski claims that these similarities are remnants of the political rule of the Hungarian kingdom in the Carpathian basin (2003: 159). It is commonly thought that the Carpathian linguistic area comprises Hungarian, Czech, Slovak, Slovene, Croatian and the Bavarian-Austrian dialect of German.

Let us imagine the map of Central Europe – the area some historians and political scientists prefer to call Eastern Europe or East Central Europe – with Hungary and the Czech Republic at its centre, and give a short overview of the history. The Slavic ancestors of Czechs and Slovaks 'appeared' in Czech and Slovak territories during the sixth or seventh century (Bideleux & Jeffries 2007: 135). At that time, the hilly western sections of the Hungarian plain and south-western Slovakia were a part of the Roman Empire as the province of Pannonia. Between 896 and 900 the ancestors of Hungarians, called Magyars after their leading tribe, took over the central Carpathian basin, Transdanubia, Slovakia, and Transylvania. As the political map of Central Europe developed, the emerging states were converted to Christianity: German-annexed Moravia in 929, Poland in 966, Hungary in 1000, and Hungarian-annexed Croatia in 1091 (Hodos 1999: 19).

During the Middle Ages, the area of our interest was divided into the kingdoms of Bohemia and Hungary (including some Slovak lands), and the Holy Roman Empire. The establishment of major cosmopolitan universities in Prague (1348), Vienna (1365) and Krakow (1400), the Hussite Reformation in fifteenth-century Bohemia, and translations of the Bible into the vernaculars in Bohemia and Hungary played important roles in Central Europe's cultural history (Bideleux & Jeffries 2007: 140–152). Hungarians owe their renaissance to King Mátyás Hunyadi (1458–1490), definitely one of Europe's most educated monarchs of the time, who laid the foundation for one of Europe's finest libraries, the Biblioteca Corvina, and invited (mainly Italian) humanists, artists and architects to live in Hungary. In 1465 the University of Pozsony/Bratislava was established. At the battle of Mohács in 1526, the Ottoman forces defeated the Hungarian forces and occupied a large area of the Hungarian Kingdom. At the same time, the Habsburgs claimed the vacant thrones of Hungary and Bohemia. The establishment of the dual monarchy of the Austro-Hungarian Empire, ruled by the house of Habsburg, in 1867 politically integrated almost the entire region: Austria, Hungary, Bohemia, Moravia and south-eastern Poland. Areas of Hungary, including present-day Slovakia, underwent strong 'Magyarization'. The independent state of Czechoslovakia was proclaimed in 1918, an act which was a remarkable novelty in the heart of Europe after the First World War (Evans 2007: 1). Slovakia had been part of Hungary without its own administrative region. The Treaty of Trianon in 1919 drew the southern border

much further south than the Slovak-Hungarian language border, consequently annexing fully Hungarian-populated areas to the newly created state (Lanstyák & Szabómihály 2005: 48). In 1945 at Yalta, an agreement on an east-west partition was reached. Beginning in 1948 communist dictatorships took control in East Central Europe, including Hungary, Poland and Czechoslovakia. Sovereign Slovak and Czech Republics were proclaimed in 1993 (the 'velvet divorce'), after political changes in 1989.

The history of Central Europe could be summed up in one sentence, aptly stated by Hodos: "Central Europe was born as a child of the West, who later married the East" (Hodos 1999: 19).

It should be clear from this short overview that, due to geographical closeness and lively historical contacts, the area of Central Europe became heterogeneous. As borders have been in a state of transition throughout history, people speaking one language can be separated into several groups when they remain in the areas of newly formed states; language contact between people living next to each other but speaking different languages is essential for their everyday communication. Because of that factor, the language structures and, especially, the vocabularies of neighbouring languages become similar. We can predict the formation of a linguistic area in Central Europe in the same way that the languages spoken near the Baltic Sea form the Circum-Baltic *Sprachbund* (Koptjevskaja-Tamm & Wälchli 2001). I therefore suggest that the phenomenon of two terms for red in Czech and Hungarian can be viewed in the context of areal linguistics, supported both by historical development and by linguistic evidence. It is a phenomenon which embraces a semantic domain of colour terms (cf. Koptjevskaja-Tamm & Rahkilina 2006 on the semantics of temperature adjectives in Russian and Swedish).

However, critics may claim that, in order to formulate an areal phenomenon, more languages should be involved. Slovak, for example, does not show any evidence of sharing the phenomenon, as it has only one term for red, *červená* (Short 1993b: 586). In Polish, which has one BCT for red, *czerwony*, the colour of hair or fur is described using the lexeme *rudy* "orange, ginger-coloured", e.g. *Ona jest ruda* "she is a redhead" or *rudy jak lis* "red as a fox" (personal communication with Polish native speakers). Clearly, more empirical field work should be carried out on the languages of the areas contiguous to Hungary and the Czech Republic in order to establish the hypothesis more thoroughly.

7. Conclusion

The results of the empirical-cognitive field work in Hungary and the Czech Republic provide clear evidence that these languages have a system with eleven BCTs. On the basis of these results, I believe that the puzzle of two salient terms for red in Hungarian and Czech cannot be explained on the basic term level, and therefore requires deeper semantic analysis, focusing on the contextual impact on meaning, where the examination

of collocations and connotations is critical. It is clear that the difference between the two terms for red lies more in collocational and emotional areas than in the basic one.

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SECTION 3

Colour in society

Preface to Section 3

One reason for the widespread interest in colour is that it impacts on so many areas of human experience. A number of papers at PICS08 explored different aspects of colour in present-day and earlier societies, with particular reference to people's perceptions of the world and of each other. The six papers in Section 3 draw on a range of disciplines, contributing insights from architecture, art, heraldry, literature, onomastics and semantics. Geographically, the studies are located in Britain, continental Europe and the United States; chronologically, they extend from the medieval period to the twenty-first century.

Two papers use the framework of cognitive semantics to investigate connotations associated with colour terminology. Jodi L. Sandford presents the results of a study designed to examine positive and negative connotations of the eleven BCTs in English, focusing on the dimension of *hue*. Her work is based on experimental data from fifty speakers of Present-Day American English. Anders Steinvall uses evidence from nineteenth-century travelogues to examine the connotations of non-basic colour terms. Since native speakers are often unfamiliar with the nuances of such terms, he argues that semantic precision in the colour domain would be achieved more effectively through the use of a BCT preceded by a qualifier. It therefore seems that the non-basic terms are selected more for their connotative effects than for precision of meaning.

Colour plays an important role not only in the natural but in the built environment, as Michel Cler demonstrates through an exploration of the distinction between colour and colour appearance in urban space. Arguing that both ancient cities and new towns present a chromatic landscape constantly changing in response to natural and artificial light conditions, shadows, activities and events, he examines ways in which the symbiosis between architectural environment and cultural context creates a dynamic network of meanings for urban colour appearances. Semiotic aspects of colour are also the topic of Nicholas Chare's paper on the paintings of the twentieth-century artist Francis Bacon. Close analysis of the techniques used in the application of pigment leads him to argue that it is through these techniques that Bacon is able to release the semiotic potential inherent in colour.

The two remaining papers in this section focus on colour and identity. Michael Huxtable discusses the heraldic blazons used not only to identify, but to symbolize the identity of, warriors from the late eleventh to the fifteenth centuries. Drawing on a range of texts including didactic and romantic poetry, historiography and treatises on heraldry, he traces developments in attitudes to armorial colours during the European

Middle Ages, and relates them to wider developments in the perceptual significance of colour in society. Also taking a diachronic approach, Ellen Bramwell shows that present-day bynaming practices can throw light on the historical evolution of surnames. Colour terms form a distinctive group of surnames in many parts of the world, generally referring to an aspect of the original name bearer's appearance. Evidence gained from interviews in a bilingual Scottish English/Scottish Gaelic speaking community in the Western Isles of Scotland throws new light on the motivations for such names, as well as suggesting revised interpretations for individual colour terms within the onomasticon.

Colours in the community

Surnames and bynames in Scottish society

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The hundred most common surnames in Scotland include seven colour terms. Surnames developed from bynames, as extra names given to individuals to distinguish them from others of the same name. Bynames are still in use within some communities, including in some areas of Scotland. By investigating how colours are used in bynaming in a present-day community and comparing this diachronically with the colour bynames from which some surnames originated, it is possible to gain an insight into how people use colours in naming more generally. Interviews were used to investigate bynames synchronically in a close-knit community in the Western Isles of Scotland. This is a bilingual community where both Scottish Gaelic and English are spoken. Gaining examples from interviews, rather than written records, allows for a firmer understanding of why these names were bestowed. This can contribute towards explaining why and how colours were assigned to people in the past.

1. Introduction

A number of Scottish surnames are based on colour terms.[1] Indeed, the hundred most common surnames in Scotland include seven colour terms: Brown, Reid, Gray, Black, Russell, White and Whyte (Bowie & Jackson 2003). This paper will discuss the issues surrounding this phenomenon, both from the diachronic perspective of surnames formed long ago, and from the synchronic perspective of bynames formed within living memory. The reasons for the origin of particular surnames are often opaque, and investigating the sources of modern bynames may help to elucidate this problem. The following discussion will take some tentative steps towards suggesting ways in which we might use contemporary onomastic research to investigate names from a historical perspective.

1. I would like to thank Professor Carole Hough both for suggestions for improvements to this paper and for her continued encouragement.

2. Bynames

Surnames developed from bynames, descriptive terms added to a personal name for purposes of identification. By adding more information, they make it possible to differentiate between two people with the same personal name, allowing them to be identified within their community or, often, by the establishment. Like surnames, these early bynames in Britain fall into four main categories: locative, familial, occupational and nicknames (Clark 1992a: 469–471; 1992b: 567). Locative bynames indicate a place associated with the name-bearer, whereas familial bynames name a relative, usually the name-bearer's father. Occupational bynames arose from the bearer's trade, and were particularly likely to be used if the occupation was important or distinctive. As McKinley (1990: 204) explains, "Some skilled crafts were distinctive because they were the work of only a few persons in any place and, consequently, were an obvious source of surnames. Smith is a case in point".[2] This idea of something being salient and therefore worthy of note is important in the concept of bynames and why they are given.

Nicknames identify people very strongly, generally being fairly idiosyncratic. This makes it difficult to identify the reasoning behind the naming when accessing historical records. However, it is possible to find some common threads and it is mainly in this category that colour terms are used uncompounded.[3] Physical descriptions of people tend towards being more uniform than many other nickname-derived surnames such as references to moral attributes or behavioral characteristics. Hair colour is a reasonably salient physical feature and there are a finite number of ways to describe it. Even now, English has the colour terms *white*, *grey*, *red*, *brown* and *black*, the general terms *fair* and *dark*, and the lexically-specific term *blonde*. Though speakers might sometimes use terms such as *brunette* and *auburn*, they rarely go beyond this. That people use a limited vocabulary to describe hair-colour is one of the reasons that surnames denoting colour are common, as many people will have been denoted by the same colour. Surnames arose through bynames being passed on to subsequent generations, and it is from these origins that hereditary surnames, such as Brown, developed.

3. Surnames

Surnames were imported to Britain after the Norman Conquest, with the introduction of names and naming practices from the continent (Clark 1992b: 553; McKinlay 1990: 28). Already during the late Anglo-Saxon period, a few names had become disproportionately popular in England (Clark 1992b: 552), and, under Norman influence, a small pool of continental forenames came to be used for the majority of children.

2. Smith is the most common surname in Scotland as well as in England and Wales (Dunkling 1995: 141).

3. Not under consideration here are locative surnames from place-names, such as Blackwood, or occupational surnames containing colour terms, such as Whitesmith "tin smith".

Because of this, a single name no longer sufficed for identification, and as a result a description was added. At first, these were literally descriptive and not hereditary, but later a name would begin to be passed down through generations and may have survived to this day as a modern surname.

4. Scottish surnames

There were, and still are, differences in surnaming between different parts of Scotland. Surnames in the Lowlands arose in a similar way to that just discussed, though later than in England, and were influenced by Norman and English nobles who already had surnames and who had been granted land in Scotland in the twelfth century. These surnames slowly became hereditary and their use spread through society. McKinley (1990: 46) suggests that this process was not complete in Scots-speaking areas until the sixteenth century. The Lowlands were, during the surnaming period, Scots rather than Scottish Gaelic-speaking.

Surnames in the Highlands and Islands of Scotland were established not only at different times from the Lowlands, but also in a different way and in a different language. Residents of these areas were Gaelic-speaking and lived in clans – familial, tribal groupings – under a common clan chief until the eighteenth and nineteenth centuries. Hough (2003: 35) describes names beginning with the prefix *Mac*, meaning "son", followed by the father's name, as being "The prototypical Highland surname": examples are MacDonald from *Mac a' Dhomhnaill* "son of Donald" and MacKay from *Mac Aoidh* "son of Hugh". Many clans-people took on the name of their clan as their hereditary surname. So a MacIntosh or *Mac an Toisich* "son of the chieftain" took that name because he was considered part of the clan MacIntosh, not necessarily because one of his ancestors had possessed that byname. Many of these names were later anglicized or translated on emigration to the Lowlands, and this creates fresh problems in looking at Scottish surnames, as will be discussed below.

5. Present-day bynames

Bynames have been replaced by surnames throughout Britain but continue to be used unofficially in some areas. This is particularly common where a limited number of names are used within the population, as is the case in parts of the Western Isles of Scotland. I conducted research in an island community which had formerly been a part of the MacDonald clan area (Bramwell 2007). As a result of the clan affiliation, a large number of the inhabitants still bear this surname. In the area studied, the four most common surnames account for 50% of the population. This percentage is

substantially higher than in most other areas of Scotland (Bowie & Jackson 2003). The stock of masculine personal names traditionally used in this area is also small, so that men are particularly likely to have the same name. If many people in a community share the same name then how can they be identified easily and quickly? The answer is in a very similar manner to centuries earlier in other parts of the British Isles, when surnames were being formed.

The research was carried out in a rural community within the Western Isles with a population of over three hundred. I had insider status in this community and used local contacts to recruit informants for the study. Data were obtained through interviews with male and female local informants whose ages ranged from eighteen to over seventy.

Though most bynames in the area consisted of patronymics, such as *Uilleam Chaluim Seonaidh* "William son of Calum John", or local bynames, such as *Eardsaidh t-Seanna Bhaile* "Archie who lives at Old Township", there were also some which referenced the name-bearer's appearance using a colour term.

These findings tie in well with anthropological research which has investigated bynaming on a small scale in close-knit societies (e.g. Antoun 1968; Brandes 1975; Breen 1982), as well as with a large-scale study by Alford (1988) which compared naming strategies in sixty diverse societies around the world and found similar byname categories. It seemed reasonable that research in this bilingual Gaelic-English community might yield insights which could be applied more widely to historical study.

6. Colour terms

The remainder of this paper will examine issues around the colours represented in the top one hundred surnames in Scotland. Some of these colours are represented by more than one surname (e.g. White and Whyte, Reid and Russell). 1881 Census data give the distribution of these surnames. They show that particular terms are more prevalent in Scotland than in other parts of Britain, but more importantly help to establish that colour terms are a significant part of the anthroponymicon in Scotland.

6.1 Brown

The surname Brown is currently the second most common in Scotland, after Smith (Bowie & Jackson 2003). Surname dictionaries trace its origin to a nickname denoting brown hair, a brown complexion or brown clothing (Hanks & Hodges 1988: 78–79). This, however, is problematic if we accept that bynames must have something salient about them to make a particular characteristic stand out as notable. Brown hair in the Scottish population, unless it has changed markedly in the past several centuries, would not be a distinctive feature. In the present-day study area in the Western Isles,

there were no people with the byname *donn* or the English equivalent *brown*. In the most authoritative dictionary of Scottish surnames, Black (1946: 107) traces the name back to an Old English personal name *Brun* from the adjective *brūn* "brown" or "dark-red". More research would have to be carried out to determine whether the reflex of this Anglo-Saxon personal name was in common usage in Scotland around the twelfth to sixteenth centuries, though it seems unlikely. However, as an adjective, *brūn* is confirmed as having this range of colours by the *Dictionary of Old English* (DOE). This information does raise the possibility that the term could still have been used for a dark red in Scotland during the surnaming period, in which case the hair colour would certainly be distinctive.

An alternative possibility is that the term was used in these bynames not primarily for hair colour, but for a tanned complexion. This suggestion is supported by DOE's definition of *brūn* as used to describe a person who is dark-skinned. The problem remains, though, why the name is *so* common, being the second most popular in Scotland, if it does not describe anything which is very distinctive. The answer could lie in the fact that there were many opportunities to give someone this byname. If there were two men named James in a community, it would have been likely that one had brown hair or was tanned and he may have been named for this feature. It would not have been necessary for a byname to distinguish a bearer from the entire community, simply from those who shared a common forename.

This colour term was also transmitted through a Norman family, *Le Brun*, who possessed estates in Northern England after the Norman Conquest (Black 1946: 107). Another source of the name, illustrating the tensions and interplay between Scots and Gaelic society, is the name *Mac a' Bhruthainn*, meaning "son of the judge". Many Gaelic surnames were anglicized or translated, either as a tool for easier integration for emigrating Highlanders or for official purposes, where Gaelic names were generally rendered into English. *Mac a' Bhruthainn*, as one example, was either anglicized partially to MacBrayne or completely to Brown and so some instances of the name Brown are not from colour terms at all (Dwelly [1902–1912] 2001: 1008, 1020; Mark 2003: 719). This illustrates another difficulty in working with surname etymology: even colour terms which appear at first glance semantically clear can be misleading.

In short, a person with the surname Brown may have had an ancestor with brown hair, with dark skin, who was a Norman or who was a Gael. Brown seems to have had a wide range of origins and this could be another reason why the surname occurs with such frequency in the Scottish population.

6.2 Red

Red hair or a red complexion are far more distinctive features than brown, though of course the red of hair is not identical to other uses of the colour term. An early byname

has developed into the surname Reid in Scots, and this features prominently in the Scottish Corpus of Text and Speech (see Anderson 2011). The same colour has also given us the surname Russell, probably derived from French *rous* "red" (Black 1946: 704–705). These competing forms were both first recorded around the same time in Scotland, in the late twelfth and early thirteenth centuries. Reid is the eleventh most common surname in Scotland, while Russell is the forty-seventh. Black (1946: 687–688, 704) gives the following earliest quotations: "Ade Ruffus witnessed resignation of the lands of Ingilbristoun in 1204" [Reid here is latinized to Rufus]; "Gilbert 'le Rede' of Coul was committed to prison and died there in 1296"; "Walter Russell witnessed a charter...to the Abbey of Paisley, c.1164–77". The 1881 Census distributions show that Reid and Russell are not restricted to particular parts of Scotland, which suggests that these forms may have been used in parallel. That one is French-derived might support this.

In the Western Isles data, the most common colour byname was one containing a red colour term. This is *ruadh*, though the term for red in Gaelic is actually *dearg*, with *ruadh* being more of a reddish-brown. Mark (2003: s.v. *ruadh, ruaidhe*) gives the examples "*Dòmhnall Ruadh* red-haired Donald", but also "*pàipear ruadh* brown paper". Through interviews, I was able to establish that the *ruadh* bynames in the Western Isles study all denoted hair colour, rather than complexion. There was also one example of an English colour byname for red hair in *Anne-Marie Ginge* and another from outside the immediate study area, *Willie Red*. These two individuals were younger than the *ruadh* examples, who were all over forty. As English is more prevalent amongst the younger population, this may explain why these terms were preferred to *ruadh*.

As the upper classes in medieval Scotland were more likely to speak French, it is possible that Russell might have proliferated as a term for red hair amongst the aristocracy, with Reid as the Scots term. If not, it is also plausible that they might have been used for slightly different contexts or colouring, or that many people acquired the surname Russell through tenancy or other affiliation and that it was only used as a descriptive term by a very few people. It is possible for a surname to proliferate from even a single ancestor.

6.3 Fair/Grey

The surnames White, Whyte and Gray are all in the top hundred surnames in Scotland, in positions sixty-seven, ninety-seven and twenty-five respectively. However, there does not appear to be an obvious candidate designating blonde hair. This is unlikely to be because being fair-haired was unremarkable. In the Western Isles study, the term *bàn*, Gaelic for "fair", was used several times as a byname signifying hair colour, for example in *Mairi Bhàn* "fair-haired Mairi". This word led to the surname Bain in northern Scotland, though it is not represented in the top hundred. Being blonde *does* seem to be something that people deem worthy of comment in Scotland, though it might

not be in countries where blonde hair is more common. It might therefore be expected that there would be a surname corresponding to this.

It also seems strange that there would be colour terms for both white and grey, unless these were being used for different domains. In present-day usage they can be employed almost interchangeably for hair colour. The surname Gray is generally glossed as coming from a byname for grey hair-colour (Hanks & Hodges 1988: 223; Reaney & Wilson 1997: 203). However, Black (1946: 325) proposes an alternative origin, that of a French place-name brought over to Scotland as a surname. *A Dictionary of the Older Scottish Tongue* (DOST) does have several examples of *gray* used for grey hair, so it is not far-fetched to imagine that it could be used as a colour term in a byname. As with other surnames, it may come from more than one origin. In the Western Isles data, there was one individual known as *Domhnall Glas* "grey Donald". His hair had started going grey when he was very young, which could explain the byname. The term *glas* was used here rather than *liath*, the traditional Gaelic word for grey hair. *Glas* has traditionally occupied a range from green to grey, while *liath* is from blue to grey, including hair colour (Mark 2003: s.vv. *glas*, *-aise*; *liath, lèithe*). However, interview data confirmed that the term *glas* was definitely given to this man because of his hair colour, and *glas* is routinely used in this community to mean "grey".

This still leaves the problem of where the Scots blonde might be. Even if Gray does not come from hair, it seems unlikely that White would mean greying hair. The Western Isles study indicated that these names are given when the name-bearer is fairly young, and the names are either forgotten and quickly replaced or they stick with the bearer through life. It would be very unusual for bynames to be given when a bearer is elderly and has become white-haired, not least because other members of his or her generation will presumably also be turning grey. Surname dictionaries generally accept that White comes from a nickname for someone with white hair or an unusually pale complexion (Hanks & Hodges 1988: 573).

However, it could be the missing colour term for fair hair. DOST has an entry for *Quhite* as "white or grey haired; fair-haired, and in to-names". To-name is another term for byname. The use of *quhite* "white" for fair hair seems possible, then. One of the quotations under this definition describes: "Quhyte [*Asl.* With] hair as gold kemmit and sched abak; Henr. *Test. Cress.* 222 (Ch.)", which roughly translates as "white hair as gold combed and cast back". *White* then could mean "blonde" during the surnaming period, making it possible to hypothesize that this is where the Scottish blonde surname is. This hypothesis is also supported by a suggestion that the byname White used in England could mean "fair" or "blonde" (Potter 1950: 148).

White or Whyte can also be a translation of the Gaelic surname *MacGille bhàin* / *Mac'IlleBhàin*, which literally means "son of the fair lad or servant" (Dwelly [1902–1912] 2001: 1030; Mark 2003: 719). That it is translated in this way suggests an established understanding that *white* could mean "fair".

The surnames White, Whyte and Gray, as with Brown, did not necessarily spring each from one source. It is very possible that some instances of the name Gray originate from a French place-name whilst others were given as colour bynames. Some instances of White and Whyte may have been bestowed in Scots, whilst others were translated from Gaelic. These names may well have proliferated from multiple origins.

6.4 Black

The surname Black is the forty-sixth most common in Scotland. Some surname dictionaries have Black as originating from nicknames for a swarthy or dark-haired man (Hanks & Hodges 1988: 54). Reaney & Wilson (1997: 46) discuss the story of Wilfricus Niger, who was given that byname in the eleventh century because he blackened his face with charcoal to avoid detection by his enemies. This ties in very nicely with an example of the byname *dubh,* Gaelic for "black", in the Western Isles study, by which a man was designated not because of his hair colour, but because of an accumulation of dirt. Kaufman (2008) discusses the historical evidence for a Spanish mercenary in the sixteenth century, Sir Pedro Negro, having had dark skin; contextual information is seen as crucial to deciphering whether the name came from a descriptive byname or a hereditary surname.

7. Conclusion

Taken together, these examples show why it is important to have as much evidence as possible when dealing with surnames and bynames. It is easy to over-simplify the material to suggest that there is always only one likely answer as to where a name comes from and what it meant to those who bestowed and bore it. This is often not the case and such complexity must be appreciated in order to investigate the origins of names more fully. Clark (1983: 70) makes the important distinction between the dictionary-meaning of a word used as a byname and the actual sense in which it is used in the name. Evidence from the present day, where people are still here to ask about name etymologies, can be important in trying to explain what might motivate people to give a certain name. They can help us to develop a little more understanding, through the onomastic evidence, of how colours were used to describe people in Scottish communities centuries ago.

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Hues and cries

Francis Bacon's use of colour

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This chapter examines the use of colour in Francis Bacon's paintings, focusing particularly on *Head VI* (1949) and the neglected *Triptych* (1977). The chapter will demonstrate how Julia Kristeva's ideas about colour and language, developed in the context of Early Renaissance art, are equally applicable to Bacon's paintings. They provide a valuable explanation for the artist's rich palette and his often unusual techniques. Kristeva's ideas also reveal how Bacon's chromatics can be understood to trigger memories of the early stages of psychic life. The chapter concludes by suggesting that Bacon's approach to colour should be understood as contributing to the expression of a sexuality for which no pre-existing visual rhetoric was available.

1. Primary colours: Giotto's joy

Julia Kristeva's essay "Giotto's Joy" was first published in English (in the United States) in 1980, and in the United Kingdom in 1981 (Kristeva 1981b).[1] Along with another Kristeva essay "Motherhood According to Giovanni Bellini" (Kristeva 1981c), it is described by Adrian Rifkin, during a discussion with Stephen Bann, as a work which "we as art historians turn to again and rethink, and read very carefully and as such, [is] very important to the practice of art and to that of art history" (Bann 1998: 77). Rifkin goes on to question whether art history has actually assimilated the lessons that Kristeva's work offers. At present the answer would seem to be not. The readings of Giotto di Bondone's use of colour in two fresco cycles that Kristeva develops in "Giotto's Joy" have not been adopted in other art historical contexts. As will be demonstrated here, however, the ideas advanced in that essay can be illuminating when employed in a Modern Art context. Firstly, however, a brief summary of the main arguments put forward in the essay on Giotto will be provided.

1. I would like to thank the Leverhulme Trust for their generous support during my research on this topic.

"Giotto's Joy" forms an extended analysis of Giotto's fresco cycles at the Basilica of St Francis in Assisi (c.1297–1305) and the Arena Chapel in Padua (1305–1308). In the essay, Kristeva tracks the way in which the drives, those internal pressures that direct us towards particular aims, such as aggression or procreation, become translated into coloured surfaces. The drives are described by Freud as being at the borderline between the psyche and the soma (Freud 1991: 83). Kristeva concurs with this, calling them "energy charges as well as psychical marks" (Kristeva 1984: 25). They are formed from forces within the body that seek satisfaction without. These marked energies – composed of ideas entwined with affects or moods – act as representatives of bodily pressures within the psychic apparatus. They speak for the body in thought.

In "Giotto's Joy" Kristeva suggests that the drives also speak for the body through colour in painting. Colour carries the energetic pressure of the drives within it. This vital dimension to the chromatic leads Kristeva to suggest that any linguistic analysis of the meaning of colouration in painting which is premised on a transposition of descriptive words to the visual field will rapidly encounter its limits. It is not possible to explain colour in terms of units of language, as phonemes, morphemes and lexemes (Kristeva 1981b: 216).

For Kristeva, because of the inadequacy of words when confronted by the chromatic, any investigation of colour should be economic rather than structural in nature. It should proceed by way of an analysis of increases and decreases of energy within pictures rather than by reducing pictures to unitary grids of meaning. According to this understanding, a painting should be understood as a field of pressures meshed with a system of signs. Colour as pressure, as drive, is inserted into paintings "under the impact of censorship as a sign in a system of representation" (Kristeva 1981b: 219). The drives are censored in the sense that they are erased by the signs representing them in the communicative system that is picture-making. In Kristeva's conception of language, the drives form the underside to the symbolic. The symbolic, painting's grammar and syntax, resides in contour, in delineation, in what shapes subject-matter and contains the semiotic (an aspect of which is embodied in painting by the drive-invested material that is colour).

There is a need to repress colour because it poses a potential threat to the subject. As an expression of the semiotic it is too resonant of what Jacques Lacan calls the Real. The Real refers to the undifferentiated state of existence experienced by a child prior to its entry into language. As a bodying within language, the semiotic carries traces of this time before language. It is a time in which lack is absent as words have not separated the child from things, there are no discrete forms and experience is unmediated. The semiotic constitutes a mnemonic trace of this moment: the prehistory of the subject that was maternal plenitude. As Griselda Pollock explains:

> psychologically, because we were all, men and women alike, once nurtured within the body of a feminine other, we carry, unknown to our conscious selves, deep, physical, tactile sensation memories of interiority and connectivity that must by definition be shapeless and formless. (Pollock 2007: 226)

In the absence of a symbolic counterbalance to the semiotic this memory would become too forceful: the subject would be too much of the Real and would fall into psychosis. It is for this reason that colour, which should be conceived of as semiotic excess, requires policing.

Kristeva explains that colour is linked to primary narcissism which occurs in the early stages of infancy when there is subject-object indeterminacy. Colours therefore possess the capacity to carry the subject back to its psychic beginnings. It acts as a troubling reminder of the fragility that ultimately underlies the self. Colour perception probably precedes the eye's capacity for centred vision: the eye's ability to perceive objects like the speculative I in what Lacan calls the mirror-stage (Kristeva 1981b: 225). This is the stage where the child first begins to recognize itself as an entity discrete from its mother. Before this phase of psychic life, however, the infant will already be registering colours with short wavelengths such as blue, a colour used extensively by Giotto in the Arena Chapel. For Kristeva, colours of all wavelengths (but blue in particular) potentially "have a noncentered or decentering effect, lessening both object identification and phenomenal fixation". This means that they return the subject to a moment "before the fixed, specular 'I,' but while in the process of becoming this 'I' by breaking away from instinctual, biological (and also maternal) dependence" (Kristeva 1981b: 225). The experience of colour therefore prompts a moment of unbecoming: unsettling the self and acting as a reminder of its fragile foundations.

2. A kind of blue

Blue is therefore potentially a particularly perturbing colour for the spectator dependent upon its treatment by a painter. In the 1950s the backgrounds to Bacon's paintings were frequently composed of "very diluted dark blue or black paint" (Sylvester 1993: 195). The eight papal portraits from 1953 which Bacon rapidly produced after completing *Study after Velázquez's Portrait of Pope Innocent X* (1953, Nathan Emory Coffin Collection, Des Moines Art Center) provide examples of this choice of ground. These canvases, which each depict enthroned popes, were given an initial thin wash of navy blue or black paint. The painter then worked out the portraits against this dark background. The popes wear blue, or in the case of *Study for Portrait 1* (1953, Collection Denise and Andrew Saul, New York), bluish purple robes, with white collars. The paintings each have similar settings, "spare, deep, dark interior spaces defined by sketchy white recessional lines that culminate in rear walls parallel to the picture plane"

(Davies 2001: 14). The white lines frequently meet up, forming rectangles. The backgrounds of the portraits exhibit blocks of delineated, seemingly uniform, colour.

Line, which recurs as a motif in the papal portraits, is a visual equivalent of syntax in painting. It operates on the side of the symbolic. It can constitute a system for ordering forms, functioning to produce and regulate shapes and spaces. As outline, it frequently operates to describe colour. It distributes colour throughout a picture, managing the work's semiotic economy. The expanses of colour in the papal portraits pose a potential threat to the subject but the danger appears to be minimized by the action of line which orders this chromatic content.

Line is, however, paradoxically itself composed of colour. The painter "uses drawings and lines, but he coats them, suffuses them with coloured matter so that they break away from strictly chromatic differentiation" (Kristeva 1981b: 231). Line separates colour, seeks to present colours as distinct units, yet it accomplishes this separation by way of colour and cannot detach itself from colouration. This means there is no outside to the chromatic, which always overspreads its borders. It is this absence of boundaries which line strives to repress. The success of line as a form of repression must, however, always be provisional given that it is constituted out of the very material it seeks to inhibit. Colour always waits as the disavowed underside to line.

On close inspection the dark blocks of colour produced by line in the papal portraits, the background colour given contour and ostensibly contained by the thin white recessional lines and the thick gold lines of the papal thrones, literally overrun those lines. The white and gold paint does not entirely cover the colour of the ground beneath, which is merely muted by the later applications of paint. Under close analysis the blocks of colour also lack uniformity. The symbolic functions through discretion and achieves communication through the reasoned placement of discrete signifiers. Colour is indiscrete, it refuses singularity. The absence of uniformity within *a* colour prevents it from forming *a* signifier. Bacon was attuned to the indiscreteness that characterizes colour and indeed painting in general.

This indiscretion was fostered by way of Bacon's frequent use of impasto. The technique of creating a thick layering of paint impacted upon the colour. In the *Interaction of Color*, Josef Albers remarks on the way that traces of the tools of painting within paintings act to vary the density and intensity of colours (Albers 1975: 7). The chance aspect to the encounter between brush and canvas, the contingency which nestles in the bristles, carries into the colour. A thick stroke of paint with a large brush will leave an uneven trail of pigment. This unevenness occurs especially in Bacon's paintings as he used a coarse-grained brown canvas and, from 1948 onwards, employed the rougher, unprimed side for his works (Hammer 2005: 51; Harrison 2005: 41). This meant that the more abrasively toothed surface of the canvas would bite the paint, holding it better. The rough surface, however, also meant that the medium had to travel across deeper interstices in the weave of the canvas.

The phenomenon is particularly apparent in an early work like *Head VI* (1949, Arts Council Collection, Hayward Gallery, London). The thick sweeps of black and

grey paint that form the notional backdrop or ground for this screaming figure often begin at the top of the canvas. They initially often entirely cover over the weave of the canvas in a block of black or grey paint but the pigment held by the brush soon becomes too thin to sustain this and more and more of the canvas remains uncovered. The paint begins to adhere to only the roughest sections of the warp and weft. The gradual decrease in the volume of pigment as the eye travels the length of these downstrokes makes it appear that colour is lighter towards the end of each stroke. The paint is less dense in places, hence the colour appears less dense. Colour is interrupted by the canvas. In those areas where it is most visible, such as the bottom left of the painting, the canvas also does not appear to have an even colour. This is probably the result both of real changes in the surface colour of the hemp and of the effect of texture upon the perception of the tan surface. The unevenness produces thin shadows which make some areas appear darker than others.

The meeting of one brushstroke of one colour with another of a different colour during the making of a painting will also produce contingent effects. If the initial dab of paint is not dry, then a commingling will occur and the canvas will become a proxy mixing palette. If the dab is dry, then it may well not be covered entirely by the second dab and will show through it. A thick stroke of paint is ridged like the weave of the canvas. A second stroke will seep into the furrows of the first leaving its ridges exposed to view. The brush can also accumulate wet paint from the canvas which, for Bacon, means that "one end of the brush may be filled with another colour and the pressing of the brush, by accident, makes a mark which gives a resonance to the other marks" (Sylvester 1993: 121). The brush itself can become not merely a carrier of colour but also a producer. It develops into a site in which colours meet and mingle becoming *impure*. Alternatively, if there is a thin underlay of dry paint, the tooth of the canvas may still influence the way a second overlay of paint behaves. There are therefore various ways in which Bacon achieves an unevenness of colour. It is the implications of this unevenness in relation to the language of colour that will now be considered through a close study of a relatively neglected work by Bacon, *Triptych* (1977, Private Collection).

3. Colour on colour

Triptych from 1977 consists of three panels (see Figure 1). The left panel depicts the artist's studio. The central panel is of his bed. The right panel is a self-portrait. The foreground of the left panel shows detritus on the floor of Bacon's studio. There is what looks like two discarded canvases resting on what might be newspaper or magazines. The forms are deliberately indistinct. This is a representation of a studio given through suggestion rather than in detail. In the background shelves can be seen. They are white in colour but stained by blue and red paint. On the top shelf a large, round mirror is balanced. Its silvering is rendered as cobalt blue. In front of the mirror are several jars or tins containing paintbrushes. The shelf below holds books or folders that have been

Figure 1. Francis Bacon, *Triptych*, 1977, oil on canvas (private collection). © The Estate of Francis Bacon. All rights reserved. DACS 2011

laid flat and also possibly small canvases. Underneath this, another shelf is shown but its contents are obscured by darkness. Resting against these shelves on the right hand side is a canvas the back of which faces the spectator. In front of it is an expanse of white cloth which also appears paint-stained. A thin rectangle of black pigment runs the length of the left-side of the canvas. It probably represents the door to the studio.

The central panel shows more objects in disorder in the mid-ground. Some of these appear to be lying on a yellow tabletop. Beneath the table is a piece of brightly coloured material, a blanket which is green, red and yellow in colour. There is another section of textile, a white sheet, visible behind it. The items on the table, which are mauve, rust-red and white in colour, could be magazines or photographs. In the background of the picture is a dark green semi-circular shadow outlined against a paler green ground. This shadow represents a bed-rest. Bacon's real bed at the time of his death did not have one. The rest in the triptych foregrounds the fact that this work is intended as homage to Vincent van Gogh's painting *Vincent's Bedroom in Arles* (1888, Rijksmuseum Vincent van Gogh, Amsterdam).

The right panel is a self-portrait of the artist. His hair, strangely as Bacon had brown hair, appears blond. It is possible, however, that the artist was working from a photograph and therefore that the yellow paint has been used to represent the way a light source from above bleached out his hair's real colour. The bottom half of the face has been impressed by fabric soaked in pigment, leaving a series of parallel black and red lines. This enhances the work's tactile effects (Chare 2009a: 683). Bacon is wearing a tailor-made shirt which also features in several other portraits including *Self-Portrait* (1972, Gilbert de Botton Collection, Switzerland), *Three Studies for Self-Portrait* (1973, Private Collection) and *Study for Self-Portrait* (1981, Von der Heydt Museum, Wuppertal). The artist is also shown wearing this shirt in real life in a series of photographs of the studio taken by Michael Holtz in 1974. It is patterned with blue, white and pink streaks which look like stripes of oil-paint. When wearing this, Bacon is dressed in, or as, a canvas. It provides an example of what Alistair O'Neill describes as

"the artist impregnating his dress with the materiality of his studio" (O'Neill 2007: 111). The shirt provides a means of carrying paint beyond the private space of the studio, which is often understood as separate from the world that surrounds it (Chare 2006: 85). A black rectangle, similar in scale to that in the panel showing the studio, runs the length of the left side of the canvas. This suggests that Bacon has chosen to portray himself in his place of work.

The three panels are united by a series of hollow circles of white paint. These were made by applying the lid or base of a paint-pot dipped in pigment onto the canvas. The likelihood is that the panels were therefore impressed with metonymic traces of the container that held the material out of which the work came to be made. There are three circles of similar size in the left panel, two in the top right corner and one at the middle left of the composition. There is also a smaller circle near the centre of the work. In the central panel there are two circles of comparable size to the three larger circles in the left panel. These are located near the centre of the picture and just over mid-way up the far left of the canvas. In the right panel a circle of similar size to the five larger circles in the two other panels is present in the middle of the artist's face, bisecting his nose.

These rings of paint are non-figurative. They are *just* circles of white paint. In this sense the circles are comparable to the patch of red paint that Georges Didi-Huberman discusses in Jan Vermeer's *The Lacemaker* (c.1669–70, Louvre, Paris). Didi-Huberman suggests that this trickle of vermilion is "strictly speaking, *unidentifiable*, other than to say it is painting in action" (Didi-Huberman 1989: 155). He goes on to state that "its form is dominated by its matter" (155). This is paint that is self-referential. The run of red in *The Lacemaker* and the white circles in *Triptych* are, however, not evacuated of significance. Paint is always conjoined with colour. It stands for and with it. When he imprints these white circles across the triptych and when he paints paint-stains on the shelves in the left panel of the triptych, Bacon offers the spectator paint that is not present to figure something else but which is portraying itself. The paint additionally signals colours that can ostensibly easily be identified by the English words *white, blue* and *red*. This would, however, be an example of linguistic oppression. Language subjugates when it divides and conquers physical experience, rendering chromatic sensations in singular terms.

This subjugation by language can be seen at work in the earlier description of *Triptych*. The blanket on the bed in the central panel, for example, was described as green, red and yellow in colour. The reduction to three words of the colours seen does not do justice to actual perception. There are, for example, traces of mauve, of pink, and of light blue present. This further chromatic division, however, whilst more nuanced, still fails to account for the shifts within each *individual* colour. The shifts could be described as hues or shades of particular colours but such an approach would carry within it a tacit acceptance that the singular is always already multiple. To write of degrees of a particular colour is actually to concede that there never is *a* particular colour. Colour is inconstant.

This variable quality of colour has already been referred to in the discussion of the chromatics of eight papal portraits from 1953. Bacon also works hard to expose it in the right panel of *Triptych*. The ridges of colour created in the late stages of the panel's composition by impressing the portrait with paint-soaked textile work to fracture the pre-existing applications of colour, to destroy any sense of their being blocks or expanses. The thin tendrils of 'pink' pigment that have been impressed across the artist's lips also fracture into darker and lighter areas because of their delicacy. These meagre lines are stutters of colour. They falter in the face of a language which is insufficient to register the slight differences within and between them. In instances such as this Bacon takes the eye to the edge of the language of colour and then beyond to an economic appreciation of intensity. He cultivates a look that is infantile but not primitive, an engaging of sight, of visual sensation in its full complexity.

That *Triptych* can be read in this way is suggested by Bacon's use of Letraset in the left and central panels. Letraset is a letter-transferring system which allows black alpha-numeric characters to be rubbed from a translucent sheet onto another surface. These characters, or fragments of them, appear in significant quantities across the two panels. They are senseless. The characters are included to reinforce that *Triptych* is about the disruption of language at the level of colour. The rich palette, when coupled with techniques such as the imprinting of textiles wet with pigment upon parts of both the right and central panels, operates to reveal how the intensities and subtleties that inhabit fields of colour surpass the capacity of a linguistic signifier to contain them. Words are too basic to capture colour in its own intense terms.

4. Conclusion: pain in colour

Kristeva's theories of colour provide a way to describe and explain how Bacon creates this intense chromatic viewing experience in which the semiotic underside to language must be confronted. To understand the artist's motivation for engendering a state of psychic anxiety in the spectator, however, it is necessary to consider the influence Bacon's sexuality had upon his art practice. Michael Peppiatt has argued that "it would be true to say that, at one level or another, much of what is painted is a projection of sadomasochistic practices" (Peppiatt 2008: 71–72). It can be argued that this projection extends to the artist's chromatics.

Bacon's approach to colour formed part of a broader project designed "to articulate sexual practices for which no pre-existing visual rhetoric was available" (Chare 2009b: 265). The perturbing blue backgrounds of Bacon's papal portraits should be seen as sadistic, callous in conception. The absence of line here forms a kind of calculated sensory-deprivation. It is against this cold backdrop that Bacon situates, isolates, his figures. The spectator identifies with these figures, depicted in their varying states of dissolution, sharing the unnerving sensation of a loss of boundaries.

In this context, it must be remembered that Bacon deliberately chose to display his paintings behind glass. He suggested that spectators gained something from seeing their own reflection in his pictures (Alley & Rothenstein 1964: 19). What they acquired was the sense of being surrounded by Bacon's backgrounds. The viewers of one of the papal portraits find themselves enclosed by the blue colour field. They see themselves *in* colour. It is colour of the most troubling kind, prompting memories of the time before their entry into the psychic safe-haven of language. Bacon's palette makes for painful viewing.

In *The Body in Pain*, Elaine Scarry describes pain as an assault upon language. She describes intense physical pain as "language-destroying" (Scarry 1985: 35). Bacon's use of chromatics produces similar effects, rupturing the symbolic aspect of language and liberating its drive-invested semiotic underside. This causes psychic distress. The artist's use of colour should be characterized as an expression of sadism. This is not simply because of the sensory-deprivation engendered by the blue fields. The way Bacon contrasts colour fields containing minimal chromatic variation with expanses of brushwork that are characterized by massive colouristic confrontation is also key here.

Georges Bataille claimed that because art-making proceeds by way of destruction (of the blank canvas or the pristine sheet of paper) the libidinal drives it liberates are sadistic (Bataille 2005: 41). Bacon's disruption of constant colour, his destruction of fields of perceived evenness and unity of tone, can be similarly interpreted as symptomatic of a release of aggressive impulses. The artist's violent treatment of colour, one that generates psychic anxiety in spectators when they are confronted by his works, should be seen as a further manifestation of the projection of sadomasochistic habits into his art practice that Peppiatt identified. The work of Kristeva allows us to understand what the psychic implications of this projection are for the viewer.

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Colour appearance in urban chromatic studies

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Making distinctions between *colour* and *colour appearance* is essential in exploring the chromatic qualities applied to and in urban and architectural space. As a chromatic landscape, the atmosphere of any urban space is a process of the ongoing construction, deconstruction and reconstruction of 'colour appearance/shadow' which is performed through and upon buildings, volumes, spaces, voids, vegetation, and networks of various systems of activities and events, including those of the city's inhabitants. Considering the diversity of colour appearances and their ephemeral, semi-permanent and permanent aspects, chromatic studies of any particular context need to be built upon aspects of the geographical environment as well as upon issues related to the cultural context and the social memory. Dealing with various environmental concerns in combination with diverse ways of life and cultures requires both openness and a focused approach. In our contemporary age of globalization, addressing culturally and contextually determined chromatic concerns is especially challenging.

1. Contextual relativity of colours

Talking about colour is the act of naming, explaining and interpreting what belongs to the field of individual and visual perception. Colour perception is associated with and related to the senses of touch, hearing, taste and smell. In addition, colour perception is complemented by memory and knowledge of colour, and by the practice of receiving and transmitting information, as well as conceiving and reproducing images.

Colours constitute a true vocabulary demonstrated by the ways in which they are commonly used or found. This not only provides information to be deciphered, similar to words, but also gives colours an inherent purpose. Colours are introduced into practice, and evolve and disappear according to the signification and symbolic meaning attributed to them by different groups of people in different cultural contexts and sites. Therefore the understanding of the contextual relativity of colours is critically important in understanding their purpose and meaning.

In this sense, urban chromatic studies or the colour treatment in architecture and urbanism can be understood and approached as either a structuring of matter or a structuring of space. Considered as the structuring of matter, the colours of materials and their textures determine urbanscape through its various surfaces, which receive, collect, absorb, reflect and diffuse light. These materials can be categorized as mineral, for example brick; vegetal, for example wood; natural, for example stone; and artificial, for example translucent methacrylate. Among these diverse kinds, some material colours are highly ambiguous, such as those of water or glass. Other material colours, as used in coatings, paints and distempers, are easy to realize, but are more fragile and thereby more temporary. These then often serve to support meanings that evolve with the development of a particular way of life and its underlying culture. For instance, old walls often show different layers of paint that have been applied and have then deteriorated over time. In an archaeological sense, we can then see how colour preferences have changed.

On the other hand, colour treatment in urbanscape as a structuring of space deals with qualities and effects of different spatial elements such as volumes, conglomerates and assemblages. In this way, each of the individual spatial elements of the whole can itself belong to a different kind of colour context with a different origin and specific historical evolution. This means that each spatial element can have a different vital rhythm. Some of these contexts of colour as a spatial element are perennial, well-known and have established parameters through geographical and physical constraints. Other contexts are more ephemeral, existing through human presence and influence, such as political, cultural, social, economic and technical developments.

Our particular point of view is a fusion of these two approaches, namely understanding the colour treatment of urbanscape as both a structuring of matter and a structuring of space. This approach enables a kind of equilibrium of the so-called natural and the built or manmade. It means that our method addresses colour appearance, as well as a range of information on colour and its organization.

2. Colour appearance

The appearance of a material varies according to its textural quality, treatment of the surface, and light and shade conditions. It depends on rather uncontrollable factors and countless variables, for example the constantly moving sun or the more stationary animation of artificial light. As a kind of final frontier, normally de-materialized, fallow nocturnal spaces can be newly cultivated through artificial light. As cyclic movement in regular rhythms or through other durations, coloured light can be used to complete or manipulate the appearances of coloured materials. In addition, shade enwraps volumes and projected shadows situate the more-or-less distorted volumes in space. In ancient city cores, as well as in new urban developments, a variety of different

colours or the totality of colour/colour appearance, related to a chain of notions such as material/texture/surface, distance, light/shadow, and natural light/artificial light, are the composite traces representing the quintessence of the way of life of a district as a whole, the representation of the identity of the city itself. As a chromatic landscape, the atmosphere of any urban space is a process of the ongoing construction, deconstruction and reconstruction of these features which is performed through and upon buildings, spaces, vegetation and networks of various systems of activities and events, including those of the city's inhabitants.

Colour appearances are, in addition, always deciphered as signs. Yet colour appearances are also always interpreted differently according to the social and cultural nature of the context, as well as the personal characteristics and experiences of the interpreter. Some of the resulting meanings are seemingly permanent, while others are more ephemeral.

2.1 Material, texture and surface

Making distinctions between *colour* and *colour appearance* is essential in exploring the chromatic qualities applied to and in urban and architectural space. In effect, it is not the colour of a material that we see, but its colour appearance. Furthermore, the appearance of the material varies according to the treatment of the surface. For example, a surface with a thick coating can be smooth, scraped, crushed or sprayed. The colour appearance of surface applications also depends on factors rather beyond our control, such as atmospheric humidity or the quantity of water used in the mixture. Paint can be applied with a matt, satin or glossy finish, and stone can be rough or fine, granulated or polished, dressed with a comb-hammer (*layée*) or chiselled. In short, depending on its surface texture and finish, a material will appear to be a different colour. For instance, while a polished surface produces varying degrees of reflectivity, a matt or opaque surface is ideal for the display of shadow. This effect can be observed in paint where a black and red striped pattern is painted on a surface. With specular highlights, a glossy black surface becomes white, while a matt red one fades away. Under these specific conditions the colour combination of black and red is no longer visible. In the case of stone, a surface processed to a high-gloss finish is flat and smooth and its colour appears darker and richer than one with a lesser degree of sheen; for example, a sand-blasted finish will appear lighter in colour. Colour appearance, therefore, is determined not only by light and shade conditions but also by the type and quality of the finish of a material. Inter-reflections can also play an important role in architecture. Sometimes they are unpredictable, like the reflections of a red awning or a sunshade on a light-coloured concrete parapet. In general, we can say that the material of a building plays an important role in the conception and perception of architecture and urban space. Depending on the surface quality, the volume of a building may dissolve, disintegrate or even disappear by reflecting its surroundings, or it may stand out as a volume.

In architecture, new chromatic and visually interesting possibilities are also being continuously developed through ongoing research. Some results include the introduction of different chromatic effects and special finishes and of particular materials, as well as the creation of new aspects through extending and improving building materials in general. For instance, concrete is no longer just grey, but can be very light grey tending to white, extremely deep grey tending to black, earthy-coloured, like yellow ochre or burnt sienna tending to luminous red, and so on. By using the material in different ways, such as using different sizes, using contrasting aggregates, like those of dark granite, rose-coloured quartz/porphyry or golden-coloured limestone, or by combining smooth and exposed aggregate finishes, a variety of effects can be achieved.

However, among these diverse kinds of materials, glass can be highly ambiguous. A mirror-glass facade is much more than a simple protective wrap; it can function not only to define but also to hide the interior, reflecting the surrounds. Here the gaze is hindered from penetrating into the interior. However, a glass facade with maximal transparency is permeable between the internal and external, and completely dissolves the architecture.

Colour appearance sets up a determinant range of possible visual results which predetermine meanings and interpretations. Therefore, colour appearance cannot simply be transferred systematically to another material as colour, but the interaction of the various properties determining colour appearance has to be considered.

2.2 Distance

During both day and night we are surrounded and affected by what we believe to be the inherent colour of various kinds of materials, such as wood, stone or water. Colour appears, however, only when we are looking at an object that is directly or indirectly in contact with some form of light. Only then can our eyes and brain receive and interpret the electromagnetic wavelengths of reflected light and thereby sensually and mentally construct the appropriate colour appearance. In this sense, our perception of colour is based in a world of inescapable illusions. Pigmented matter changes its appearance according to both natural and manmade light. The variables are countless; for example, the nature of light depends upon the course of the day, the season, and the geographical position relative to the angle of incidence of sunlight. What is then the physically true colour identity of an object? One way of precisely specifying such a colour is colorimetry, which is rigorously independent of the variations of light and the receptor's perception. The Natural Colour System (NCS) provides a second way of specifying colour identity, and is a system based solely on defining the visual quality of

a colour, namely its appearance.[1] Both ways of defining and identifying colour are useful according to the function and situation in which they are applied.

Some examples will show how drastically colour appearance can change under the influence of light. For instance, looking at two pictures of a church taken on the same day but at different times, namely in the bright morning and in the evening, we may ask, "Which colour appearance is nearest to the colour of the real building?" Another example is that of a mountainous landscape. With increasing distance from the mountains, the colour appearance of their planes becomes less saturated and increasingly shifts to blue. Such an everyday experience is verified with colour samples in an NCS study in which green begins to shift to blue at a distance of several hundred metres (Hård & Hård 1991; Sivik & Hård 1977).

Another striking example of how distance changes colour appearance is demonstrated by a series of photographs in my possession of a village in the M'Zab Valley in southern Algeria. Perfectly adapted to the arid desert environment, at a distance of three to four kilometres the colour appearance of this conglomerate of traditional human habitations becomes less saturated, and shifts to white against the golden and reddish ochre mineral landscape, with its slightly purplish sky in the background. The closer we approach, the more chromatic differences appear, until soft ochre and light blue buildings are visible. From the distance, this broad chromatic diversity had blurred into a light ochre off-white. Therefore, in order to better insert individual architecture into a site, it is important to consider such respective colour shifts of distance in chromatic studies for urban spaces. The better the chromatic insertion, the greater is the evoked harmony of all elements in the space. In fact, such a harmonious colour scheme can actually be conceived by 'borrowing' from the colour appearance of the surrounding distant landscape, a traditional strategy developed and applied by Japanese architects and landscape architects.

1. The Natural Colour System (NCS) is a perceptual colour model developed by the Scandinavian Colour Institute (Skandinaviska Färginstitutet AB) of Stockholm, Sweden. It is based on the six elementary colour percepts of human vision as described by Ewald Hering's opponent colour theory of 1878. The three opponent pairs are white-black, red-green and yellow-blue. All other perceptual colours are composites defined in terms of these six colours. This means that the appearance of a colour can be described via its NCS notation. The amount of blackness (darkness), chromaticity (saturation), and a percentage of two adjacent elementary colours (hue) are the three NCS parameters. The percentage of blackness and chromaticity are added up to less than or equal to 100% and give the amount of whiteness (lightness). The NCS is represented as a double cone whose upper tip is white and lower black. At the circumference of the cones' basis is located the colour circle. This system is useful for matching colours and colour combinations as well as for communicating about colour.

2.3 Light and shadow

As a fundamental condition of colour appearance, light not only enables the reflection of electromagnetic wavelengths, but also the casting of shadows. Although shadow is often seen as a disturbing and upsetting element in contemporary architectural photography, and in architectural design in general, the sense of colour appearance and the chromatic fluctuations of shadow play an essential role in the perception of space in architecture and urbanism. How important shadow is to capture and comprehend the visual world is illustrated by a sphere. What would a sphere be without shade? It would lose its third dimension and become a circular plane, a two-dimensional geometric figure. Thus shadow gives depth to bodies and spaces. Shadow exists, dematerialized, elusive and intangible. Shadows are fugitive, changing, unstable, shifting, appearing and disappearing. Shadow seems not to belong to the real world; however, it is there, inseparable from its body and source of light, adapting to physical environments. Thus shadows are large or small, distorted or precise. Shadow belongs to human existence. An Indian story tells of a princess who is able to recognize her beloved among five suitors because of his shadow. As deities, the four pretenders could take on exactly the same human shape as her fiancé, but they could not cast a human shadow.

Although the natural progression of the sun is our primary means of structuring time, the exact movement of the sun is not perceptible to the naked eye. Technical aids, such as film, are necessary for such an observation. However, sunrise and sunset are special times of day through which the progression of the sun is nearly always noticeable. The actual duration of dawn and twilight, however, varies considerably according to the distance of any concrete location from the equator. For example, in the tropics, the transition of sunrise from night to day and of sunset from day to night is rapid, and appears as a sudden, dramatic change. Here insects mark the transition, creating a sonorous space which replaces the visual one. On the other hand, in countries near the Poles, as in northern Scandinavia, the long, slow transitions at dawn or twilight can occur for several weeks or even months. In mid-latitudes, with their temperate climates, transitions are more perceptible to the eye, and weather conditions there can especially influence the duration of dawn or twilight, for example clouds can shorten them.

The darkness of night is itself only a big shadow, a kind of regular shade provided by the earth. Writing about the effects of light, the Italian Renaissance painter Leon Battista Alberti observed that shadows vary considerably according to the source of light. For example, shadows are larger than the body when light is coming from a small source, such as a fire or lamp, since the rays are not parallel but divergent.

A world unto itself, night darkness fosters richly ambiguous re-definitions of colour appearance and space. Under decreasing light conditions, the peak of the vision curve shifts to values of short wavelengths, that is to the blue end of the visible spectrum. This means that sensitivity to longer wavelength colours, such as red, is more or less lost. General sensitivity to light, however, is increased as the human eye adapts to the changing level of light. In more technical terms, referring to the physiology of the eye, the

activity of the cones switches to rod activity. Amplified or reduced, blurred or distorted, simplified or submerged in a quilted atmosphere, in the darkness of night volumes, forms and dimensions, as well as colours, all appear and are perceived differently.

Reflected as moonlight, indirect sunlight varies in intensity according to its own trajectory, either blurring or sharpening the field of vision. As the night progresses, this light changes from greenish-yellow to greenish-blue.

2.4 Natural and artificial light

In both urban and natural micro-sites, the dark 'sculpture of obscurity' has been modified by artificial light, revealing new spatial and chromatic aspects. Some consider any artificial light cast by cities as a kind of pollution of the 'virgin' field of nocturnal space, while others find beauty and purpose in restructuring this same field through artificial light. For example, at night a whole range of colour projections can produce images upon the facade of a Romanesque or Gothic church. In this way, sculptures can be dressed with symbolic colours which fade away with the dawn as sunlight emerges to chase away nocturnal phantoms and reveal a facade of bare stone. The absence of colour leads to an absence of energy. In some cultures, this low energy becomes the norm: medium grey eventually tends to white. In such a context, any other kind of colour is a scandal. The cathedrals were once painted in polychrome, but now bare stone is much more attractive!

The colour effects of new facades have become, for example, huge screens changing colours via digital programmes, or transparent glass membranes have become media screens with fluctuating colours. Facades that rapidly change colour while projecting large-format advertisements, however, not only have an irritating effect on people, but also proclaim the 'death' or 'end' of urban space. This negative example points to the underlying and dramatic trend in architecture to create new screen-like facades whose effects in urbanistic terms are often unconsidered.

3. Colour appearance and cities' identities

Considering the richness and diversity of colour appearances and their ephemeral as well as their semi-permanent and permanent aspects, chromatic studies of any particular context need to be built upon aspects of the geographical environment as well as upon issues related to the cultural context and social memory. Dealing with various environmental concerns in combination with diverse ways of life and cultures requires both openness and a focused approach.

In our contemporary age of globalization, addressing culturally and contextually determined colour concerns is especially challenging. In general, ancient or historically meaningful districts are preserved in order to ensure the continuity of a chromatic

tradition, thus risking zero evolution. Some cities are built with local materials giving a specific chromatic appearance. Aix-en-Provence appears golden ochre, Clermont-Ferrand dark purplish, and Thionville is constructed with rosy sandstone from the Vosges. Paris has its own chromatic appearance with ranges of pale to middle yellow ochre from the limestone taken from quarries underneath the city, or from 'fake' materials to match the natural stone. Every city has its own dominant colour appearance. Urbanscape is a place of representation. Sometimes it is the field and support for the manipulation of all kinds of colour and visual signs. Effective colour treatment in urban space is achieved through the careful consideration of how colour communicates; that is, how it plays a key role in determining the overall kind of image(s) that is/are in harmony with traditional elements.

Certainly, the special qualities of unique locations need to be carefully considered. However, often a kind of protective regionalism means that 'tradition' is used to promote formal fetishism, a kind of historic compensation of an individual's or group's viewpoint in a particular time period. As a result, a kind of colour range is reconstructed according to a set of colours which is believed to be traditional, despite its lack of content and evocations. Should 'tradition' not be better understood as a more open state of mind, capable of changing and adapting to a diversity of contexts, light conditions and ways of life?

In some cultures there is not only sensitivity to, but also even a desire for, colour. Colour is applied beyond its function to inform. A special vocabulary is developed to express the culture itself. Other cultures, however, seem to aim in the opposite direction. Colour is disempowered. Even the word *colour* itself is dematerialized. Neutralized, colour becomes a pale, practical matter of covering over – mere merchandise.

The loss of colour is, of course, an important consideration in chromatic studies. It can occur as the result of a wide variety of conditions such as developments related to materials. For example, some pigments might become unavailable due to ecological sanctions such as the protection of the environment. Other losses of colour stem from legal limitations and stipulations which suppress the market. For example, an industrialist is selling a product and a technique, but never 'colour'. As a result, the necessary protection is not available to ensure that colours are cultivated and maintained. Further, urban regulations requiring conformity, as well as the interventions of architects concerned with the cultural heritage in France, lead to the loss of specific ranges of historical colours, because of the many historical layers of colour coatings, as well as the use of new building materials with different appearances. And, finally, the failure on the part of intervening professionals to recognize and acknowledge the different kinds of colour context plays an important role.

Today we have a large variety of materials from which to choose. More fully exercising this opportunity of choice would permit the strengthening and encouraging of geographical and cultural variations, as well as of various diurnal and nocturnal aspects. Could it be, however, that the very number and diversity of possible choices form obstacles to the use of the vocabulary of light/material/colour appearance? Could

it be that part of the problem is that we have a shortage of meanings to accord to colour? Could it be that the shortage is so extreme that we are compelled to become necrophagous followers, unwilling commemorators of colour as a merely traditional artefact? And, as we lose the energy of a variety of hues and values, we de-incarnate, so that colour is becoming but a thing of the past in urban architecture. Indeed, colour is a *diablerie*: that is, it is magically diabolic, since colour always suggests variety, chaos and cacophony. Therefore using colour is mostly related to questions of power, as in cultural heritage, colour standards, colours associated with national identification, brand colours, colours representing security, and so on. Thus identifying and naming colours remains a delicate thing to do.

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Aspects of armorial colours and their perception in medieval literature

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This article builds on work previously published (Huxtable 2006: 199–217) to explore three key aspects of the interpretation of armorial colours as written in texts of different genres from the twelfth to fifteenth centuries. These key aspects are: (1) the use of a didactic theological discourse that had emerged in the late eleventh century and was concerned with the 'spiritual' nature of knighthood (viewing it as a military wing of the priesthood); (2) the use of ideas gleaned from the period's natural philosophy, concerned with the nature of colour as material (that is, derived from the elemental qualities of bodies); and (3) the use of a creative mode in which complex symbolic and allegorical models of identity could be composed.

1. Introduction

Medieval heraldic and chivalric writings offer a relatively unexplored genre of texts that are of considerable interest for the historical study of colour language and theory.[1] In part they establish a specific code for colour – the restricted language of blazon[2] – that

1. Recent references to armorial colours and language include Anderson (2003: 181–190); Gage (1993: 80–91); Pastoureau (2000: 55–63); Pleij (2002: 24–25; 80–85).

2. Blazon typically makes use of five basic colour and two metal terms in which all blues are *azure*, all greens *vert*, all reds *gules*, all purples *purpure*, black *sable*, white or silver *argent*, and gold or yellow *or*. There are also two fur terms: *ermine* and *vair*. The oldest Roll of Arms in England, the Glover's Roll (compiled about 1254 but known to us through the copy made by Robert Glover, Somerset Herald, in 1586), mentions only three colours: *goules* (red), *azur* (blue) and *sable* (black), and two furs: *veree* (squirrel) and *ermyn* (stoat) (Wagner 1960: 18). The fourteenth-century *Tractatis de Armis* of Johannis de Bado cites four colours and two metals: black, blue, red, green, silver and gold, based upon the four elements and four colours of the rainbow. The colour *purpill* is mentioned as a fifth and *tawny* is discussed as a French phenomenon in the early fifteenth century (Johannis de Bado in Jones 1943: 215) by a writer also calling himself John Vade but not believed to be the same person as De Bado.

includes a set of function-specific colour terms derived from French that carry specific semantic resonances into romance and other literature; and further these texts present a long and varied discourse concerned with armorial interpretation that invests the act of visual recognition with complex evaluations of secular and spiritual identity and cultural meaning. This paper focuses on the literary context of a selection of armorial writings from the twelfth to fifteenth centuries in order to present aspects of their semantic construction and use of chromatic symbolism. In summary, the paper suggests that early heraldic and chivalric texts show three literary dimensions: (1) the use of a didactic theological discourse that had emerged in the late eleventh century and was concerned with the 'spiritual' nature of knighthood, viewing it as a military wing of the priesthood; (2) the use of ideas gleaned from the natural philosophy of the period that was concerned with the nature of colour as material (that is, derived from the elemental qualities of bodies); and (3) the use of the period's dominant creative literary mode in which complex allegorical representations of identity were composed, utilizing classical and biblical sources to achieve dynamic symbolic resonances for the design and perception of colours and devices on the painted shield. These broad literary aspects (and their combinations) by which armorial displays were described and interpreted by the informed 'period eye' are mediated to modern readers by a vast array of surviving documents that includes tournament rolls, chronicles, treatises, commentaries and poems (see further Huxtable 2008: 148–245).

2. Heraldry and the herald

The phenomenon of heraldry arose in the eleventh century in relation to the emergence of the herald, and with it came an increased significance of armorial displays in medieval society. There was nothing created *ex nihilo* in medieval European heraldry – world history is replete with cultures and civilizations that have visually encoded their warriors (and still do) for the purposes of battlefield recognition, rank decoration, intimidation of the enemy and genealogical identification.[3] References to national and tribal banners, family emblems and individualized military tokens abound in world literature, testimony to the cultural and social significance that such items have held. The significant development in the use and perception of armory that occurred from the late eleventh century onwards was the establishment of 'scientific' systems for armorial description and interpretation that were capable of far more articulation and sophistication in meaning than had been attempted previously. Visual tokens that incorporated meaningful colours thus emerged as an orderly, pan-societal system for

3. An arguable exception is the (apparently) non-militarized people of the ancient Indus valley civilization of the third to second millennium B.C. Few bronze weapons have been discovered, although some fortified settlements indicate a defensive capability (see Kenoyer 1998).

the projection of the social elites' type-identities, heritage, and individual status differentiations.

The earliest appearance of 'heralds' – that is, of those having a public role in part fulfilling the tasks of identifying, interpreting and recording armorial devices – is in the French poems of the late twelfth and early thirteenth centuries. Numerous references bear witness to a new breed of courtier that appeared in relation to changing aristocratic practices and interests.[4] Chrétien de Troyes encapsulates the idea of the new type of servant or follower in his romance of *Yvain* (c.1177). Here Sir Kay discusses the difference between cowards and heroes and concludes that it is reasonable for the coward to boast about his own deeds because:

> S'il ne le dit, qui le dira?
> Tant se teisent d'ax li hira
> Qui des vaillanz crïent le ban,
> Et les malvés gietent au van... (Chrétien de Troyes 1994c:lines 2204–2207)
> [If he doesn't speak of it, who will? Everybody keeps quiet on the subject, even the herald, who calls the names of the valiant but ignores cowards.]

This type of supporter or hanger-on (*li hira*) made his presence felt at tournaments by proclaiming the names and achievements of the participating nobles. Further, according to Chrétien's Sir Kay, such men reserved their efforts for the benefit of the *vaillanz* 'valiant ones'. For a brave knight to praise himself would be unbearable according to the ideals of chivalry, but the coward had to praise himself because no one else would do it for him – hence a herald was, or at least was supposed to be, a speaker of 'true worth'. Kay's comment therefore offers a precursory glimpse of the authority heralds would later hold in matters of armory and chivalry.

Chrétien's late twelfth-century romances also provide what is generally accepted to be the earliest mention and description of an individual connected with the term 'herald' who recognises 'true' knighthood, although ironically this does not transpire from his knowledge of armorial bearings. In *Le Chevalier de la Charette* (c.1176), Lancelot is spotted by a "fellow in his shirt-sleeves, a herald-at-arms (*hyraut d'armes*), who had left his coat and shoes as a pledge at the tavern and come rushing in, barefoot and in a general state of undress" (Chrétien de Troyes 1994b: lines 5545–50).[5] Chrétien's treatment of this new phenomenon does not, however, yield an armorial expert. The scruffy herald-at-arms fails to discern Lancelot's identity from his shield: he is "unable

4. Wagner (1960: 127–135) gives further examples of early heralds and their activities, including instances from Jakemes' *Le Romain du Castelain de Couci et de la dame de Fayel* and Meyer's *L'Histoire de Guillaume le Maréchal*.

5. "A tant ez vos un garnemant, /Un hyraut d'armes, an chemise, Qui an la taverne avoit mise/ Sa cote avoec sa chauceüre, /Et vint nuz piez grant aleüre, /Desafublez contre le vant". The scene is given a contemporary airing in the film *A Knight's Tale* (2001), but one which conflates medieval history to present the naked herald as Geoffrey Chaucer before he started writing.

to recognize it or tell who owned it or who was to bear it" (lines 5546–95).[6] And yet later on he is able to recognize the knight when he sees him in person, and this despite his wearing borrowed arms in order to obscure his identity; the herald rushes off to announce: "Now the one who will take their measure has arrived!" (lines 5573–4).[7] Chrétien's first literary herald was thus, if no expert in armory, a supporter and communicator who was concerned with the 'true' identity of a knight at a time when the means of identification was his prowess in combat established via the tournament system – that is, within a hierarchy of knights derived from their conduct and performance during a series of personal combats.

The herald's role as a go-between and communicator also appears to have been related to the business of official public boasting and to have arisen in response to the specific circumstances of an increasingly public event: the tournament.[8] Before the twelfth century there is little mention of tournaments or jousts or similar behaviour in the surviving literature; however, Geoffrey of Monmouth's description of some variety of public fighting game in his *Historia regum Britanniae* (c.1136) allows us the view that the Church's antipathy towards this violent pastime was less influential by the mid twelfth century – enough at least for explicit references to be made to it in a prestigious work. Just before Geoffrey's mention of the instigation of a 'simulachrum' of a fight on horseback, he refers to a proto-system of armorial displays which, though mirrored by the ladies of the court, did not include any heralds or 'herald-like' officials:

> Quicumque uero famosus probitate miles in eadem erat. Unius coloris uestibus atque armis utebatur. Facete etiam mulieres consimilia indumenta habentes.
>
> (Geoffrey of Monmouth 2007:ix.14)
>
> [Every knight in the country who was in any way famed for his bravery wore livery and armour showing his own distinctive colour; and women of fashion often displayed the same colours.]

This system appears unsophisticated and informal, so as not to have required administration by officials or specialists. Its underlying logic, which was exploited and refined by romance writers, seems clear and functional: in times of peace as well as war, a knight needed his own colours to distinguish him in public from his peers so that his tournament and jousting achievements could be recognized and remembered and wider renown generated. Association with a particular colour was a matter of reflected prestige for an entourage, and the wearing of a knight's identifying colour a means by which a sympathetic lady or aspiring courtier might communicate interest or proffer allegiance to a publicly identifiable individual. Geoffrey's lines do not suggest, however,

6. "L'escu trova a l'uis devant, /Si l'esgarda; mes ne pot ester/Qu'il coneüst lui ne son mestre, /Ne set qui porter le devoit".

7. "Or est venuz qui l'aunera!/Or est venuz qui l'aunera!"

8. The English term derives from the French *tourné* 'turn', which would occur before a cavalry charge. See Keen (1984: 83–101) for an overview of the rise of tournaments and their culture.

that a one-to-one colour correspondence was established between knights and individual ladies of court – the possibility remained for more than one to wear the colour of the same knight, as was the case for an entourage. Again, there is no suggestion that such displays of colour in any way reflected the dynastic aspect of a knight's identity.

The important genealogical element in the development of systematic armorial significance (that is, hereditary uses of devices and rules for 'differencing' between members and generations of the same family sharing a coat of arms) can also, however, be traced back to the early twelfth century. Evidence is provided by sources such as John of Marmoutier's life of Geoffrey Plantagenet, Count of Anjou, written about 1170, in which is described his ceremonial knighting by Henry I of England in 1127. Here Geoffrey is given a shield which bears 'golden lioncels'. As Wagner has shown (1960: 16), "Geoffrey's bastard grandson, William Longespee, Earl of Salisbury, later bore these same arms, while his own son, William Fitz Empress, the younger brother of Henry II, who died in 1163, bore a single lion". By the time of the English Glover Roll (of Arms), compiled about 1254 and containing two hundred and eighteen coats of arms of lords and knights from all over the country, blood-line and heritage had come to inform armorial displays as a clear mode of visual definition.

3. Colouring chivalric identity

The ideological aspect of medieval knighthood, in both secular and spiritual terms, was of increasing cultural significance from the twelfth to fourteenth centuries and entailed a new set of approaches to armorial colouring and its perception. Three influential sources were Cistercian St Bernard of Clairvaux's *De laude novae militae* (c.1130), the anonymously authored *L'Ordene de chevalerie* (c.1178–9), and Catalan theologian Ramon Lull's *Le libre de l'orde de cavalleria* (c.1280). In a tract praising the new order of Temple knights at Jerusalem, Bernard of Clairvaux gave a polarized interpretation of appearance values for knights in which armorial bearings were deemed to be either indicative of shameful, overweening pride or, if simple and plain, indicative of purity, humility and faith.[9] His ideal form of knighthood was a militarized order of monk-like warriors dedicated to fighting the Church's battles against unrighteousness and the enemies of Christ. Bernard reduced the colourful armorial displays of 'worldly' knights to the vainglorious boastings of a sinful nature, and perceived in their costly brightness and visual impact only evidence of a damnable effeminacy and spiritual weakness:

> Quis ergo, o milites, hic tam stupendus error, quis furor hic tam non ferendus, tantis sumptibus ac laboribus militare, stipendiis vero nullis, nisi aut mortis, aut criminis? Operitis equos sericis, et pendulos nescio quos panniculos loricis superinduitis; depingitis hastas, clypeos et sellas; frena et calcaria auro et argento,

9. Cistercian attitudes towards colour and ornamentation are discussed in Duby (1979).

> gemmisque circumornatis: et cum tanta pompa pudendo furore et [Col. 0923C] impudenti stupore ad mortem properatis. Militaria sunt haec insignia, an muliebria potius ornamenta? Numquid forte hostilis mucro reverebitur aurum, gemmis parcet, serica penetrare non poterit? (Bernard of Clairvaux 1854: Col. 0923B-C)

[What then, O knights, is this stupendous misapprehension and what this unbearable impulse which bids you fight with such pomp and pains, and all to no purpose save death and sin? You drape your horses in silk, and plume your armour with I know not what sort of rags; you paint your shields and your saddles; you adorn your bits and spurs with gold and silver and precious stones, and then in all this pomp, with shameful wrath and fearless folly, you charge to your death. Are these the trappings of a warrior or are they not the trinkets of a woman? Do you think the swords of your foes will be deflected by your gold, spare your jewels or fail to pierce your silks? (Bernard of Clairvaux 1977: 37)]

By contrast, the anonymous *L'Ordene de chevalerie* defines a set of chivalric colours, meanings and values drawn from scripture in which red, black and, most of all, white stand out as spiritually significant and forming integral parts of a knight's visual identity. The text survives in ten medieval manuscripts from the thirteenth and fourteenth centuries (six in England and four on the continent).[10] The subject of this text is an incident (possibly historical, but this has not been proven) that occurred in 1178 or 1179: the capture and release of a French knight named Hue de Tabarie by Saladin during a skirmish on the banks of the Litani River near Beaufort Castle (now in southern Lebanon). An early tradition that might have inspired the poet presents Homfroy de Toron (Constable of Jerusalem) knighting Saladin, who had been inspired by his valour during the battle and had requested instruction in the order of knighthood.[11] Returning to Hue, he proceeds to instruct Saladin in the rituals and symbolism of Christian knighthood, a process which highlights certain elements of costume rhetoric encoding chivalric colour values. The description of symbolic elements, which takes up the majority of the poem, is summarized below:

1. He (Saladin) had his hair and beard and face well prepared (lines 104–105).
2. He (Hue) made him (Saladin) enter a bath: "just as the child leaves the font free from sin when he is brought from baptism, Sire, so you should leave this bath without any wickedness, for knighthood should bathe in honesty, in courtesy, and in goodness, and be beloved of all the people" (lines 104–125).
3. Hue took him out of the bath and laid him in a fair bed: "Sire, this bed tells you that by one's chivalry one should win a bed in Paradise, the kind that God grants

10. See Busby in Raul de Hodenc (1983: 15). Subsequent references and paraphrases are from this edition and Busby's translation (170–175).

11. For details on these traditions, persons and the various versions of the dubbing of Saladin see, for example, House's introduction to *L'Ordene de chevalerie* (1918: 1–6).

to his friends, for this is the bed of rest; he who will not lie in it is indeed foolish" (lines 126–136).

4. When Saladin had lain a little while on the bed, Hue raised him up and clad him in white (*blans*) sheets made from linen: "Sire...these white sheets that are close to your flesh give you to understand that a knight should always strive to maintain the cleanliness of his flesh if he wishes to come to God" (lines 137–147).
5. Afterwards, he clad him in a red (*vermeille*) robe: "Sire, this robe gives you to understand, quite simply, that you should spill your blood in order to defend God and his holy law. This is meant by the red" (lines 147–157).
6. Afterwards, he put on him fine hose of black (*noire*) silk: "Sire...I surely give you all this as a reminder by way of these black overshoes that you always have in mind death and the ground where you will lie, whence you came, and whither you will go. Your eyes should look to this, so that you do not fall into pride, for pride should not reign or reside in a knight; he should always strive for candour" (lines 160–173).
7. Then Hue arose and girded on him a small white (*blanche*) belt: "Sire, this belt signifies that you should preserve in holiness your pure flesh, your loins, and your whole body, and keep your body pure, as in a state of virginity. You should not practise lechery, for a knight should cherish his body and keep it pure so that he does not incur shame thereby, for God much hates suchlike filth" (lines 174–188).
8. Afterwards, Hue attached to his feet a pair of spurs: "as you would want your horse to be inclined to run when you spur him on, to go everywhere at your will...so these spurs, gilded (*doré*) all about, mean that you should always be of a mind to love God all your life, for thus do all knights who love him deeply from the heart – they always serve him with a tender heart" (lines 189–204).
9. Then Hue girded the sword on him: "this is safeguard against the attack of the enemy. Just as you see two edges that tell you that a knight should always possess justice and loyalty together, so this means, it seems to me, that he should protect the poor man so that the rich man cannot harm him, and support the weak man so the stronger man cannot bring him to shame. This is a deed of charity" (lines 205–221).
10. Then Hue placed on his head a cap which was all white (*blanche*), and told him the meaning of it: "Sire...just as you see this cap which is placed on your head to be without filth, and fair and white and clean and pure, so at the day of judgement you should promptly give back the soul to God, free from the sins of the body, pure and untainted by the follies unceasingly committed by the body, in order to be deserving of Paradise, rich in delight; for no tongue can relate, nor ear hear, nor heart imagine the great beauties of Paradise that God grants to his friends" (lines 222–240).

Of more interest to this study than the text's flagrant political propaganda is its colour symbolism relating to a spiritual dimension for armory. According to Prince Hue's account, which became a practical template handed down through the centuries, *blanche,*

noire, vermeille and *doré* are significant descriptors for the various pieces of clothing and accoutrements provided for a prospective knight undergoing the dubbing ceremony. The starting point for these significant colours cannot have been simply Paul's letter to the Ephesians (6.13–17) – the essential biblical source for martial imagery in medieval theology – because it contains no colour references. Two other scriptural passages from the genre of Apocalyptic writing probably helped the author encode his symbolic colours in *L'Ordene de chevalerie*: Zechariah 6.1–3 and Revelation 6.1–8. In the minor prophet Zechariah's account of his apocalyptic vision, various divine messengers are described going out on two missions – the first to acquire news, the second to bring about divine judgement. The messengers are colour-coded by their horses: red, black, white and of mixed colour (ambiguously translated into English variously as "dappled" or "bay"). In St John's vision, four horsemen appear one after another in response to the opening of the first four of the seven heavenly seals, and are coloured white, red, black and pale (the last from Latin *pallidus*, Greek χλωρός (*chlōros*), which might imply a greenish tinge!).

An important conceptual link between the theological approach to knighthood and the parallel ideology of secular medieval chivalry (including the rise of systematic heraldry) is provided by Ramon Llull's *Lelibre de l'orde de cavalleria*. Llull allegorized a knight's armory and trappings in detail based on the aforementioned scriptural precedent, Ephesians 6.13–17, in order to redefine a knight's coat of arms as his identity badge which ascribed his place within chivalry and was the means of accountability for his conduct. In the words of Caxton's translation: "A cote is gyuen to a knyght/in sygnefyauce of the grete trauayalles that a knyght must suffre for to honoure chyualrye" (Llull 1926: 87). Llull's book was the single most influential treatise on chivalry in the medieval period, as can clearly be discerned from the debt owed to it by a late fourteenth-century work, the far more practical book of chivalry written by Sir Geoffroi de Charny (c.1350–1). Charny's *Livre de chevalrie* is notable for its systematic approach to the concept of chivalry and his articulation of a specific hierarchy of behaviours indicating the quality and honour of men-at-arms, through to knights, lords and ultimately princes and kings.

By the late fourteenth and early fifteenth centuries, however, there were also being written across Europe a more 'scientifically' sophisticated species of text dealing with armorial colours: 'books of arms' as opposed to books of chivalry. These pseudo-scholarly works, including Francois de Foveis' *De picturis armorum* (a lost work), Bartolo di Sasso Ferrato's *De insignis et armis*, Johannis de Bado's *Tractatus de armis*, and, in Wales, Bishop Trevor's *Llyfr dysgread arfau*, plundered medieval natural philosophy and scholarship to inform their similarly hierarchical and honour-orientated approaches to questions of chivalry. Thus Johannis de Bado, in his *Tractatus de armis* (1394), sought to "put the differences between the colours, that the more worthy or

noble of them may be discovered",[12] and proceeded to posit a hierarchy of armorial colours from white to black to yellow/gold through to red, blue and the least honourable, green. This system is derived, via other armorial sources, from Aristotle's definition of the five intermediary colours between white and black found in the *De sensu et sensato* section of the *Parva naturalia* (Aristotle 1984; 1955: 437a-449b). Here a set of basic colours is produced by the elemental contraries of hot, cold, wet and dry, which are manifested within bodies according to the elemental mixtures of the primary contrary colours. The Aristotelian material understating of colour is described in Trevisa's fourteenth- century translation of Bartholomaeus Anglicus's encyclopedia, *De proprietatibus rerum*, as follows:

> In the matiere, if the mayster partyes beth watry and ayry, the colour schal be white. And if watery and fuyry parties haueth the maistry, the colour is reede. And if watry parties and erthy haueth the maistry, the colour is blu or blewisch. And if fuyry parties and erthy haueth eueneliche moche maystry, thanne mich might the colour be grene or blak.
>
> (Bartholomaeus Anglicus 1975: 1290, line 32; 1291, line 1).

Implications for chivalric honour arose from the idea that, whilst white and black have primary material status, yellow/gold, *tawny* and *citryne*,[13] red, purple, green and blue have only mediary status, in being mixtures of white and black. Green is even further devalued by such armorial theorizing because it is twice-mixed and a so-called 'submediary colour', that is a product of a mediary colour mixed with black. The root of the theory, according to *De proprietatibus rerum*, is as follows:

> For blak tempereth the schedngy blasenes [dividing fieriness] of rede. And clerenesse incorporate in that blak maketh it mene and temperate. Thanne grene is ygendred by maistry of eorthy parties and fuyry.
>
> (Bartholomaeus Anglicus 1975: 1290, lines 20–31)

12. "Primo differentias colorum ponam, et quis eorum dignior vel nobilior inveniatur" (Johannis de Bado, in Jones 1943: 95). Jones's edition has two variants of De Bado's tract, one based on two similar copies (MS London, British Library, Additional 37526, and Additional 29901), and a slightly different version from MS London, British Library, Additional 28791. All three manuscripts belong to the fifteenth century.

13. In Middle English, *citryne* was located between white and red, closer to red than white, as opposed to *3olow*, its counterpart on the white side. In his encyclopedia, *De proprietatibus rerum*, Bartholomaeus Anglicus defines it by direct application to the Aristotelian scale: "Aristotil nempneth thise fyue colours by name, and clepeth the furst 3olow, and the secounde citryne, and the thridde rede, the fourthe purpure, and the fifthe grene; so that bitwene whyte and rede the 3olow is toward the white and the citryne toward the rede; bytwixe blak and rede, purpure is toward the rede and the grene toward the blake" (1975: 1276, lines 1–7). *Tawny*, which is described by the heraldic writer John Vade as being like the "Calcidony stone", appears in later blazon and heraldic writings from the late fourteenth century (see, for example, Jones 1943: 215).

In keeping with this idea, Johannis de Bado describes the meaning of green in armory as follows (mentioning his direct source, Bartholus de Sasso Ferrato's *De dignitatibus*):

> De colore viridi. Quidam tamen addunt alium colorem, scilicet viridem colorem, qui color, ut ego credo, initium habuit ab aliquo milite histrione vel gaudente, ut dicit Bartholus, C. *De Dignitatibus*, 1.i, circa medium tractatus sui. Sed quia in quorundam dominorum armis in Anglia color ille invenitur, portantem reprehendo in nostrum librum ipsum colorem admisimus. Et pudor causam praestat, ne vereamur cum colorem ipsum in armis videremus, ipsum discernere non valentes. Et ratio est quare antiqui ipsum colorem inter colores armorum non admiserunt, quia videbatur illis absurdum et inconveniens dicere quod quis deberet dare differentiam triplicem colorum, sic dicendo, colorum quidam sunt principales secundum se, quidam medii sunt colores, et quidam submedii. Colores principales secundum se sunt color albus et niger; colores [p. 100] vero medii sunt azoreus, aureus, et rubeus; colores autem submedii sunt color viridis et alii similes si inveniantur. (Johannis de Bado, in Jones 1943: 99–100)

[Of the colour green. Some would add another colour to those noted, namely the colour green, which colour, I believe, was borne first of all by some play-acting soldier (*milite histrione*) or pleasure seeker (*gaudente*), or so says Bartholus in *On the Dignities*, l.i., around the middle of the book. But because we see lords in England carrying arms of this colour, we must admit the colour to our book and not reprehend it. And the sense of shame showed that this colour in arms was not seen to be strong enough to stand apart. And the reason why some colours in the past were rejected and not admitted as armorial colours is because it was thought strange and inconvenient to include three varieties of colours, so they said some colours are principal in themselves, some colours are mediary, and some sub-mediary. The colours primary in themselves are the colours white and black; the colours truly mediary are blue, gold, and red; the sub-mediary colours are green and any similar if there are any.]

By the mid fifteenth century, the Aristotelian view of a lesser status for green in armorial displays was out of favour with early heraldic writers, as evidenced by Nicholas Upton in his *De studio milites* (1446) when he wrote: "I must confess to have made many errors, as in condemning the colour green" (Upton 1931:ix).

4. Colouring identity in medieval romance

One advantage of approaching medieval colour theory, symbolism and semantics from an armorial perspective is that it helps us to make sense of classic questions in medieval literary criticism. A memorable example of such questions is the meaning of the curious 'greenness' of the mysterious green stranger who, in the late fourteenth-century Middle English alliterative romance, *Sir Gawain and the Green Knight*, challenges King

Arthur's court one New Year's Day.[14] The challenge is to a beheading game (lines 279–300) which Gawain takes up in Arthur's stead, severing the stranger's head with his own axe (lines 417–43). The green stranger (or Green Knight) stands up and picks up his head, which declares that, in a year's time, he will make a return blow on Gawain's neck (lines 444–66). On his quest to meet the Green Knight, Gawain obtains a magical life-preserving green girdle from a seductive lady, the wife of another knight (Bertilak) he meets along the way (lines 1826–35). According to the rules of another game he enters into with his host (the exchange of winnings from hunting), Gawain should relinquish the girdle to his opponent, but he keeps it in order to escape his impending death (lines 1861–65; 1936–41). He rediscovers the green stranger – ambiguously located at a green chapel – and submits to his return axe blow (lines 2189–2258). The Green Knight swings his axe three times and finally nicks Gawain's neck; he immediately leaps up and insists that honour has been satisfied because his blow has been returned (lines 2259–330). The green stranger laughs and agrees, explaining that he only nicked him because he had failed his final test – to give up the girdle (lines 2337–68). He reveals that he is in fact Gawain's earlier host and the husband of the seductive lady. Gawain ends the story mortified with shame for his dishonourable conduct (lines 2369–88), but is forgiven back at Arthur's court, which takes the girdle as a symbol of their order (lines 2513–30); the story ultimately offers a fictional origin for the highest order of chivalry in England, Edward III's then recently instigated Order of the Garter.

The complete story is, of course, far more sophisticated than this summary allows, and many questions have presented themselves to scholars over the years regarding the nature of the green stranger, the chapel and girdle.[15] My view, incorporating the ideas of period armorial writings into a reading of the romance, is to suggest that, if one sees the Green Knight's challenge as intentionally set against the secular ideals of knighthood, then his greenness encodes how the lowliest colour of chivalry can challenge and humiliate a higher value; thus challenging the integrity of the hierarchy itself as a measure of conduct. In other words, the challenge is taken up by Gawain, whose primary armorial colour is red (line 619: *gouleh*, a higher, mediary colour, but one which also suggests the impetuousness of his sanguinity.[16] The Christian moral of the tale could therefore be that appearances are not to be trusted, and that honour cannot be guaranteed by symbolic representations or displays. Moreover, the Green Knight's behaviour offers a model for the related scriptural truths that were clearly of great

14. Subsequent line references are to Barron's edition (1998). I discuss the details of my theory in depth in Huxtable (2008: 326–339).

15. See Brewer (1997: 181–90) for an overview of the scholarship and other sources. For the Green Man theory in particular see Doel (2001).

16. Gawain is also depicted wearing a blue gown (line 1928), but this is not part of his armorial costume. I am grateful to Graham Caie for pointing out this other colour association to me. The typical heavenly association with blue (as opposed to its mediary armorial value) could suggest that the poet's use of it here is indicative of the Green Knight's power to 're-dress' his guests.

significance for the *Gawain*-poet, as evidenced in his other works: *Pearl*, *Patience* and *Cleanness*. Those truths are that, in divine terms, earthly hierarchies are to be perceived in reverse, so that "the last shall be first" (Matthew 20.1–16); and "For whosoever exalteth himself shall be abased; and he that humbleth himself shall be exalted" (Luke 14.11); and that ultimately, "He that findeth his life shall lose it: and he that loseth his life for my sake shall find it" (Matthew 10.39).

5. Conclusion

This article shows something of the range of medieval armorial literature and its significance for our understanding of colour, language and perception for the period. In essential terms, medieval writers who were concerned with and engaged imaginatively with armorial displays created a sophisticated discourse that incorporated a diverse range of ideas about the world and humanity's place within it – as individuals and elite members of a society – and one which was underpinned by belief in the divinely ordered nature of the universe. This latter engine of meaningfulness was deemed to be manifest in natural and man-made signs and symbols available for decoding, up to and including the very fabric of visuality itself: colour.

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Warm, cool, light, dark, or afterimage

Dimensions and connotations of conceptual color metaphor/metonym

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Conceptual color metaphor/metonym (CCMM) and our semantic frame of color are motivated through the embodied co-occurrence of color experience as light (RGBu) and as pigment/substance (RYBu [CYM where C= cyan M = Magenta]). Conceptual perceptive mapping establishes a cognitive mechanism to accommodate the positive and negative connotations in relation to both conventional and non-conventional color items. Fifty participants assessed 143 items in four color tasks, involving the eleven universal basic color concepts. The items were divided between the visual and the linguistic aspects: color metaphor and color metonym. This paper investigates the results in the strictly *hue* dimension in comparison with the conceptualization of temperature WARM/COOL and brightness LIGHT/DARK. Furthermore, the presence of a linguistic and a visual 'afterimage' effect is analyzed. CCMM theory helps explain how individuals conceptualize and categorize opponent polysemic association functions in the parallel signal/symbol cognitive processing of color and color language.

1. Introduction

Conceptual color metaphor/metonym (hereafter CCMM) represents a complex frame of thought that requires multiple dimensions of conceptualization and mental processing. Our embodiment of color motivates linguistic elaboration of these dimensions and antagonistic connotations. This study analyzes data resulting from a color study involving fifty participants' assessment of 143 visual and linguistic color items. Initially we analyzed how people assign positive and negative connotations to color object and color light *hue* associations. The objective of this phase of the analysis is to compare three color frame conceptualizations of color signal/symbol processing, i.e. *hue* compared to *temperature* WARM/COOL, and *brightness* LIGHT/DARK.

Next we will briefly outline the background theory of this study and its objectives. The theories of embodiment, Figure/Ground relations, vantages, categorization, basic color terms (hereafter BCTs), prototypes, polysemy, and conceptual metaphor are the most pertinent aspects in respect to this research. All of these theories are tightly interlaced; therefore our analysis of color conceptualization includes them all.

We then briefly define the approach to each of these aspects in color theory, before presenting the actual study and results. Only limited references will be cited due to lack of space.

2. Embodied color and background

CCMM and the semantic frame of color and categorization are motivated through the *embodied* co-occurrence of color experience in a trichromat semantic frame of light (RGB) and substance (RYB [CYM]). The constant primary experience of color and assessment of color connotation in judging distance, measure, time, cause and effect, movement, and substance make all individuals color experts. Research suggests that people make comparative (vantage) assessment of opponent and basic level complementary pairing, e.g. black (Bk)/white (W), red (R)/green (G), yellow (Y)/blue (Bu), in relation to context association (Hardin & Maffi 1997; Sivik 1997; Seitz 2005).

Embodiment of visual perception dictates human interpretation of color input. Our body structure and cognitive mechanisms employed to speak and understand in turn constrain how we are able to elaborate our senses and process available information (Gibbs 2005). The mind reflects the basic functions of the body. The human body operates in virtually the same way for everyone; these body capacities are responsible for the creation and the constraints of the range of potential experiences. "The body does not exist by itself, in isolation from the world, but instead develops in contact and through experimentation with it" (Rohrer 2001: 58). Two basic corollaries in Cognitive Linguistics describe the embodied motivation of language: (1) language is representation of other conceptual structures; (2) cognitive processes that govern language use are the same as other cognitive abilities (Croft & Cruse 2004: 2). One of the principal cognitive processes, involving aspects of attention, memory, perception and categorization, which color allows us to process, is Figure/Ground alignment.

2.1 Figure/Ground alignment

Humans use general cognitive processes to judge and compare information, thereby establishing a spatial-temporal *Figure/Ground* alignment. The Figure/Ground relation enables access to the correct meaning of a color concept. Cognition of visual sensation

creates image schemas. Individuals use these conceptual representations of experience in language to establish abstract concepts as reference points for other concepts. We use a given color association with Figure/Ground to interpret mappings between and within domains. Leonard Talmy (2003: ch.5) uses the Gestalt terms Figure/Ground, with a capital letter to indicate the theoretical specification. The Figure stands for the focus of attention on one aspect of a situation or utterance, whereas the Ground is what we set the Figure against.

> The Figure is a moving or conceptually movable entity whose path, site or orientation is conceived as a variable, the particular value of which is the relevant issue. The Ground is a reference entity, one that has a stationary setting relative to a reference frame, with respect to which the Figure's path, site or orientation is characterized. (Talmy 2003: 312)

The need to separate a dominant shape-concept or 'figure' from a background or 'ground' is apparent both visually and linguistically. Bilateral embodied motivation allows us to access and express both the positive and negative connotations of each color as dictated by Figure/Ground, perception/cognition, and situation/surround relations. Vantage theory, introduced by Robert MacLaury (1997), establishes how an individual elaborates available data by judging difference and similarity.

2.2 Vantage theory

Vantage theory is an accomplished explanation of how we manage to construct and alter mental categories by means of fixed and mobile coordinates in relation to the surround. MacLaury explains, "The theory was originally developed to account for the dynamics of color categorization, especially continuous change and the relation of the viewer to the categorization process" (2002: 493). This theory models our experience of categorizing in reference to 'images schemas', with degrees of similarity and difference. Starting with a reference point that may be fixed, and then mobile, the analogy of what is similar and different moves in coordination with it. MacLaury discusses how these coordinates compose a Figure/Ground relation between our reference as Ground and similarity as Figure. In categorizing color we establish prototypes or BCCs that serve as the contextual reference point for our specific categorization.

2.3 BCTs, prototypes to polysemy

Today there is wide consensus that there are eleven basic color terms in English (Kay & Reiger 2006). These are the terms that have been taken into consideration in this study: they correspond to the six basic primary colors of light and substance combined, R, G, Y, Bu, plus the achromatic color terms Bk and W, and the five secondary BCTs Gray (Gy), Brown (Br), Purple (Pu), Pink (Pk), and Orange (Or). All eleven BCTs are salient in CCMM, especially the primary BCTs (Sandford & Buck 2007).

Berlin and Kay's original research (1969), together with Eleanor Rosch Heider's work in the early 1970's, investigates the concept of focal color, best exemplar, prototype or prototypical effects (see, for example, Rosch Heider 1972).

A prototype represents a conceptual 'ideal' of an entity or an abstraction, similar to a default status. In cognitive linguistics a prototype is a core, or a primary, concept around which a series of related concepts radiate. The primary signification of a polysemic term has a series of different meanings that radiate around it, forming a radial category. The 'other senses' evolve through conceptual metaphorical and metonymical extension of the primary meaning, and may be close to the original, distant, and even opposite or antagonistic. Embodied motivation of meaning and image schema representation of categories are useful to understand extension of primary color term meaning and color polysemy.

3. Study objective

The study hypothesis, in keeping with the initial results of our data analysis, is that conceptual perceptive mapping establishes a cognitive mechanism to accommodate the positive and negative connotations in relation to both conventional and non-conventional realization of CCMM (Sandford & Buck 2007; Seitz 2005). Comparative vantage assessment of a conventional or non-conventional linguistic expression with a BCT is made on the basis of antagonistic pairing, e.g. Bk-W, R-G, Bu-Y, and through Figure/Ground alignment. "The pervasiveness of polar associations suggests that their roots may be embedded deeply within our physical make-ups" (Hardin 1988: 130). Each color is intrinsically a polar association, which we assess on-line with ease and rapidity. Seitz (2005) confirms that we may have sensitivity to the polar processes, e.g. light-dark, warm-cool, positive-negative, on-off. In particular, humans may have some neural level that records such facts as the excitation and inhibition of the opponent processing.

The first phase of this study – analysis of color in the hue dimension – illustrated a clear ability to understand conventional and non-conventional connotation of a color metaphor or metonym. Color and substance associations were seen as more positive (M = 36, SD = 1.92) than color and light associations (M = 27, SD = 1.87) by the fifty participants. The robust agreement (M = 38) among participants on general positive assessment was unexpected. In this paper we compare participants' assessment of the CCMM task items in two other embodied polar conceptualizations of color: WARM/COOL, and LIGHT/DARK. Finally, we observe and analyze data regarding presence of a linguistic-visual simultaneous contrast or 'afterimage' effect (MacLeod 2003; Tornquist 2005).

4. Methodology – study tasks

The four tasks in our study considered the eleven BCTs in visual and linguistic items. Each task concentrated on a specific aspect of CCMM. *Task 1, Color-Vision*, presented color patches to establish preference, an idea of the individual approach. *Task 2, Color-Vision*, considered color convention and prototypical color/object association. *Task 3, Color-Language*, used metonyms and evaluated the role color terms have in identifying natural things through conventional and non-conventional color meaning. *Task 4, Color-Language*, used metaphor and evaluated the role color terms have in giving a specific connotation to conventional/non-conventional inferences.

4.1 Participants

Fifty participants, ranging in age from eleven to ninety-three, took part in the study. This group represented a cross section of a mono-language group, in this case native American English speakers, for proper future comparison with other linguistic groups and speakers of English as a second language. Color blindness and visual impairment were exclusion criteria.

4.2 Study design

Media RT software was used to write the study program script. The study was divided into four tasks. In each task, the items (pictures or written words) were presented on a computer screen. The participants assigned a positive or negative value to each item, by pressing the (P) or (N) key. This study employed the positive-negative polar association in keeping with the 'clustering of opposition' in the color frame. In discussing these terms Hardin highlights that the positive-negative pairing "is particularly interesting, because it is quite abstract, and yet most people have no difficulty in connecting it with the hue division" (1988: 129).

Examples of each task are mentioned below. The same prototypical objects were used for conventional and non-conventional color term object-topic association. All of these objects were natural objects. The non-conventional colors associated were opponent or basic level complementary ("paint bias", Miller 1997: 153) colors when possible. Each item represented one of the eleven BCTs. There were four examples for each color in tasks 2, 3 and 4. This resulted in a total of 143 items: eleven color patches plus four items for each of the eleven colors multiplied by the three tasks. Participants were asked to assess the colors as positive or negative. RGB values were applied to the visual objects presented on a computer screen.

4.2.1 *Task 1: VISION – Color*

Each item – color patch – corresponded to one of the eleven universal focal color concepts.

4.2.2 *Task 2: VISION – Objects*

This task showed a series of visual depictions of color prototypes. Two of the items depicted prototypical colored objects. Two items depicted the same objects, but with an impossible or non-conventional color. The objects were iconographic illustrations with flat coloring, against a white rectangular background, or a white object against a light gray background.

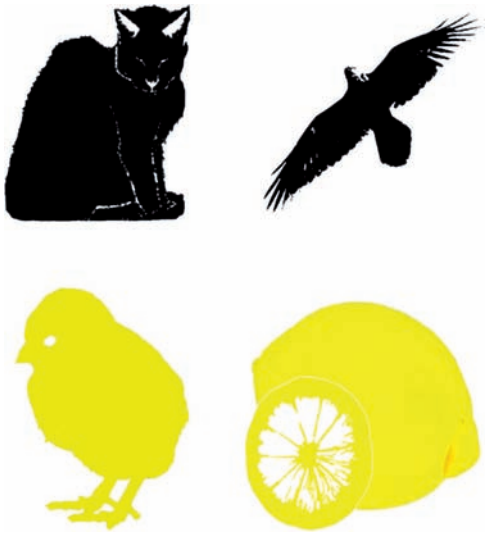


Figure 1. Prototypical colored objects: a black cat, a black bird, a yellow chick, a yellow lemon

Figure 2. The same objects with impossible or non-conventional colour: a green cat, a green heart, a blue chick, a blue pumpkin

4.2.3 *Task 3: LANGUAGE – Metonym*

This task involved a series of short narratives, verbal descriptions of concrete conventionally and non-conventionally metonymically related items. For each color term, two items were prototypical color associations: (1) *The milk is white. The moon is white.* In addition, two items were impossible or non-conventional color associations: (2) *The milk is black. The moon is purple.* The four metonyms representing RED were: (3) *The blood is red. The fire is red. The grass is red. The bread is red.* The four metonym, for the opponent GREEN were: (4) *The grass is green. The light is green. The hair is green. The fire is green.* These narratives used color metonym, i.e. the attribute color for the entity. The conventional items were associated with one concrete-substance object and one intangible or light-related topic (with the exception of BROWN, where it was not possible to find an intangible object): (5) *The ice is blue. The sky is blue.* The text was presented on the screen in light yellow letters on a black background, following conventions of legibility.

4.2.4 *Task 4: LANGUAGE – Metaphor*

A series of short narratives, verbal descriptions of abstract conventional and non-conventional metaphors, was presented on a computer screen. The items were about color term abstraction in an emotional or qualitative function through metaphor. For each color term there were four items: two had positive connotations and two had negative connotations.

One negative aspect was represented by an emotional function (except for PINK): (6) *The future looks black. She is white with fear. They see red with anger. The three were too yellow to stay. The bite of green envy is strong. They are all in a blue mood.* The other negative aspect was a non-conventionalized color metaphor (an idiomatic expression where the conceptually opposite substituted the expected color term): (7) *It is a black Christmas. The robber was caught white handed. It happens out of the yellow. The pages blued with age.* The items included equal numbers of conventionalized metaphors and non-conventionalized metaphors.

The positive connotations were exemplified by "*We are* [color]", addressing ethnic, political, social, and historical grouping color metaphors, considered positive because of the self-inclusive pronoun "we". (8) *We are black. We are white. We are red. We are yellow. We are green. We are blue.* The other clearly positive conventional color metaphor connotation type was an idiomatic expression with a BCT, e.g.: (9) *It is white magic. Spring is covered with green hope. He gives them the red carpet treatment. He runs a blue streak.*

4.3 Sequence and timing

Each of the four tasks was performed separately in one sitting in a randomized order. The items were also randomized within each task. The software recorded total response time for each of the four tasks and response times for each individual item. The items

used predominantly the present tense and equally *he* and *she* sentence subjects, to avoid unwanted inferences.

5. General study results

Chromatic information was used to evaluate both the visual and linguistic items. Language used in perceptual experiences was metaphorically extended for conceptualizing experience abstractions.

In Task 1 all color fields, except Black and Gray, were assessed as positive (more than 50% of the participants agreed on assessment). In Task 2 iconographic items were seen as more positive than negative; even fifteen non-conventional items out of twenty-two were assessed as positive. Conversely, out of the verbal texts (metonyms) in Task 3, twenty of the twenty-two non-conventional items were assessed as negative, all except for a Pink item and a Purple item. In Task 4, participants judged the color metaphors less positively than the color metonyms.

5.1 WARM/COOL and LIGHT/DARK compared to hue results

In categorizing the items to assess the results we grouped the eleven BCTs according to the conventions of WARM/COOL, and LIGHT/DARK. The color division was:

WARM > W, R, Y, BR, PK, OR;
COOL > BK, G, Bu, GY, PU;
LIGHT > W, R, Y, GY, PK, OR;
DARK > BK, G, Bu, BR, PU.

In each bi-polar group, WARM-COOL and LIGHT-DARK, the number of responses analyzed (7150) was divided differently due to the fact that the eleven BCTs are necessarily grouped by five or six. Hence, the number of the total responses analyzed for WARM and LIGHT is (13 items x 6 colors) x 50 participants = 3900, and for COOL and DARK is (13 items x 5 colors) x 50 participants = 3250. Let us consider each attribute separately according to the participants' positive or negative assessment (see Figure 3).

The participants assessed *all* the items more positively than negatively: WARM items mean positive response 63% = 2457; COOL items mean positive response 57.3% = 1862; LIGHT items mean positive response 61.3% = 2391; DARK items mean positive response 59.8% = 1944. WARM items were assessed slightly more positively compared to LIGHT, 1.7% more total responses. DARK items were assessed as more positive compared to COOL, 2.5% difference.

The mean RT shows WARM as taking longest to assess, and DARK as the shortest (mean RT WARM: 1807 ms, SD = 1508; COOL: 1760 ms, SD = 1255; LIGHT: 1793 ms, SD = 1459; DARK: 1750 ms, SD = 1323). When the mean category value is divided into

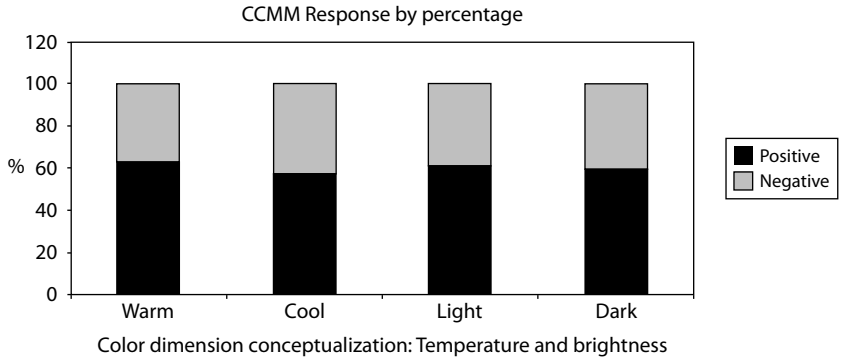
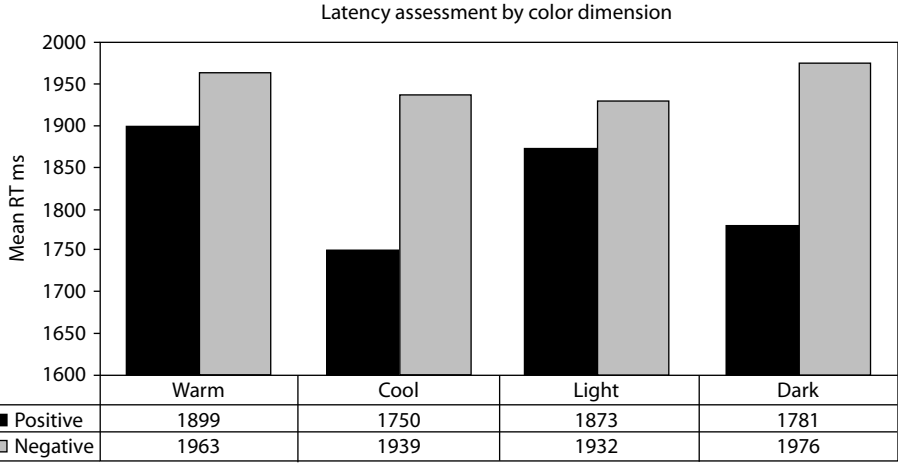


Figure 3. WARM/COOL and LIGHT/DARK response percentages per group



	Warm	Cool	Light	Dark
Positive	1899	1750	1873	1781
Negative	1963	1939	1932	1976

Figure 4. Color dimension latency assessment in mean RT ms

positive and negative (see Figure 4), COOL positive mean RT = 1750 ms is shortest and DARK negative = 1976 ms is longest.

5.1.1 WARM-COOL *and* LIGHT-DARK *result summary*

The percentage of positive item ranking is WARM, LIGHT, DARK, COOL. WARM and LIGHT assessment is more positive than COOL and DARK. All conceptualizations of color associations are seen more positively than negatively; the division in percentage of positive-negative response appears regular. Mean RT ms for ORANGE = 1935, BLACK = 1882, and BROWN = 1850 were longer, compared to the faster hue (COOL–DARK) item mean RTs PURPLE = 1706, BLUE = 1721, though it took longest to ascribe a negative value to BLACK = 2238, WHITE = 2145, RED = 2037, a decisive mean latency aspect.

5.2 After-image color in relation to positive and negative assessment

All items and color associations tested (conventional and non-conventional) are numerously present on the Internet. This high frequency of anomalous or non-conventional color associations was unexpected. It appears that when individuals use a non-conventional color association, they tend to pick an opponent color, or its basic 'paint bias' complement. Maybe the sensation of already having 'seen' the opponent color associated with the item, as in an after-image, makes the items seem familiar, allowing for a positive reaction. This was true mostly for the visual items tested, much less so for the linguistic items.

There were fifty-five non-conventional color association items. Table 1 shows the eighteen non-conventional color item associations that were assessed positively. It indicates the color change for these items, e.g. Blue > Yellow 2/4 stands for a Blue thing called Yellow, two out of four judged positively.

Positive assessment resulted for eighteen out of fifty-five items with non-conventional color association, for a total of 33% (see Table 2).

Table 1. Non-conventional item color change

Color Change	Positive Result	Color Change	Positive Result
Blue > Yellow	2/4	Yellow > Blue	1/3
Red > Green	1/3	Green > White	1/1
Red > White	1/2	–	
Purple > White	1/1	White > Purple	1/1
Yellow > Purple	1/1	–	
Gray > Brown	1/1	Brown > Pink	1/2
–		Brown > Orange	1/1
Pink > Gray	1/3	Gray > Red	1/1
Pink > Purple	1/1	Purple > Pink	1/1
Pink > Orange	1/1	Black > Pink	1/1

Table 2. Percentages of positive assessment per task

Task	No. Items	% Positive
TASK 1– objects	15	27%
TASK 2– metonym	2	4%
TASK 3– metaphor	1	2%
Total	18	33%

5.2.1 *Opponent and complementary result summary*

Participants assessed opponent color (RGB) inversion, or the 'after-image' effect, more positively than for a complementary basic level (RYB) color inversion. Opponent color change shows 31% of items assessed positively compared to 18% with a basic complementary color (e.g. yellow-purple) inversion. Thirty-three other inverted color items had more than 25% of positive consensus.

5.3 General research results

Visual and linguistic information are two major sources of knowledge for human beings; color terms combine both signal and symbol processing. The study data show us that CCMM is activated to a different degree-reaction time (RT ms) for (a) purely visual, non-linguistic information, (b) apparently concrete metonymic linguistic information, and (c) abstract metaphorical linguistic information (see Table 3 for the average percentages and mean RT per task).

Individual participants applied different color parameters and preferences to different situations. The group agreed more than it disagreed on positive-negative interpretation. The more the information, Figure/Ground image schema constraint, the greater the agreement. Non-conventionalized items presented more variation in response; conventionalized items presented more agreement. Non-conventionalized items took longer to assess. It took participants consistently longer to make negative assessments. Metaphors took longest to assess, though the RTs were relatively close; this was not a matter of syllables, but of conceptual complexity. Color anomaly requires greater 'attentional' expenditure. The group adapted color term polysemy and the positive and negative connotations according to the three dimensions (hue, brightness, saturation) and the synesthetic warm/cool temperature divide of each color term.

There was more agreement and faster RT for the primary basic color terms: BK, W, R, G, Y, Bu and GY. Fast RT illustrates the degree of entrenchment of the multifaceted semantic frame of color.

Table 3. Average Percentages and mean RT per Task

	Task 1 11 BCTS		**Task 2 44 ICONS**		**Task 3 44 METONYMS**		**Task 4 44 METAPHORS**	
mean	%	RT ms	%	RT ms	%	RT ms	%	RT ms
Pos.	82%	1165	84%	1278	55%	1508	48%	2261
Neg.	18%	1857	16%	1406	45%	1739	52%	2913

6. Conclusion

There is a large amount of research that supports CCMM embodiment theory. Studies on other perspectives of color, including the extensive work of Berlin, Kay and colleagues (cf. Kay, Berlin, Merrifield 1991; Kay, Berlin, Maffi & Merrifield 1997; Kay and Maffi 1999) on BCTs, regarding the evolution of color terms and the development in partitioning by WARM/COOL differentiation, give validation to this concept. This study confirms the correlation highlighted by Hardin and Maffi:

> ...the association between warmth and positive activation of opponent systems, and coolness with negative activation, would suggest a possible reason for the relationship of lightness with warm colors and darkness with cool ones in the WCS. (1997: 336)

The etymology of color terms, which reveals a semantic shift from brightness to hue terms, is also in keeping with the conceptualization of rival color systems and dimensions (cf. Biggam 1997; Cacciari, Massironi & Corradini 2004; Casson 1997). Others have found evidence of pre-linguistic categorial perception of color (e.g. Franklin, Clifford, Williamson & Davies 2005), which in turn seems to reflect the idea of the embodiment of receptor cells and opponent neurons (Hardin 1988; Werner, Pinna & Spillman 2007; Zegura 1997). MacLeod (2003) has studied embodied neural effects and surround influence on visual adaptation. Barrik, Taylor & Correa (2002) have worked on embodied effects of color sensitivity and mood change. Primary metaphor, embodiment, mirror neurons and Gestalt theory have been the stimulus of color research ranging from cognitive linguistic theory to neurological studies, color processing and conceptual mapping (cf. Gibbs 2005; Lakoff 1990; Rizzolatti & Sinigaglia 2006; Seitz 2005; Talmy 2003).

Cognitive linguistic *Embodiment Theory* and *Conceptual Metaphor Theory* establish a well-founded basis to understand how language is a representation of other conceptual structures, and indicate how cognitive processes that govern language use require these same cognitive abilities. The polysemic nature of CCMM reflects the motivated embodied patterns of color experience: perception and cognition. CCMM assessment in the three dimensions: *hue*, *saturation*, *brightness*, and *cross modal synesthetic conceptualization*, such as the *temperature* warm/cool divide, appear to be balanced and in keeping with the bilateral embodied motivation of color. A color may connote a positive or negative association depending on the aspect (light or substance) that is activated. Furthermore, the complexity of color as an experience activates our right hemisphere, in the emotional holistic signal sense, and it activates our left hemi-sphere for the verbal, symbolic, and logical senses that must be processed at a conscious level (Ronchi 1998; Sandford 2008). It follows that language and color represent essential cognitive operations in human perception and cognition of available and pertinent information.

This research helps us to understand the cognitive perceptive mechanism that permits us to discern subtle differences and categorize opponent functions in the processing and adaptation of CCMM among individuals. The presence of a linguistic/visual simultaneous contrast or 'afterimage' effect seems possible, although further investigation is necessary. Image schemas and semantic frames of color conceptualization, with the resulting assessment of a given item, support the hypothesis that it is impossible to interpret color without context; indeed the meaning is made known to us through our perception of color in an embodied Figure/Ground alignment.

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The power of colour term precision

The use of non-basic colour terms in nineteenth-century English travelogues about northern Scandinavia

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In this paper I analyze and discuss the effects of the use of specific colour vocabulary employed by five English-speaking travelogue writers visiting northern Scandinavia in the nineteenth century. The number of different colour terms (types) and their frequency of occurrence (tokens) as well as the objects they describe are presented and analyzed. The results show that the objects described most often with specific colour vocabulary are natural objects in the landscape. I argue that this use of colour precision in the discourse can be viewed as reflecting two aspects: first, a desire to add attributes such as exoticness and exclusiveness to the narrative as they are readily available associations in many terms; second, the writers' engagement and involvement in the landscape they travel through, as the use of specific terminology can be very clearly linked to the writers' opinions about what is described.

1. Introduction

How do we describe what has not been described previously? How do we paint a verbal picture for those who have not seen what we are seeing? What words should we use, and what level of precision should we choose? Such questions may very well have lingered in the heads of travellers in northern Scandinavia trying to write down their impressions for a larger audience. In particular, the last question is well worth taking a closer look at, especially from the point of view of colour semantics, since the use of specific terms could have implications for a more general description of how to codify the meaning of colour words.[1]

1. This study was supported by the Swedish Research Council. It was conducted within a cross-disciplinary project, 'Foreign North', at Umeå University.

The pragmatic functions of specific vocabulary were discussed in a seminal paper by Cruse (1977), and although taxonomic levels have been attended to in recent linguistic research, little interest has been shown in specific vocabulary and its function in literary texts. This is not least true of the field of colour studies, in which the great majority of papers address issues linked to the category known as Basic Colour Terms (Berlin & Kay 1969).

In this paper I try to remedy this lack of attention to specific vocabulary in literary texts by analyzing the use of specific colour vocabulary in some nineteenth-century English-speaking travelogues about northern Scandinavia. The reason for choosing this genre is that it deals with unknown territories, and the level of description can be quite detailed. In terms of text typology, the travelogue could be said to have a middle position: it is expected to present facts, but at the same time it has artistic aspirations and values (Englund, Ledin & Svensson 2003).

The aims of this study are:

1. To give a quantitative description and analysis of the use of non-basic English colour terms in five nineteenth-century travelogues about northern Scandinavia.
2. To look more closely at the pragmatic or discourse function of non-basic colour terms in these travelogues.
3. To provide a semantic model of non-basic colour terms which can explain the effects found in the texts.

2. Some necessary definitions

The exact definition of a basic colour term (BCT) has been debated since Berlin and Kay's study in 1969, but the category itself appears acceptable to most scholars. However, the colour terms not belonging to the basic category form a heterogeneous group of terms. The lack of studies outside basic colour terms has meant that there is occasionally a terminological problem, and for this reason I will here suggest some definitions to be used in the remainder of the paper:

1. BCT derivations. This category comprises derivations based on BCTs and BCT-based compounds. Examples of the former are *bluish* and *yellowy*, and examples of the latter are *yellow-orange*, *jet-black* and *navy blue*.
2. Elaborate Colour Terms (henceforth ECTs). This category consists of conventional simplex lexemes referring to a colour nuance, for example *vermillion* and *beige*. The phrase 'Elaborate Colour Term' has previously been used for this category by Nowaczyk (1982) and Steinvall (2002).[2]

2. This term is preferred to 'secondary colour terms' used, for example, by Casson (1994), because the latter can easily be confused with secondary basic colour terms (*brown*, *purple*, *pink*, *grey* and *orange*).

3. ECT derivations. In this category we find parasynthetic constructions such as *leaden-coloured* and also derivations of the type *rosy* and *snowy* when such a term does not modify a BCT.

3. People's knowledge of ECT meaning

The comparatively few studies that cover non-basic colour terms fall into two broad categories – those addressing the issue of gender and use of non-basic colour terms, and those addressing the origin of specific terms. Although these topics are not of immediate interest to the present study, some aspects of this previous work are relevant to it.

There is evidence which indicates that people's knowledge of the exact meaning of non-basic colour terms, in the sense of colour nuance, is not impressive. Nowaczyk (1982) showed that both men and women are not very accurate in a matching task concerning colour nuances and specific colour terms. The women were significantly better than the men, but the overall figures were not impressive at forty-two per cent and thirty-five per cent correct respectively.

Another piece of evidence regarding the variability of meaning of non-basic terms is my own study of dictionary definitions (Steinvall 2002: 133–160). It showed that even such common colour terms as *crimson*, *lime* and *lemon* are defined in different ways, suggesting that there is no unanimous view of the exact designation of these terms. In another experiment, Nowaczyk (1982) asked subjects to describe the colour represented by an ECT. Again women were more successful than men, but the averages were low in terms of correctness at 24.0 and 16.5 out of 47 respectively. However, the problem should not be overstated. Most often, the terms are defined as denoting the same broad area, for example in the case of *turquoise* between green and blue. There is often a difference, however, in the emphasis on blue or green and the degree of lightness of the nuance. It could be claimed, therefore, that, if only the nuance is sought after, it is much safer to use a modified basic term – say *bright bluish green* – than the precise term *turquoise*.

4. Lexical meaning – a cognitive linguistic perspective

From the position of cognitive linguistics as proposed by Langacker (e.g. 1999), meaning is held to be open-ended and encyclopaedic in nature, best characterized in terms of a network. Consequently, there is no difference in principle between central aspects of a word (denotation) and vaguer associations (connotations); instead they are viewed as representing different levels of entrenchment. Advocating a usage-based model, Langacker argues that meanings encountered more frequently in the context of a particular lexeme are more deeply entrenched and, therefore, acquire unit status as

conventionalized meanings. However, in a given context, other aspects of meanings (attributes) can be accessed if they are part of a lexeme's network of senses. Accordingly, meaning is held to be under continuous negotiation through usage, which can lead to elaborations of the lexical content.

This view of meaning, I believe, is useful to bear in mind when we analyze the full meaning of ECTs. Casson (1994), Kerttula (2002) and Steinvall (2002) have shown that the great majority of ECTs derive from objects. Many of these object senses occur frequently in texts (Steinvall 2002) and are identifiable through the colour word, that is they are transparent (Casson 1994). Such lexemes can be viewed as polysemous. For the cognitively oriented linguist, this means that attributes associated with, say, the object meaning of the lexeme are also available at a usage event when the colour sense is central. Figure 1 is an attempt to visualize the model.

The most frequent unit of the lexeme will be more entrenched than other facets of meaning. Typically, those facets can be viewed as attributes to the central entity. The link between facets is illustrated through lines. A crucial aspect here is that various facets of meaning are actually linked through more or less well-established channels. Thus, the use of a word such as *aubergine* with reference to colour will provide access to the object, but could also, in a particular context, give access to attributes of, say, taste, even though there is no direct channel between the taste and the colour. Repeated encounters of contexts in a usage-based model will create well-rehearsed avenues of links to attributes. Genre, in a wide sense, could be such an attribute.

It is vital to acknowledge the significance of perspective here. The reader faced with the form *aubergine* will have access to an entire network of senses as described above. The writer faced with a nuance will potentially have several competing terms to choose from, and the reason for a particular choice may be linked to the understanding of the nuance, but also to the other facets of meaning that the choice of word may evoke.

In what way is the level of specificity important? Cruse (1977) addresses lexical specificity in discourse and shows convincingly that the choice of specificity can be crucial, as semantic underspecification or overspecification creates markedness effects.

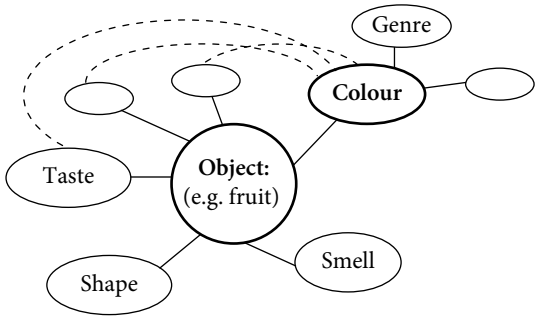

Figure 1. A schematic picture of the semantic network of a polysemous colour word

In short, Cruse suggests that any taxonomy has one level which is inherently neutral and that, unless context so demands, the choice of other levels of semantic specificity affects our interpretation, in the sense that new attributes are introduced. In the colour domain, it is safe to identify BCTs as forming the neutral level of specificity. Consequently, unwarranted use of ECTs could create markedness effects, if we are to believe Cruse.

5. The travelogue texts and their time

At the beginning of the nineteenth century, the Nordic countries started to attract interest from travellers as an alternative to established destinations such as Italy and Greece. Northern Scandinavia was then very close to pure wilderness, thus representing a positive challenge to the romantically inclined traveller as well as the more adventurous one. Around the same time, the genre of travel writing became both more literary and more popular. Several hundred travelogues on journeys in Scandinavia were published in the nineteenth century alone, predominantly in English and German. Here I restrict my study to five randomly chosen travelogues, just a small sample which cannot be claimed as representative of the bulk of travel literature produced in the period (see Primary Sources in the References at the end of this article). However, as the aim is not to make claims about the genre as such, but to describe and analyze the function of specific colour vocabulary in the texts, the small size is justifiable even if a larger corpus would have been desirable.

The books are of very different length and character, mostly resulting from the pretentions of the writers, and their backgrounds. Bayard Taylor, American and the only non-Briton of the five, was an experienced traveller who had previously written several books about travels in the Middle East and Far East. Susanna Henrietta Kent, the only woman in my corpus, had published a travelogue about a trip to Palestine a few years earlier. Donald MacKinnon was later to write two books, neither of which was a travelogue. As to the remaining two, W. D. Knight and F. L. H. Morrice, these books were, to the best of my knowledge, their only publications. The five trips cover more or less the same areas – the north of Sweden and Norway – and they all describe summer trips, lasting between six weeks (Knight) and three months (Morrice), with the exception of Taylor. His travelogue, as the title suggests, also includes a winter trip (in total, a period of ten months). All except MacKinnon went up the Norwegian coast by boat to the North Cape, and then further, to the northeast corner of Norway. Knight and Morrice walked from there (although not taking exactly the same route) across the mountain range into Sweden. Taylor, Kent and MacKinnon also travelled in northern Sweden, mostly by cart or sledge, and arrived from the south. In order to narrow the study, I have only considered the parts of the books that deal with Scandinavia north of the 60th parallel, that is all of Norway and Sweden north of Uppsala.

6. Some quantitative data: Colour term types and their density

Since the books are of different lengths, counting the mere number of words gives us little insight into how prominent the domain of colour is in the narrative. Therefore, a rough calculation was made of the number of words per page. The estimation was carried out in the following way: firstly, the number of relevant pages was counted; next, five randomly chosen pages were identified for which the number of words was counted; and, finally, an average per page was calculated. On the basis of these facts, a rough estimation of the density of colour words could be calculated.

The use of colour terms can be compared to that found for different text genres in the Bank of English (Steinvall 2002: 93). The sub-corpora with the most frequent use of colour terms, British magazines and British books, contained 1.8 and 1.36 colour words per thousand words respectively. These numbers are fairly close to that of Morrice's *Nightless North* (1.78). Three writers in this study, however, use colour words considerably more often on average than we find in a large modern text corpus. The nature of the text genre, the travelogue, in which descriptions are central, could be one explanation. The time gap is also significant, and stylistic preferences may have changed through time.

A closer look at the distribution of colour terms classified in different categories reveals some major differences among the writers. It also provides a picture of what type of non-basic construction is preferred.

Table 2 shows some noteworthy patterns. Firstly, as expected, the proportion of BCTs greatly exceeds that of non-basic terms. Taylor stands out again as using the largest proportion of non-basic terms, accounting for 36% of all instances in his book. The other writers have much lower proportions of non-basic terms: Knight 23%, Kent 18%, MacKinnon 10% and Morrice 5%, the last two with very few instances of non-basic terms and with only single instances of each type. We can observe an interesting correlation between the density of colour words in general and the proportion of non-basic terms.

Table 1. The number of colour words and their density in the five travelogues

Author	Pages	Words per page (average)	Words in text (estimate)	Colour words: types	Colour words: tokens	Colour words: tokens per 1000 words
Kent	*450*	152.4	68580	43	317	4.62
Knight	*102*	230	23460	21	77	3.28
MacKinnon	*118*	193.2	22798	8	19	0.83
Morrice	*172*	425.8	73238	15	130	1.78
Taylor	*313*	327.4	102476	81	592	5.78

Table 2. Distribution of colour terms as types and tokens in five travelogues

Author	BCTs tokens/types	Non-Basic tokens/types			
		BCT derivations/ compounds	ECT-derivations	ECTs	Total Non-basic
Kent	259/11	13/12	11/9	34/11	58/32
Knight	59/10	2/2	1/1	15/8	18/11
MacKinnon	17/6	1/1	–	1/1	2/2
Morrice	123/8	3/3	–	4/4	7/7
Taylor	375/11	27/22	37/14	153/37	217/73

Another conspicuous feature is the very low token/type ratio for derived forms such as compounds and ECT combinations. As far as the first category is concerned, only four compounds have a higher score than one: *apple-green* in Kent, and *jet-black*, *snow-white* and *tawny red* in Taylor. *Jet-black* is used four times, the other three terms twice each. The same picture emerges in the ECT-derivations, where only four out of twenty-four types have a higher score than one: *silvery* in Kent, and *rosy*, *snowy* and *rose-colour(ed)* in Taylor. Of these terms, *rosy* stands out as it is used frequently, namely nineteen times in Taylor, mostly for descriptions of facial colour. Thus, this fairly small sample indicates that the use of derived forms is unsystematic and infrequent for the most part.

7. Object domains and the precision of colour terms

The types of objects described by the non-basic terms in general and ECTs in particular is another essential issue. In order to present a general picture of the objects described, identified or classified by means of colour terms, the objects were first classified into notional domains (for example, landscape features, clothes, buildings and so on) which in turn were assembled into three 'super-domains': Natural Objects, Artefacts and Humans. Natural Objects include things such as animals, plants, landscape features and celestial phenomena, Artefacts include anything man-made (clothes, vehicles, buildings and so on), and Humans include body parts such as hair, skin, eyes, face and more.

In order to identify any particular pattern typical of non-basic terms, a comparison was made between usages in the three super-domains. Such a procedure should give insight into a writer's particular preferences. Because of the very low numbers of non-basic terms in Morrice and MacKinnon, however, they were excluded from this analysis.

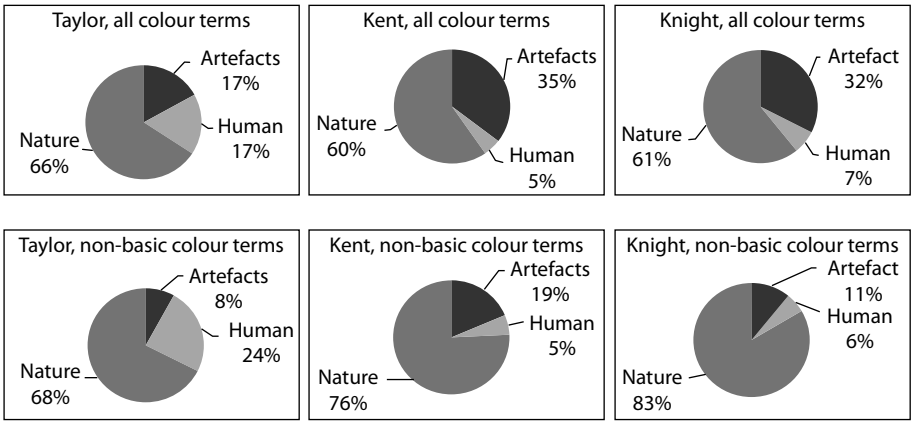

Figure 2. Distribution of colour words among three super-domains in three travelogues

Figure 2 demonstrates that the focus of non-basic colour description is the unfamiliar territory through which the travellers move. It should also be noted that the super-domain of Artefacts has proportionally fewer instances of colour attribution among non-basic terms than the overall figure. On the face of it, this is quite surprising given that the development of non-basic terminology, in the sense of ECTs, has frequently been attributed to naming in the domain of artefacts (cf. Rakhilina & Paramei 2011). Apparently these three travelogue writers, who use colour terms fairly frequently, prefer the specific terms for other things than the expected artefacts. In the final part of this article, I will exemplify this use and discuss possible reasons for and effects of their choices.

8. The effects of non-basic colour terms in texts

The natural phenomenon that inspires these five writers to use ECTs most extensively is the sky, most often in the context of the midnight sun. Light has a significant role in descriptions of the landscape too, in particular when ECTs are used. Consider first Taylor and Kent's descriptions of the midnight sun, and then Knight's of the effect of the rising sun.

> A few bars of dazzling *orange* cloud floated above him, and still higher in the sky, where the *saffron* melted through delicate *rose-colour* into *blue*, hung light wreaths of vapour, touched with *pearly, opaline* flushes of *pink* and *golden grey*. The sea was a web of pale *slate-colour*, shot through and through with threads of *orange* and *saffron*, from the dance of a myriad shifting and twinkling ripples. The air was filled and permeated with the soft, mysterious glow, and even the very *azure*

> of the southern sky seemed to shine through a net of *golden* gauze. (Taylor 1858: 267–268; italics added)
> [A]nd the *golden* glory of the evening has merged in to the pale *apple-green* and delicate *roseate* flush of morning. (Kent 1877: 75; italics added)
> Behind us rose his majesty Sol. *Golden* and glorious from his earth-couch, and lighting with marvellous brilliancy the *white* and *vermilion*-coloured houses in their *emerald* frame. (Knight 1874: 95; italics added)

These three quotations have not only colour precision in common, but also a tone of marvel and almost euphoria (especially in the case of Taylor). This is something that we can see as typical in most descriptions of scenes involving colour precision.

In stark contrast to the above descriptions is Morrice's complete lack of colour words in his description of the midnight sun:

> It was a *queer* sight: the sun itself was bright enough, but did not seem to have much power, and somehow you still imagined it was night; his beams glinted *strangely* on the snow...as we watched the *peculiar* light.
> (Morrice 1881: 26; italics added)

Where the other travellers marvel at the light and the sun, Morrice emphasizes its strangeness, and the whole passage conveys a feeling of uneasiness.

MacKinnon gives no direct description of the sky, and the quotation below is the only example in his book of the landscape being affected by the light:

> ...a glowing light *struggled* through the *blackened limbs* of birch and pine, contrasting *strangely* with the *dark green* outline of mountains upon mountains, rising one above the other in dim distance, clothed in never-ending forest.
> (MacKinnon 1878: 97; italics added)

As in the case of Morrice, a completely different picture is painted compared to those in the quotations from Taylor, Kent and Knight, and it suggests a very different mood.

The issue here, however, is whether the elaborate descriptions in the quotations from Taylor, Kent and Knight help us understand the writers' perception in terms of nuances. It is true that Taylor's description above, using nine non-basic terms, gives us an idea of the midnight sun in terms of the colour and the light. But recall Nowaczyk's 1982 study (see Section 3) which clearly showed a lack of correct matching and correct description among his informants. Can we envisage the nuances correctly? What exact nuance is "a thread of saffron" anyway? I would argue that the main significance of such a specific term lies elsewhere.

These terms evoke other attributes which are potentially more important for the text. The use of non-basic terms such as *saffron, rose, pearly, golden* and *azure* gives access to the attributes of the objects from which they were derived. Figure 3, an elaboration of Figure 1, visualizes what attributes could be activated.

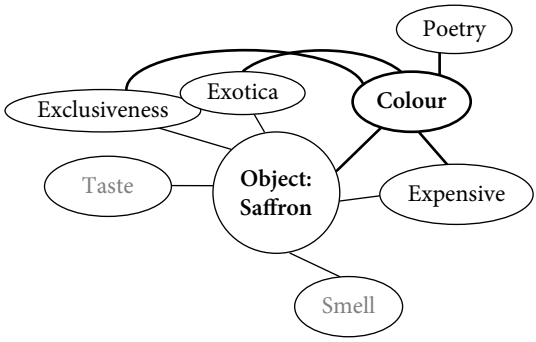

Figure 3. Possible attribute structure evoked by the colour term saffron as used in Taylor (1858: 267-268)

The spice (and dye) saffron has been cultivated at various times in the Middle East and the Mediterranean region, and it was, and still is, very expensive and thus exclusive. It seems likely that attributes such as those in Figure 3 could be evoked by this term. Furthermore, the *Oxford English Dictionary* and the resource *Literature Online* show that *saffron* was occasionally used in descriptions of sunrise and sunset in poetry in the nineteenth century. For the knowledgeable reader, such an attribute could therefore be highlighted. In fact, the knowledge of the reader is crucial as regards which attributes come to the fore. For example, the spice saffron consists of the stigmas of a type of crocus, and they look very much like the threads mentioned by Taylor. Their colour is dark red, so for a reader with this knowledge, "a thread of saffron" could evoke a very precise shade as well as a distinct shape.[3] In the same way, colour terms such as *slate*, *azure, golden* and *rose* give access to a number of attributes outside the domain of colour.

The effect of colour words used in this way has previously been observed by Pratt (1992). Analyzing the rhetoric of Victorian explorer Richard Burton's descriptions of travels in central Africa, she noticed a certain preference for colour terms derived from nouns, many of which were linked to England: "Unlike plain colour adjectives, these add material referents into the landscape, references which all, from steel to snow, tie the landscape explicitly to the explorer's home culture, sprinkling it with some little bits of England" (Pratt 1992: 204). In relation to Pratt's observation, an interesting difference can be found between Kent and Taylor. Colour terms only found in Kent are *apple-green, buff-colour, lavender-coloured, peat*, and *raven* and the more exotic *canary, cerulean blue* and *coral red*. Among Taylor's terms are *alabaster, amber, amethyst, beryl, indigo, ivory, olive, opal, pearl, saffron* and *sapphire*. It appears that Kent is closer to Pratt's African traveller in that she evokes England, whereas Taylor appears to strive in the opposite direction – using terms which in many ways bear attributes linked to the

3. I would like to thank Carole Biggam for her insightful comments which made me aware of the subtle aspects of the semantic network of *saffron*.

Mediterranean or southern latitudes. Taylor does not sprinkle Scandinavia with bits of England but with attributes relating to far more exotic places.

The effect of the choice of colour terms is most obvious in the description of humans, in particular in the description of the Sami people. The Sami speak a Finno-Ugric language and live in the northern areas of Sweden, Finland and Norway. At the end of the nineteenth century, they still led a traditional nomadic life based on reindeer herding, and lived in tents or turf huts. Reading the travelogues, it is obvious that the Sami were perceived as very different, and the choice of words makes the position of the writer explicit. Consider the examples below, all representing first descriptions of the Sami.

> The boat in which these Laps were sailing was of this cut; *dirty-brown*, with one *dirty-brown* mast and a ditto coloured sail, *dirty brown* people inside, and horrible children of the same hue...the man had on a hat, also *dirty brown*, shaped somewhat like a bishop's go-to-meeting headpiece. (Morrice 1881: 25; italics added)
>
> A number of Lapps crowded the place. Diminutive, *yellow-skinned*, swinish-eyed, high-cheek boned, squat-nosed, thick-lipped people, dressed in short skirts. (Kent 1877: 85–86; italics added)
>
> These women were neither remarkably small nor remarkably ugly, as the Lapps are generally represented. The ground-tone of their complexion was rather *tawny*, to be sure, but there was a *glowing red* on their cheeks, and their eyes were a *dark bluish-grey*. (Taylor 1858: 101; italics added)

Kent's use of *yellow* classifies the Sami as different, and throws them into the same category as the Chinese and the Mongols according to the vocabulary of those days. Morrice's use of *dirty brown* is also explicit. Taylor prefers the more ambivalent and almost euphemistic *tawny*, which, nevertheless, is in line with the specific vocabulary he uses in description of Swedes, Finns and Norwegians: *rosy, ruddy, scarlet*, all of which reflect healthiness. Although this is not true of *tawny*, it is interesting to note that this term was frequently used in reference to Arabs in the nineteenth century, in which context an attribute of exoticness can again be evoked.

9. Concluding discussion

Discussing the character of the travelogue as a genre, Lisle (2006: 40) claims that "all travelogues pursue an engagement with difference, with something other than usual... and organise that engagement through categories of subjectivity, space and time". Three key words here are *engagement*, *difference* and *subjectivity*. I believe they are all relevant to an analysis of the use of non-basic colour words.

In this article I have shown that non-basic terms are primarily used by some travelogue writers for descriptions of natural objects. This appears to contrast with ordinary use. It is believed that specific colour terms are most often used with artefacts, in

this way serving a need to distinguish otherwise identical objects. Colour in nature, on the other hand, changes constantly, and therefore such detailed description could be viewed as marked, as described by Cruse (1977), stimulating the reader to access other attributes than that of colour nuance. Using specific vocabulary can also be read as reflecting the engagement, or involvement, of the writer. Categorizing what is different in a detailed manner entails involvement, and in this small study there is a very clear relationship between the use of specific colour terms and the involvement of the writer, and, alternatively, a distinct lack of colour terms appears to reflect a lack of engagement in and a dislike of the difference.

As potential sources of rich associations, Elaborate Colour Terms can be powerful tools in a narrative: an area such as Scandinavia can be made similar to England or to the Middle East. I believe that the use I have described here reflects some travelogue writers' awareness of how ECTs can add to the subjectivity and suggestion of an image.

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SECTION 4

Categorical perception of colour

Preface to Section 4

The categorical perception of colour has proven, over the last forty years or so, to be one of the most controversial areas in the psychology of colour vision. It is not surprising, therefore, that a number of papers presented at PICS08 dealt with this issue.

'Categorical Perception' is a term which refers to the breaking up of a perceptual continuum into discrete chunks, which are often associated with verbal labels. It is generally acknowledged that the approach originated in studies of the auditory perception of speech-like sounds and how these are categorized into recognisable phonemes. The basic idea is that if two physically defined stimuli (e.g. two colours) are given two different verbal labels they will be easy to discriminate, but if they are given the same label they will be hard to discriminate. The interest in this phenomenon comes from the intimate link it appears to demonstrate between language and perception.

The controversy in this approach to colour (and other types of) perception comes from the need to define a perceptual continuum. How can we be sure that the chunking is due to properties of the perceptual system and not to lack of homogeneity in the so-called continuum? If the latter is the case, then demonstrations of categorical perception would simply be reflecting inherent properties of the stimuli, rather than anything about how the perceptual system is organized.

Clifford and co-authors, in the first paper in this section, approach the problem from the viewpoint of cognitive neuroscience and, in their review of the literature on the use of event-related potentials in the investigation of the categorical perception of colour, demonstrate how the search for neural correlates of categorical perception may provide clues as to its nature. Drivonikou and co-authors report an empirical study which uses more conventional behavioural methods to look at the role of training in categorical perception of colour. They find that categorical perception around a newly-defined colour boundary can be learned better in the right visual field than the left, suggesting an effect confined to the Left Hemisphere of the brain (the hemisphere most commonly associated with language processing). Finally in this section, Wright embeds colour categorization into the established body of knowledge on psychophysical "range effects", arguing that the range of stimuli displayed in a given experiment can affect the responses obtained. He argues that these range effects may account for some of the contradictory results previously obtained in colour categorical perception experiments.

The conclusions of all three of these studies of the categorical perception of colour suggest that more research is necessary to clarify the basis of this enigmatic and controversial phenomenon.

Investigating the underlying mechanisms of categorical perception of colour using the event-related potential technique

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Categorical perception (CP) of colour is demonstrated by faster and more accurate discrimination of colours that cross a category boundary than equivalently spaced colours from the same colour category. Despite a plethora of behavioural research investigating the origin and nature of colour CP, the underlying mechanisms involved in the effect are still unresolved. A recent body of work has made use of the Event-Related Potential (ERP) technique, which involves the measurement of event-related brain potentials at the scalp, enabling exploration of the time course of neural processes that are involved in colour CP. The merits of the ERP technique are presented and five studies that have used this approach to investigate colour CP and colour categorization are reviewed. Each is discussed in relation to the debate about the origin and nature of colour category effects.

1. Introduction to the debate

Although the colour spectrum is a physical continuum of light, we perceive it as a series of discrete categories. The categories that make up the colour spectrum are marked by our language in the terms that we use for colour. For example, the English language uses terms such as *red, orange, yellow, green, blue, purple*, etc. to define colour categories, but other languages use different numbers of colour terms and place category boundaries in different locations (e.g. MacLaury, Paramei & Dedrick 2008). As well as being present in language, colour categories are also evident in the way that we respond to colour. Indeed, there appear to be qualitative differences between colour categories, coupled with a heightened discriminability around category boundaries that affects our perceptual and cognitive judgements about colour. For example, it is

easier to distinguish between two colours that are from different categories than two colours that are from the same category, even when chromatic separations are equivalent. This effect is known as 'categorical perception' (Harnad 1987).

Categorical perception (CP) of colour appears to be a robust phenomenon that can be demonstrated using a range of techniques, stimuli, colour spaces and measures. However, there is no clear consensus on the origin of colour categories or the underlying mechanisms of colour category effects. A key point of contention is whether there are universal restrictions on how colour categories form, or whether the way that the colour spectrum is divided up into categories is arbitrary (e.g. Berlin & Kay 1969). There is variation in how the world's languages segment colour space and this may suggest that the formation of colour categories is arbitrary (e.g. Roberson, Davies & Davidoff 2000). For example, the location of colour category boundaries and the number of basic colour terms used differs across languages, and colour lexicons have also been found to evolve over time (e.g. MacLaury et al. 2008). Conversely, investigation of over one hundred of the world's unwritten languages has provided evidence to suggest that the colour naming systems of different languages share some commonality, with statistical tendencies for colour categories to form at certain points in colour space (e.g. Kay & Regier 2003).

Despite a large amount of debate there is currently little agreement on the origin and nature of colour category effects such as CP. The term 'categorical perception' suggests a role for perceptual mechanisms, and some have argued that category effects could be due to greater perceptual discriminability around category boundaries than within categories (e.g. Harnad 1987). This 'warping' of colour space at the boundaries between categories could be innate or pre-linguistic (e.g. Franklin & Davies 2004), or it could be learned under the influence of language, as the Linguistic Relativity hypothesis suggests (e.g. Roberson, Davidoff, Davies & Shapiro 2004). Another possibility is that colour CP could be due to the direct or 'on-line' use of language during task execution, with discriminations made on the basis of verbal as opposed to perceptual codes (e.g. Roberson & Davidoff 2000). Here, the influence of language could be explicit, through the use of category labels. It could also be implicit, involving a category code at the semantic level (Bornstein & Korda 1984), or even some pre-phonological representation such as the 'lemma' (Caramazza 1997).

The relative contributions of perceptual and linguistic mechanisms to colour category effects are unresolved because performance on behavioural tasks used to investigate colour CP could be influenced by perceptual processes, or by linguistic processes, or by a combination of the two. For example, on a 'triads task', where three stimuli are presented and participants must identify the stimulus they think is most different, a stimulus may be selected as the odd-one-out for several reasons. Selection may be made on the basis of a perceptual difference, choosing the stimulus that looks the most different, or, on the basis of a nominal difference, choosing the stimulus with a different name. Alternatively, a stimulus may be chosen as the odd-one-out for both these reasons. Similarly, behavioural studies that measure performance using accuracy and/or reaction times are unable to attribute variations in these measures to specific

cognitive processes (e.g. Luck, Woodman & Vogel 2000). Therefore, behavioural investigations of colour category effects can be problematic as it is difficult for them to isolate the different mechanisms involved in CP and determine the relative contributions of processes such as perception and language. Indeed, the findings of behavioural studies of colour CP present a complicated picture of the roles that language and perception play. Category effects on perceptual tasks such as visual search tasks implicate perceptual mechanisms in colour CP (e.g. Daoutis, Pilling & Davies 2006). Additionally, studies of CP in pre-linguistic infants suggest that language is not the origin of CP (e.g. Franklin & Davies 2004). However, studies of cross-cultural differences (e.g. Roberson et al. 2000), and hemispheric asymmetries (e.g. Gilbert, Regier, Kay & Ivry 2006), point to a role for language in the development and maintenance of category effects, but have not shown conclusively whether language affects perception or whether it is merely used as a task strategy. Studies of category learning have shown that colour CP can be induced following relatively short-term category training (Özgen & Davies 2002), but it is not clear what mechanisms cause acquired CP, or how long they last. Therefore, despite a plethora of research in this area, debate about the underlying mechanisms of colour CP continues.

2. The ERP approach

To further understand the processes involved in colour CP, an alternative approach that builds upon the findings of behavioural studies is required. Electrophysiological measures such as Event-Related Potentials (ERPs) have been used in studies of CP in domains other than colour, for example phoneme CP (e.g. Dehaene-Lambertz 1997) and CP of facial expressions (e.g. Rossignol, Anselme, Vermeulen, Philippot & Campanella 2007). The ERP technique involves the measurement of event-related brain potentials at the scalp, enabling exploration of the time course of neural processes that occur during a defined period of time within which a stimulus is shown or an event occurs. ERP waveforms consist of a sequence of positive and negative voltage deflections, which are referred to as 'peaks' or 'waves', or more generally as 'components'. ERP components relate to specific neural processes and are typically defined by three key features: polarity (whether the peak or wave is positive or negative), latency (the time at which it occurs) and general scalp distribution. The naming of ERP components often takes a format in which the letters 'P' or 'N' are followed by a number. P and N refer to the polarity of a component, indicating positive-going and negative-going components respectively, and the number indicates a component's ordinal position within the waveform. It is possible to measure the amplitude and the latency of ERP components and to apply statistical analyses to these measurements. An example of an adult ERP waveform can be seen in Figure 1.

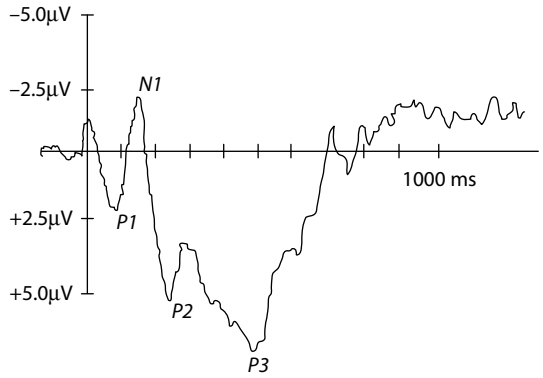

Figure 1. An example of an adult ERP waveform elicited in the 1200 ms interval following stimulus onset. The vertical axis represents amplitude (μv) and the horizontal axis denotes time in milliseconds. The P1, N1, P2 and P3 components are indicated

Because of their excellent temporal resolution, ERPs have the potential to show when in the processing stream categorical effects may occur, and to distinguish early perceptual effects from later post-perceptual ones (see Rugg & Coles 1995). The ERP technique is still a relatively novel approach in the field of colour perception and to date there have only been four studies that have used ERPs to investigate colour CP (Clifford, Franklin, Davies & Holmes 2009; Fonteneau & Davidoff 2007; Holmes, Franklin, Clifford & Davies 2009; Liu, Li, Campos, Wang, Zhang, Qui, Zhang & Sun 2009). In addition, Thierry, Athanasopoulos, Wiggett, Dering and Kuipers (2009) used the ERP technique to investigate effects of colour language on colour perception, making a further contribution to the debate about the origin and nature of colour categories. We review each of these studies in turn.

2.1 Fonteneau and Davidoff (2007): Unattended colour change

Fonteneau and Davidoff (2007) provide the first electrophysiological evidence of colour CP. They recorded ERPs in adults during a visual oddball task. Oddball tasks entail the presentation of infrequent (deviant) stimuli among high-frequency (standard) stimuli, and are particularly appropriate for investigating CP as the waveforms elicited by deviant stimuli correspond to processes involved in event categorization. The task used by Fonteneau and Davidoff required the detection of infrequent cartoon characters amongst a sequence of colour patches. Within each block there were two colours appearing in the sequence, a standard that was presented frequently and a deviant that was presented infrequently. Colours differed only in hue with lightness and saturation kept constant. No differential response to the colours was required, only a response following the detection of the infrequent cartoon characters. The crucial manipulation

was the nature of the difference between the two colours in the sequence, which were either within-category (e.g. two greens) or cross-category (e.g. a green and a blue). The hue difference between stimuli, as specified in Munsell colour space, was the same for within- and cross-category conditions.

Several differences for within- and cross-category conditions were revealed through analysis of the ERP waveforms (using analysis of variance [ANOVA] and Fisher LSD tests for post-hoc comparisons). First, an 'oddball effect' was observed for cross-category and within-category conditions during the 160–200 ms time range, where the deviant elicited an ERP with greater amplitude than the standard. However, for the within-category condition only, this oddball effect was also present during the extended 200–280 ms time range. The extension of the oddball effect for the within-category condition was interpreted as evidence that within-category discrimination was more difficult than cross-category discrimination. Additionally, the morphologies of the 'difference waves' of within- and cross-category conditions from the standard were found to differ. The peak latency (the time at which the maximum amplitude was elicited) for the cross-category difference wave occurred at 195 ms, which was 19 ms earlier than for the within-category difference wave. Fonteneau and Davidoff interpreted this difference in peak latency as a neural correlate for colour CP. This can be linked to a late phase of the N1 component, which occurs after an initial stage of discriminative perceptual processing (Ritter, Simson & Vaughan 1983; see also Vogel & Luck 2000 for a review on the visual N1 component). Thus, it can be argued that this study provides evidence for the involvement of post-perceptual mechanisms in colour CP. However, Fonteneau and Davidoff directed participants' attention away from the colour patches towards the cartoon characters and participants were not aware that the task was even concerned with colour. It is therefore possible that sensitivity to early perceptual effects of colour CP may occur on a different task or on a task where attention is directed towards deviant colour stimuli.

2.2 Holmes et al. (2009): Attended colour change

Holmes and colleagues (2009) also employed the ERP technique to investigate the time course and neural markers of colour CP. They used a visual oddball task that differed in several ways from that used by Fonteneau and Davidoff. Crucially, Holmes et al.'s task required participants' attention to be focused on the coloured stimuli, by instructing them to mentally count the number of deviants occurring in each block. It has been suggested that early perceptual effects of CP are more likely to be exhibited if attention is explicitly directed towards the feature being categorized (e.g. Luck et al. 2000). Additionally, Holmes and colleagues used two deviant colours instead of one, one of which was within-category and the other cross-category. The separation sizes between stimuli were equated in Munsell colour space but were considerably less than Fonteneau and Davidoff's stimulus separations, being more typical of those commonly

used in experiments on colour CP (e.g. Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies 2007). Unlike Fonteneau and Davidoff, Holmes and colleagues also collected behavioural data from a separate group of participants. The behavioural data revealed that participants were faster and more accurate at detecting cross-category deviants compared to deviants that were within-category, thereby confirming the presence of classic CP effects (see e.g. Bornstein & Korda 1984).

ERP analysis (using ANOVA and planned linear [Helmert] contrasts) also revealed the presence of category effects, with differences in the waveforms for within- and cross-category deviants occurring during several time periods. First, greater mean amplitude was elicited during the P2 and P3 time windows for cross-category relative to within-category deviants. The P2 and P3 components (occurring 210–270 and 350–600 ms post-stimulus onset respectively) are linked to post-perceptual stimulus evaluation and typically have larger amplitude for novel or infrequent stimuli (Patel & Azzam 2005). It is possible that verbal labelling contributes to CP during this stage of processing, although the P2 and P3 components can reflect a wide range of post-perceptual processes (e.g. McCarthy & Donchin 1981). This evidence for post-perceptual involvement in colour CP is consistent with the findings of Fonteneau and Davidoff. However, unlike Fonteneau and Davidoff, category effects were also found during earlier time ranges. Cross-category deviants elicited earlier peak latencies compared to within-category deviants for P1 and N1 components, with differences in the waveforms occurring as early as 90 ms post-stimulus onset. Category differences in peak latencies were typically smaller than those found in the Fonteneau and Davidoff study (~6 ms vs. ~19 ms, respectively [effect sizes not provided]). It should be noted, however, that peak latencies were measured from original ERP waveforms in the former case whereas they were taken from difference waves in the latter, and so a comparison of the magnitudes of these effects is not entirely meaningful. The P1 component (80–120 ms post-stimulus) and the early phase of the N1 component (130–190 ms post-stimulus) correspond to early perceptual and sensory processes in the brain (e.g. Polich 1998). These components are primarily sensitive to the physical characteristics of sensory stimuli as well as reflecting manipulations of attention (e.g. Luck et al. 2000). This finding provides evidence for an involvement of early perceptual processes in colour CP, showing stronger early perceptual discrimination for cross- than within-category deviant stimuli.

2.3 Liu et al. (2009): Hemispheric asymmetries

Liu and colleagues (2009) used a combination of behavioural and electrophysiological measures to explore hemispheric asymmetries in colour CP. Several studies have investigated the lateralization of CP using behavioural techniques (e.g. Gilbert et al. 2006), but the ERP technique had not previously been employed. Studies of hemispheric asymmetries offer a novel approach to exploring the origins of colour CP. As the left hemisphere (LH) of the brain is dominant for language, then CP should be

stronger for the LH if language has a role in the effect (e.g. Gilbert et al. 2006). Due to the contra-lateral organization of the brain, if there is a contribution of language, CP should be more pronounced for target stimuli appearing in the right visual field (RVF) than the left visual field (LVF). An LH advantage for colour CP has been demonstrated by several behavioural studies (e.g. Drivonikou et al. 2007; Gilbert et al. 2006; Roberson, Pak & Hanley 2008). A recent study by Siok, Kay, Wang, Chan, Chen, Kang-Kwong and Tan (2009) has also provided functional MRI (fMRI) evidence for the involvement of LH language regions in colour CP. Additionally, the hemispheric asymmetry for colour CP has been found to disappear with verbal interference, adding strength to the argument that linguistic strategies contribute to colour category effects (Gilbert et al. 2006). However, from these findings alone, the nature of the influence of language remains unclear.

Liu et al. used a visual search task that required the detection of a randomly positioned target colour amongst eleven distractors. Stimuli were displayed in a ring around a central fixation point occupying the twelve positions of a clock face. Targets were either from the same colour category as the distractors (within-category) or from an adjacent colour category (cross-category), with chromatic separations for within- and cross-category stimuli equated in Munsell colour space. Participants were required to respond as to whether the target appeared to the right or left of fixation (see Gilbert et al. 2006). Both reaction times and ERPs were analyzed to compare performance on within- and cross-category trials in the LVF and the RVF. The behavioural data revealed that reaction times were faster for cross-category than within-category trials. This was the case for both visual fields, with no significant difference between the LVF and the RVF.

Interestingly, Liu and colleagues' ERP data (for the N2pc component) revealed a different pattern of results to their behavioural data, highlighting the importance of replication using a range of measures. The N2pc (N2 posterior-contralateral) is a component that is commonly exhibited during visual search tasks (e.g. Brisson & Jolicoeur 2007), and arises at around 180–350 ms after stimulus onset, contralateral to the location of the target (e.g. Holmes, Bradley, Kragh Nielsen & Mogg 2009). N2pc activation is thought to reflect the attentional selection of task-relevant stimuli and/or the suppression of irrelevant distractors (e.g. Eimer 1996). Liu et al. found that an N2pc component was elicited by within- and cross-category targets. In the RVF, N2pc amplitude was larger for cross-category targets than for within-category targets (effect size not provided). However, in the LVF there was no difference in the mean amplitude of the two conditions. An ANOVA of stimulus type (within- versus cross-category) by hemisphere (left versus right) was not reported and so it is unclear whether these two pairwise comparisons differed significantly from each other. Liu and colleagues argued that the N2pc for stimuli in the RVF (LH) suggested that there was some kind of linguistic processing of the stimuli that may have enhanced the discrimination of a target amongst distractors with a different name (e.g. a blue amongst greens). It is also conceivable that the presence of category effects in the LVF (RH) in the behavioural

data could have arisen as a result of the transfer of language-related information from the LH to the RH, occurring after (i.e. beyond ~350 ms) the processing indexed by the N2pc (e.g. Roberson et al. 2008). It should be noted, however, that although the presence of CP in the ERP data for targets in the RVF (LH) could have reflected the involvement of linguistic mechanisms, it is also possible that the LH advantage for colour CP might be related to an LH specialization for the perceptual encoding of categorical representations (see Kosslyn, Koenig, Barrett, Backer Cave, Tang & Gabrieli 1989).

2.4 Clifford et al. (2009): Infant effects

Clifford et al. (2009) used the ERP technique to investigate colour CP in seven-month old infants. This was the first ERP study of colour CP in infancy and so provides an insight into the development of the time course and electrophysiological markers of colour category effects. It also builds on the findings of behavioural studies of pre-linguistic CP, offering further evidence of categorical responding in the absence of language (e.g. Franklin & Davies 2004; Franklin, Drivonikou, Bevis, Davies, Kay & Regier 2008; Franklin, Pilling & Davies 2005). Clifford and colleagues used a visual oddball task that was similar to that used by Holmes et al. but specially adapted for use with seven-month old infants. Frequent repetitions of a standard colour were shown, interspersed with infrequent presentations of two deviant colours, one of which was from the same colour category as the standard and the other from a different category. Hue separations between standard and deviants were equidistant in Munsell colour space. Coloured stimuli were displayed in the shape of schematic faces to sustain infants' attention over many trials (e.g. Catherwood, Crassini & Freiberg 1990).

Analysis of the ERP data (using ANOVA and pairwise comparisons with the Bonferroni correction method) revealed differences in the ERP waveforms for within- and cross-category deviant stimuli. These occurred during the time ranges relevant to the three key infant ERP components typically elicited during visual oddball tasks, which are quite different from those that occur in adults. First, the cross-category deviant evoked an Nc component with greater mean amplitude than the standard (d = 1.04), whereas the Nc amplitude for the within-category deviant did not differ from that of the standard. The Nc is an early infant ERP component that arose in Clifford et al.'s study between 250 and 650 ms. It is thought to be a marker of attentional allocation to the stimulus (e.g. Quinn, Westerlund & Nelson 2006). This finding therefore suggests that infants processed the cross-category deviant as if it were notably more different, allocating it more attention than the standard or the within-category deviant, which each received the same amount of attention. The category effect for the Nc indicates that infants first register the categorical status of a colour at least 250 ms after stimulus onset. Second, Clifford et al. found category differences during the time range for the negative slow wave (NSW; associated with novelty detection, Nelson & Monk 2001) and the positive slow wave (PSW; associated with stimulus encoding and working

memory updating, Nelson & Monk 2001), which in this study occurred between 1150 and 1700 ms. Here, there were differences in the amplitude and polarity of the slow waves elicited by within- and cross-category deviants. Although there was a slightly different pattern of results across different electrode sites, the cross-category deviant was found to elicit a greater NSW than the within-category deviant and the standard (all $d \leq 1.50$). Additionally, at some central sites the standard and the within-category deviant were found to elicit equivalent PSW amplitudes. Although the within-category deviant is different from the standard, it appeared to be incorporated into the infants' representation of the standard and processed as if it were the same. Clifford and colleagues conclude that mechanisms involved in both attention, novelty detection and recognition memory play a central role in infant colour CP.

2.5 Thierry et al. (2009): Effects of colour language

A recent ERP investigation by Thierry et al. (2009) explored the effects of colour language on pre-attentive colour perception. Both Greek and English have one basic colour term that includes light and dark green. However, whereas English has one basic colour term that includes light and dark blue, Greek distinguishes light and dark blue with the basic terms *ble* and *ghalazio* (Androulaki, Gômez-Pestaña, Mitsakis, Jover, Coventry & Davies 2006). Thierry et al. compared ERPs elicited from English and Greek native speakers during a visual oddball task in which participants were required to detect occasional coloured squares in amongst a sequence of coloured circles. Within each experimental block, the sequence of coloured circles consisted of a standard that was presented frequently, and a deviant that was presented infrequently. The standard and the deviant were either two different shades of blue (*ble* and *ghalazio*) or two different shades of green. The assignment of colour was counterbalanced so that in one block the standard was *ble* and in another block it was *ghalazio*. Similarly, for green stimuli, in one block the standard was light green and in another block it was dark green. The difference in luminance between the stimuli was equated for blue and green stimulus pairs. The authors aimed to establish whether the blue lightness difference that is marked in the Greek language would be reflected in low-level and pre-attentive stages of perceptual processing.

The results (using ANOVA and follow-up pairwise comparisons) revealed that blue and green deviants elicited a negative ERP component within the time range associated with the visual mismatch negativity (vMMN) component (100–250 ms post stimulus onset). The vMMN is typically evoked in response to infrequent unattended visual events, and has been linked to unconscious pre-attentive change detection and low-level visual processing (e.g. Czigler, Balázs & Pató 2004). Thierry et al.'s data revealed that change detection within the vMMN time range was equivalent across the blue and green deviants for English speakers. For Greek speakers, however, change detection was greater for blue deviants than for green deviants (effect size not provided). The authors attributed this stronger change detection in the blue region of colour

space to the Greek language having two basic colour terms for blue. They concluded that differences in colour language can affect early stages of colour perception and are not constrained in their effects to higher level stages of semantic categorization.

Thierry et al.'s approach offers a novel and effective way of investigating the influence of language on colour perception. However, future studies should ensure that change detection within the vMMN time range truly reflects processes that are independent of attention. It is not entirely clear that this was achieved in Thierry et al.'s study, as a P3 component looked to be present in the grand averaged waveforms for English speakers (indicating possible attention to the colour change). It is conceivable therefore that vMMN effects may have been obscured to an extent by the presence of an overlapping N2b – a component that often arises prior to the P3 in response to infrequent attended targets (Pazo-Alvarez, Cadaveira & Amendo 2003). If English speakers were attending to the colour change then caution is advised when drawing conclusions based on cross-linguistic comparisons of pre-attentive colour perception. Further research is clearly needed to assess the influence of language on early pre-attentive stages of colour perception. If the findings of Thierry et al. are supported, this would suggest that even early perceptual category effects could be modulated by language (see Ting Siok et al. 2009).

3. Summary

ERP studies have provided evidence of colour CP on visual oddball tasks in adults (Fonteneau & Davidoff 2007; Holmes et al. 2009; Thierry et al. 2009) and infants (Clifford et al. 2009), and on visual search tasks in adults (Liu et al. 2009). Fonteneau and Davidoff found category effects in ERPs during stages of post-perceptual processing, which suggests that post-perceptual stimulus classification and target probability contribute to colour category effects. These post-perceptual stages could reflect a range of different processes, including linguistic or memorial mechanisms (e.g. McCarthy & Donchin 1981). Holmes and colleagues' findings also implicate post-perceptual processes in colour CP, but additionally show category effects from as early as 90 ms, demonstrating that early perceptual mechanisms contribute to colour CP. These findings are compatible with those in the auditory domain, which reveal that phoneme CP occurs at a very early stage in processing (e.g. Dehaene-Lambertz 1997). Using a visual search task, Liu et al. found that neural markers of CP were greater for targets in the RVF than the LVF, although CP was present in both visual fields. This finding provides support for laterality effects in colour CP (e.g. Gilbert et al. 2006; Siok et al. 2009), and implicates the involvement of language. Clifford and colleagues provide electrophysiological evidence of colour CP in pre-linguistic infants, attributing these category effects to mechanisms of attention and novelty detection, consistent with studies of infant category effects in other domains (e.g. Dehaene-Lambertz & Baillet 1998; Quinn et al. 2006). Thierry et al. interpret their findings as evidence for effects of language on

early pre-attentive stages of colour perception. If this is the case, it would suggest that colour discrimination is modulated by language even at a perceptual level. However, further research is needed to verify this claim.

These studies provide evidence for the involvement of a range of processes in colour CP, ruling out purely perceptual or purely linguistic explanations. They build on the findings of previous behavioural studies by presenting clearer and more detailed accounts of the mechanisms involved in colour category effects, revealing the time course of colour CP and the relative contributions of perceptual and post-perceptual processes. However, to fully understand the interplay between these mechanisms further research is necessary. For example, further investigation of early perceptual processes is required to clarify whether early colour category effects are related to pre-linguistic colour categories, or whether they reflect a process of language-mediated perceptual change. Additionally, direct exploration of whether the identified neural markers of colour CP are found in populations whose language segments colour space differently would clarify the potential interactions of perceptual and post-perceptual processes. Future studies should investigate whether colour category effects in ERP components extend to category boundaries other than blue-green.

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Category training affects colour discrimination but only in the right visual field

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There is indirect evidence that categorical colour perception (better discrimination of colours from different categories than those from the same category) can be learned. For instance, CP can be induced across a newly learned category boundary (Özgen & Davies 2002). Here we replicate and extend Özgen and Davies's category learning study to try and pinpoint the nature of the changes underlying category learning. Participants learned to divide green into two new categories 'yellow-green'/'blue-green' across four days. The trained group showed CP across the new boundary on a target detection task and this was restricted to the left hemisphere (LH; cf. Drivonikou et al. 2007), whereas the controls did not. The results could suggest that category training produces changes at early stages in visual processing mainly in the LH.

1. Introduction

1.1 Overview

In this chapter, we present evidence that learning new colour categories changes colour discrimination. In particular, discrimination between colours crossing the category boundary is improved relative to discrimination of colours within the new categories. This pattern is the signature of 'categorical perception' (CP) of colour (Harnad 1987). However, this newly learned CP only occurs for stimuli presented to the right of where we are looking (right visual field: RVF). As the information in the RVF is first sent to the left half of the brain, and this hemisphere is responsible for language, it may suggest that language is involved in colour CP.

We begin by outlining the nature of the neural pathways from eye to brain that enable the behavioural isolation of the two hemispheres, at least for briefly presented

stimuli. We then move on to review briefly previous findings, before describing the experiment and its results.

1.2 Background

The optics of the eye combined with the neural pathways from the retina to visual cortex result in stimuli in the right visual field (RVF) being initially represented in the left hemisphere (LH) of the brain, and stimuli in the left visual field (LVF) being initially represented in the right hemisphere (RH), as shown in Figure 1.

This initial segregation of information from the two visual fields has been exploited to investigate whether the two hemispheres of the brain might have different specialist functions. If stimuli are presented briefly (less than 200 ms) in just one visual field, the information is initially available to just the contralateral hemisphere. If the hemispheres differ in their capabilities, then comparing performance when stimuli are presented either in the left or right visual field can reveal differential specializations. For instance, word recognition is better for RVF (LH) stimuli than for LVF (RH) stimuli.

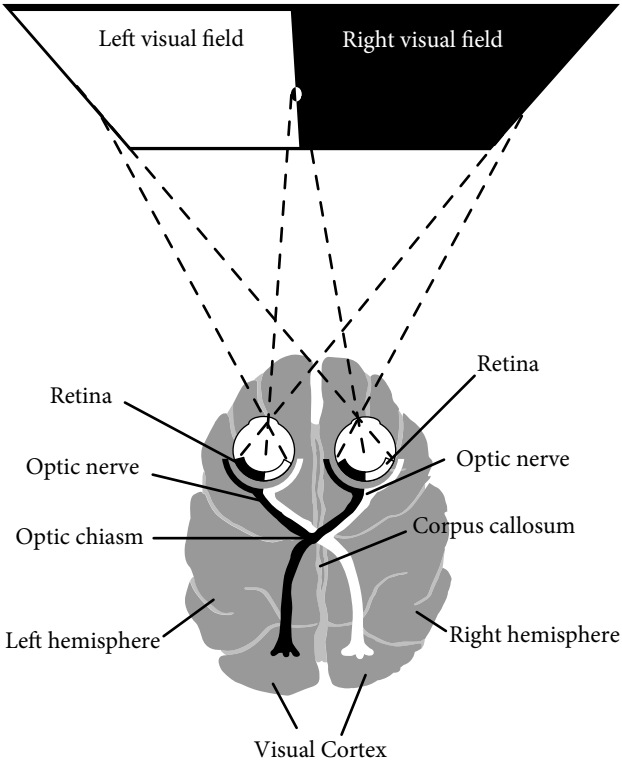

Figure 1. Neural pathways from eye to brain viewed from above: each half-visual field is initially represented in the contralateral visual cortex

Very recently, it has been discovered that the phenomenon of categorical perception (CP) of colour is stronger for RVF (LH) stimuli than for LVF (RH) stimuli (e.g. Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies 2007; Gilbert, Regier, Kay & Ivry 2006). Colour CP is shown by better discrimination of colours that straddle a category boundary than of colours from the same category. For instance, Drivonikou et al. found that detecting the location of a small coloured target on a differently coloured background was faster when the target and background were categorically different (e.g. blue1 on green1) than when they were just physically different (blue1 on blue2). However, this categorical effect was substantially more pronounced for RVF (LH) targets than for LVF (RH) targets.

As the LH is also the 'language hemisphere', Gilbert et al. speculated that the LH bias in colour CP reflects the influence of language on perceptual processes in the LH. Evidence that left hemisphere dominance of colour CP does not arise until colour terms are learned supports this speculation. Colour CP in infants and toddlers – before the acquisition of colour terms – is lateralized to the right hemisphere (RH), and the category effect appears to switch to the LH around the time that the relevant colour terms are learnt (Franklin, Drivonikou, Bevis, Davies, Kay & Regier 2008a; Franklin, Drivonikou, Clifford, Kay, Regier & Davies 2008b). Learning colour terms may highlight similarities among colours given the same term and highlight differences among colours given different terms, leading to within-category compression and between-category expansion of perceptual colour space, particularly for RVF (LH) stimuli.

There is evidence that the plasticity of colour categories apparent during child development might persist into adulthood. For example, Goldstone (1994) showed that learning to categorize stimuli varying in shape and lightness induced CP across the newly learned boundary (see also Goldstone 1998; Goldstone, Lippa & Shiffrin 2001). Indeed, Schyns, Goldstone and Thibaut (1998) argue that, in general, category structure is adaptive, and adjusts to meet tasks demands. There is also evidence that the neuro-physiological substrate of these perceptual changes may occur at early stages of visual processing. For instance, changes have been observed in the tuning of orientation sensitive neurons in V1 (the first visual area in the cortex) resulting from practising orientation discrimination (Schoups, Vogels, Qian & Orban 2001).

Consistent with the idea of sustained category plasticity, Özgen and Davies (2002) found that learning to divide blue or green into two new categories with the boundary at the category prototype induced CP around the newly learned boundaries. Before training, discrimination was worst around the category prototypes (a form of the perceptual magnet effect, Kuhl 1991), whereas after training, discrimination peaked across the new boundary.

1.3 The current study

Although Özgen and Davies showed newly acquired CP, they did not investigate whether the categorical effect varied with the visual field that the stimuli appeared in.

Hence, it is not known whether newly learned CP shows the same LH bias found by Gilbert et al. (2006) and others. The current study sought to address this issue. Participants learned to divide green into two new categories (A and B) using the same methods as Özgen and Davies, but assessed the effect of learning using Drivonikou et al.'s (2007) target detection task which had revealed LH bias in CP. On each trial, a single circular target of one colour appeared on a chromatically different, uniform background. The target and the background could belong either to the same category, e.g. A1 on A2, or to different categories, e.g. A1 on B1. If LH lateralized CP were found following categorization training, it would provide converging evidence of the role of language in colour CP.

As our experiment was based on combining tasks from previously published work (Özgen & Davies 2002 for the category training task, and Drivonikou et al. 2007) we chose to replicate (in all essentials) the methods from the two tasks. One potential drawback of doing so was that the colours in the category training task and in the target detection task appeared in different contexts. In context training, the first colour appeared against a grey background, and, as the task proceeded, the number of comparison colours increased, until finally there were 16 different greens in the display. In the target detection task, each trial started with 1000 ms of black screen with a white fixation cross, followed by about 500 ms of the target colour on a coloured background that filled the monitor. While the difference in context in the two tasks may have induced small changes in colour appearance, we think it unlikely that these could bias the results in favour of the two hypotheses under test. There is no reason to suppose that induced colour changes would lead to improved discrimination around the newly learned boundary relative to within-category discriminations only for the training group. Moreover, we think it even less likely that any artifactual changes resulting from differing contexts would only affect discrimination in the RVF.

A training group learned to divide the green region into 'yellow-greens' versus 'blue-greens' with the category boundary centred on the green prototype (7.5G). Following training, the target detection task was used to compare discrimination that straddled the newly learned boundary with within-category discriminations either side of the boundary. The training group were compared to a control group that just did the target detection task. If category training induced CP, the training group should show peak discrimination around the new boundary, whilst the control group should show poorest discrimination for this region. As a test that any difference between trainers and controls was due to category training, both groups also performed the target detection task for equivalent points in the blue region with no prior category training. If any differences between the groups were really due to training, then there should be no differences between them for the blue stimuli.

2. Methods

2.1 Participants

Forty-nine participants (Mean Age = 20.2 years) were randomly allocated to the training group (16 females and 8 males) and the control group (19 females and 6 males). All had normal colour vision as assessed by the City Colour Vision Test, were right-handed, and English was their first language. All were students at the University of Surrey and received course credits for their participation.

2.2 Training phase

2.2.1 *Stimuli*

The test stimuli were coloured squares (5 cm^2) displayed at the centre of a Sony Trinitron CRT monitor (model GDM-F520) against a background of neutral grey. Stimuli were drawn from a two-dimensional area of Munsell[1] colour space: Hue 5BG-10GY (blue-green to yellow-green) by Value 5–7, at constant Chroma 6. During training, on each trial the test stimulus was drawn at random from the training region with the exception that stimuli within 0.2 Munsell hue units of the boundary were avoided (7.3G-7.7G).

2.2.2 *Procedure*

The training group performed categorization training for three daily sessions and a refresher session on the testing day. They were seated 50 cm away from and at eye-level to the monitor. During training, they learned to categorize all stimuli between 5BG and 7.3G in one category, and those between 10GY and 7.7G in the other category, irrespective of Value. There were two types of category training: 'context training' and 'singleton training', with context training always occurring first.

2.2.2.1 *Context training*. Participants made category judgements while being able to see examples of stimuli they had previously categorized correctly. A randomly chosen colour was presented in the centre of the screen, together with sixteen 'slots' to be filled with the incoming colours divided into two groups: eight slots (two columns, four rows) on each side of the test stimulus (see Figure 2). The participants sorted the test stimuli into two groups around this boundary by placing the colour in the centre into an empty slot on the left or right using left and right arrow keys. The first colour

1. Munsell colours vary on three dimensions: Hue (from red (R) through yellow (Y), green (G), blue (B) to purple (P)); Value or lightness scaled from zero (black) to 9 (white); and Chroma (roughly saturation or purity of the Hue). Extensive standardization produced a set of colours so that the size of the perceived difference between pairs of colours separated by the same number of Hue steps at the same Value and Chroma would not vary across the Hue dimension.

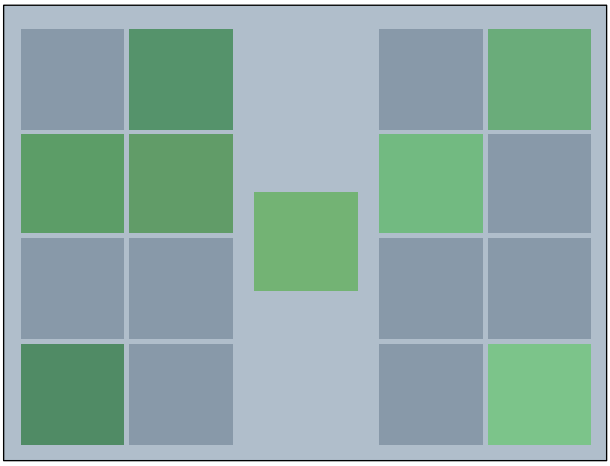

Figure 2. Illustration of stimuli in context training. The central green square has to be categorized by placing it either to the left or to the right among stimuli in the same category

could be placed on either side of the screen, but thereafter colours from the same experimental category had to be placed on the same side. Immediate feedback was given: the colour remained in the slot following a correct response, but disappeared and a sound indicated 'incorrect' if the response was incorrect. The number of colours for comparison increased with correct responses in each block (up to the maximum number of slots available: 16). When they correctly filled all sixteen slots, a 'block' was complete, and a new one began; the cycle continued until the criteria for successful category learning were met. No instructions on what the categorization was based on were given. The first stage of training finished when at least 20 blocks were completed and there were at least three error-free blocks.

2.2.2.2 *Singleton training*. In the second stage of training, single test colours appeared at the centre of the screen. The participant had to decide which of the two categories it belonged to by pressing left or right arrow keys. Incorrect choices were signalled by the word 'incorrect' replacing the test colour, accompanied by a sound. The criteria for finishing this stage were completion of at least 250 trials, and 25 consecutive correct responses.

2.2.2.3 *Refresher phase*. The procedure for the refresher phase on the testing day was the same as for the training phase, except that the criteria for completing training were less stringent than on the training days. The criteria for completing context training were that at least 10 blocks were completed, and there was at least one error-free block. Context training typically took about 10 minutes. The criteria for completing singleton training were completion of at least 100 trials, and 25 consecutive correct responses.

2.3 Target detection task

2.3.1 *Apparatus and stimuli.*

Stimuli were displayed on the same monitor as for category training. There were two within- and two between-category pairs for the green region (see Figure 3a) and two within- and two between-category pairs for the equivalent blue region (see Figure 3b). Participants were not trained to divide the blue region into two new categories; nonetheless, for consistency and ease of reference, the equivalent pairs in the blue region are called within- and between-category pairs. Target-background separations were 5 Munsell Hue steps, with Value and Chroma constant at 6 and 6 respectively (see Table 1 for CIE Y x y chromaticity co-ordinates).

2.3.2 *Design*

On each trial, a single circular target of 30 mm diameter appeared on a chromatically different, uniform background (~ 3.5° of visual angle from the viewing distance of 50 cm). The target could appear in one of 12 equally separated (30°) locations on a notional circle of 110 mm diameter around the fixation cross at the centre of the monitor (~12.5° from fixation). In clock face terms, six locations were in the RVF from 12:30 to 5:30 at hourly intervals and six were in the LVF (6:30 to 11:30). For each colour region (blue or green) there were 168 trials made up from 42 trials for each condition: within-category left, within-category right, between-category left and between-category right, presented in a random order for each subject across trials. The green and blue regions

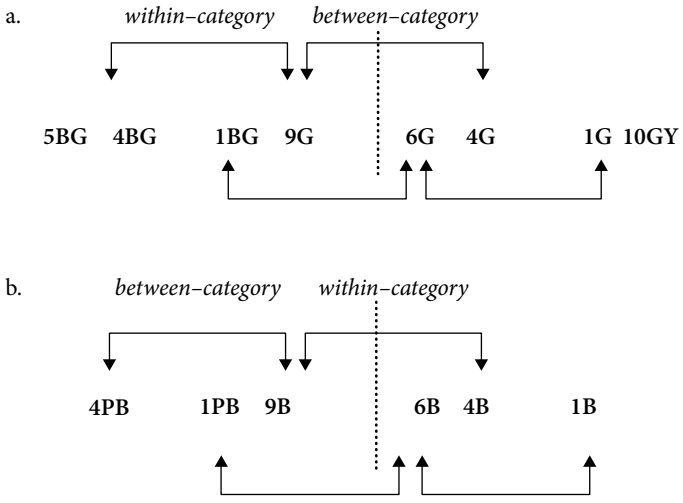

Figure 3. a) The pairs of the stimuli used in the green colour region. Dashed line represents the new boundary (7.5G): there are two within-category pairs, and two between-category pairs. The range of the trained region was from 5BG to 10GY. b) The pairs used in the blue colour region

Table 1. CIE (1931), Y, x, y chromaticity co-ordinates of the stimuli. White point of monitor as measured on screen: Y = 64.80 cd/m^2. The stimuli emulated a reflectance of 30.05

HUE	Y	x	y
4PB	19.47	0.251	0.257
1PB	19.47	0.243	0.263
9B	19.47	0.233	0.276
6B	19.47	0.231	0.283
4B	19.47	0.233	0.297
1B	19.47	0.294	0.575
4BG	19.47	0.245	0.332
1BG	19.47	0.257	0.351
9G	19.47	0.262	0.360
6G	19.47	0.271	0.375
4G	19.47	0.281	0.386
1G	19.47	0.303	0.409

were tested in separate blocks, with approximately half of each group (training and control) doing blue followed by green, and the remainder doing the reverse.

2.3.3 *Procedure*

A trial sequence consisted of a white fixation cross on a black background for 1000 ms, followed by the test display with the target appearing for 250 ms, on the coloured background, which remained present until a response was made. The cycle then repeated. The task was to decide whether the target appeared to the left or right of fixation. Responses were made on a games pad (PCL RP100) with the left index finger indicating left, and the right index finger indicating right. A high-resolution timer DLL (ExactTics) ensured accurate event timing. Reaction times were measured from the onset of the target display until a response was made. No feedback was given during either practice or experimental trials.

3. Results

3.1 Training results

Table 2 shows the mean number of trials across subjects for both types of training across training days and test day. There appears to be a reduction in the number of context training trials across the days of training, especially on the second day. A similar pattern is present for the singleton training trials; however, the improvement is mainly on the second day.

Table 2. Mean number of trials taken to complete context and single colour training across the three days of training and on the testing day (refresher training)

	Day1	Day2	Day3	Test Day	Total
Context Training	844	660	600	197	2301
Singleton Training	335	292	268	116	1011
Total	1179	952	868	313	3312

3.1.1 *Errors in context training across the training days*

The percentage of incorrect context training classifications across all blocks for all three training days was calculated for each subject. Data were analyzed with ANOVAs and follow up t-tests; all reported effects were significant, at least $p < .05$. As Figure 4 shows, errors reduced across the training days.

3.1.2 *Errors in singleton training across the three training days*

The percentage of incorrect classifications for each day on the 'singleton' training trials was calculated for each subject and these are shown in Figure 5. These were analyzed in the same way as for context training. Participants made fewer errors on the second day than on the first day; however, there was not much improvement on the third day.

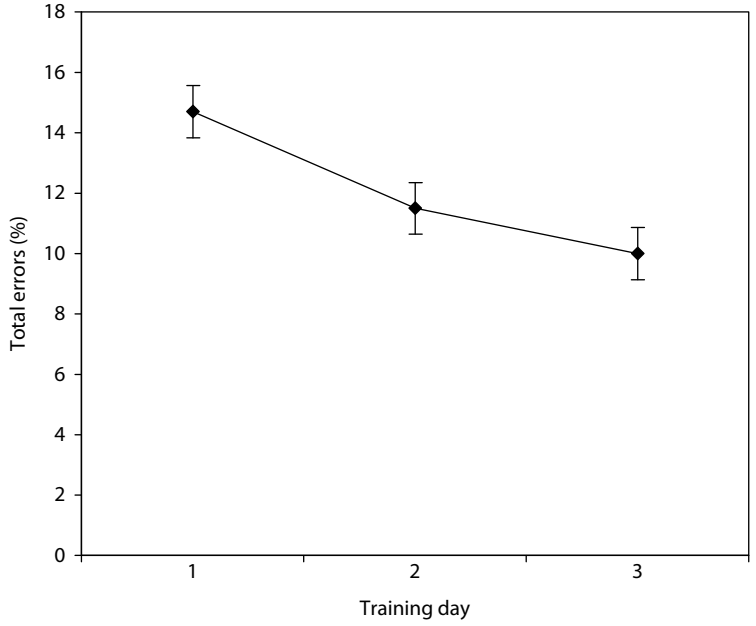

Figure 4. Total percentage errors across the three days of training. Error bars are within-subjects 95% confidence intervals

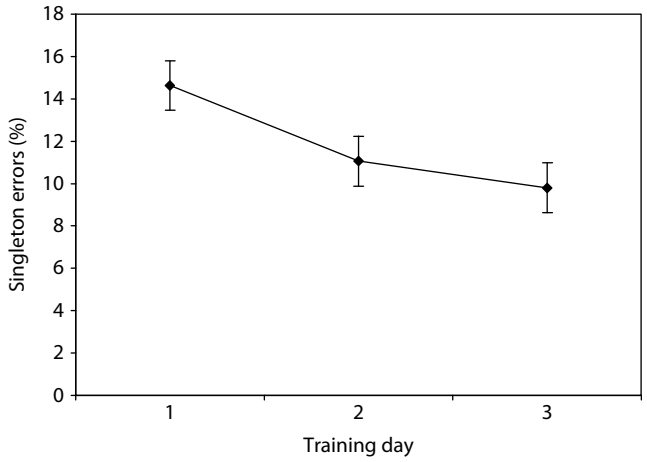

Figure 5. Error percentages on 'singleton' training across the three training days. Error bars are within-subjects 95% confidence intervals

3.2 Target detection results

There were far more errors made in the blue region (~ 30%) than in the green region (~ 2%) by both groups, and therefore the data for the two regions were analyzed separately. Analysis of the green region is reported first followed by the analysis of the blue region. The initial analyses were three-way ANOVAs: category (within/between) by visual field (LVF/RVF) by group (trained/control), with the first two factors being repeated measures. Separate follow-up two-way ANOVAs (category by field) for each group were conducted if the three-way interactions were significant, and they are reported under separate sub-headings.

3.2.1 *Green region*

The percentage of correct responses was calculated for each participant, for each combination of category and visual field. The means across subjects were very similar for the two groups (97.81% and 98.83% for the control and training groups respectively). For each subject, median response times (RTs) for correct trials were calculated for each combination of category (within/between) and visual field (LVF/RVF) for each observer. Figure 6 shows the mean RTs across subjects (mean of the subject's median RTs) for each group.

Analysis showed that within-category responses were about 13 ms faster than between-category responses. In addition, there was a strong 3-way interaction between visual field, category and group. From Figure 6, this appears to be due to the category effect for the trained group in the LVF differing from all the other group-by-visual-field combinations. Specifically, in all combinations, there appears to a reverse-category

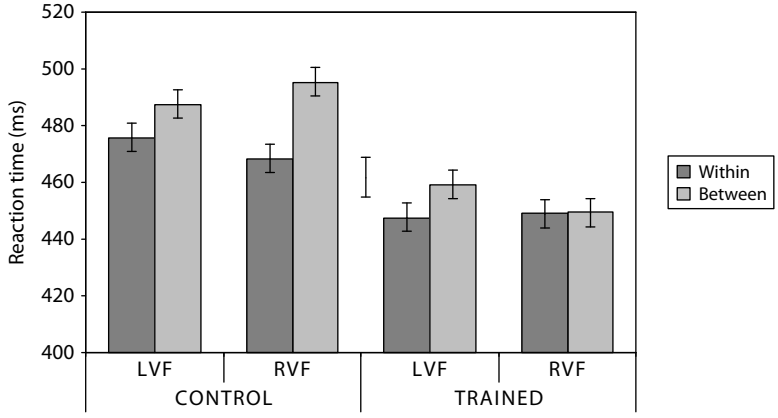

Figure 6. Green region: mean RTs for target detection for the control and the trained group for each combination of visual field and category. Error bars represent 95% within-subject confidence intervals calculated by using the error term from the three-way interaction. Between-subjects 95% CL calculated by using the between groups error term is shown as the separate error bar

effect (within- < between-category), whereas for the training group in the RVF within- and between-category conditions are virtually identical.

3.2.1.1 *Control group.* Analyzing the groups separately showed that for the control group, there was a significant reverse category effect (means: 472 ms and 491 ms for within- and between-category respectively). In addition, as can be seen in Figure 6, this appears to be due to the larger reverse category effect for the RVF than for the LVF: the reverse category effect was on average 17 ms larger in the RVF than in the LVF.

3.2.1.2 *Trained group*. For the trained group, the within-and between-category RTs did not differ. However, there was a two-way category by field interaction. As Figure 6 shows, the interaction reflects a reverse category effect for the LVF, but no such effect for the RVF. Training has nullified the strong RVF reverse category effect shown by the control group.

3.2.2 *Blue region*

The percentage of correct responses was calculated for each combination of visual field (LVF/RVF), category (within/between), and group (trained/control). The percentage of correct responses for the control group was 66.38%, and for the trained group was 72.90%. In addition, participants were more accurate on within- than between-category trials (73.09% versus 66.19% respectively). All other main effects and interactions were not significant. Figure 7 shows the mean RTs for each combination of visual field (LVF/

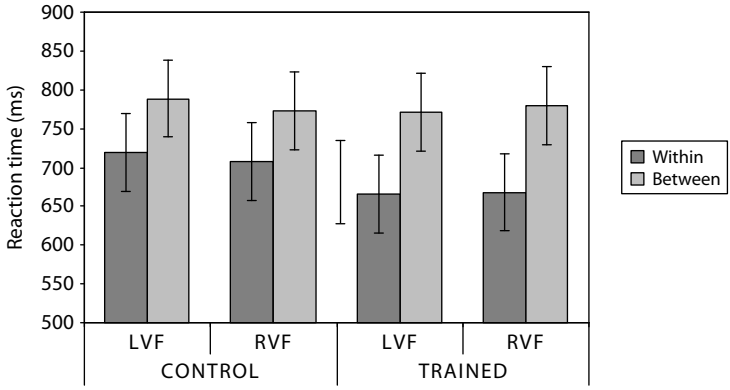

Figure 7. Blue region: mean RTs for target detection for the control and the trained group for each combination of visual field and category. Error bars represent 95% within-subject confidence intervals calculated by using the error term from the three-way interaction. Between-subjects 95% CL calculated by using the between groups error term is shown as the separate error bar

RVF), category (within-between-category), and group (trained/control). A large reverse category effect of about 90 ms was observed. Nothing else approached significance.

To check that the similar RTs for the two groups were not due to different speed-error trade-off functions for the two groups, the above ANOVA was repeated with accuracy as a covariate. The analysis revealed essentially the same pattern as the ANOVA, with category being the only significant effect.

4. Discussion

The trained group were making approximately 10% classification errors at the end of training. All performance measures converge to indicate that categorization improved significantly. However, the largest change occurred between day 1 and day 2 with relatively little change between day 2 and day 3. A prominent feature of the results was that, as expected, there was a clear pre-existing 'reverse-category' effect: discrimination around the category prototypes was worse than discrimination either side of the prototype. This was true for both colour regions. Thus, as in Özgen and Davies (2002), if training were to induce CP around the newly learned boundary, the reverse-category effect had itself to be reversed. Moreover, the reverse-category effect for the controls was primarily present in the LH; if induced CP were to be lateralized to the LH as expected, the scale of the required reversal would be particularly severe. In fact, the training group did not show CP around the new boundary after training. However, there are strong indications that the induction of CP was underway. The reverse category

effect was eliminated in the RVF for the training group, consistent with between-category expansion and acquired distinctiveness. It seems likely that, with more training, full CP may have been induced. Performance in the blue region indicates that the partially induced CP resulted from category learning rather than some odd pre-existing difference between the two groups. All combinations of visual field and group showed a clear reverse-category effect, and there were no differences between the control and training groups. Additionally, the results for the blue region show that the effects of training were restricted to the training region, as with Özgen & Davies (2002).

We were surprised that the target detection for blue colours was much harder than for green colours. Özgen and Davies found that they were about equally difficult. Moreover, the test colours were chosen so that the target-background differences in the two regions were the same number of Munsell Hue steps. One possible reason for poor performance for blue pairs is that detection time as measured by simple RT is substantially slower for good blues than for any other colour (McKeefry, Parry & Murray 2003). Detecting a blue target relies almost entirely on the short-wavelength retinal cone (S cone), and the responses of the S cone appear to be slower than those of the long medium and long-wavelength cone (see e.g. Bompas & Sumner 2008). Özgen and Davies used target colours presented at fixation, and they remained on the monitor until a response was made. In addition, their dependent variable was accuracy rather than RT. In the present experiment, to fulfil the requirements of lateralizing the stimuli, the target was presented away from fixation, and for just 250 ms. It appears that this is not long enough for reliable detection of a blue target.

As Özgen and Davies (2002) argued, category training could provide an intensive version of the category learning undergone by children learning colour terms. The fact that the learning effect was restricted to the LH is consistent with previous studies showing that LH colour CP only occurs if the boundary is within the linguistic repertoire of the individual (Roberson, Pak & Hanley 2008; Franklin et al. 2008b).

Neuro-physiological evidence shows changes resulting from practice at early stages of visual processing. For instance, small changes have been observed in the slope of neural tuning within V1 resulting from practice on an orientation discrimination task (Schoups et al. 2001). Moreover, on the target detection task, target-pop-out is unlikely to be influenced by on-line labelling. On these grounds, it appears that genuine perceptual change must have occurred. Nevertheless, labelling may have been used during categorization training. Although not required to, participants may have generated labels to help them learn the new categories, and these personal labels could have been available to them to affect performance (somehow) on the target detection task. The LH lateralization of the learning effect is consistent with the possibility that language (albeit implicitly) may be involved even in these seemingly low-level tasks. Alternatively, learning, possibly guided by labelling, could have induced changes in perceptual representations in the LH that were different to changes produced in the RH. In conclusion, the findings suggest that category training leads to greater perceptual change in the LH than the RH.

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Effects of stimulus range on color categorization

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This chapter reports three experiments detailing the influences of stimulus range on color categorization. The results show that both categorization and speed of categorization of colorful stimuli can be influenced by stimulus range. Two potential consequences are considered. First, the influences of stimulus range on color categorization can help explain inconsistencies in the color literature relating to the reliability of color categorization. Second, the same influences appear relevant to the interpretation of experiments investigating color categorical perception.

1. Introduction: Color categorization and range effects

This chapter reports three experiments addressing the issue of whether (and to what extent) changed range contexts influence judgments about color. A range effect would be shown if, for instance, a stimulus categorized most often as 'blue' when embedded in one stimulus range is categorized as 'green' most often when embedded in a different stimulus range. Differences in the time taken to categorize a stimulus contingent on its location in a stimulus range would be another kind of range effect.

Little work has been done investigating the influence of range on color judgments. Mitterer and de Ruiter (2008) provide data suggesting that range effects do not influence color categorization. This is somewhat surprising since numerous studies show other kinds of psychological judgments are influenced by stimulus range (e.g. Crawford, Huttenlocker & Engebretson 2000; Hollingworth 1910; Parducci 1965; Petzold 1982; Petzold & Haubensack 2004; Watson 1957).

Stimulus range might influence performance in several different ways. What Hollingworth (1910: 462) called the "central tendency of judgment'" suggests that stimulus estimates are biased towards the center of a presented range. A related idea, proposed by Parducci (1965) and Petzold (1982), is that participant reference scales are adjusted to the endpoints of the subjective range. Poulton too (1973, 1974, 1989)

has given detailed consideration of range effects and their influence in within-subjects experimental designs.

In studies that show influences of stimulus range on categorical judgments, the categories used have usually been those for which participants must establish their own standards, such as size judgments (Parducci 1965; Petzold & Haubensak 2004). It is possible therefore that the lack of a range effect for color categorization reported by Mitterer and de Ruiter (2008) stems from differences between color categories and other categories, such as size, which have a more arbitrary basis.

Another reason to be interested in the possible effects of range on color categorization relates to a lack of clarity concerning the reliability of color categorization and in particular the 'sharpness' of category boundaries. Berlin and Kay (1969: 13) suggested that:

> Category boundaries are not reliable, even for repeated trials for the same informant... In fact, in marked contrast to the foci, category boundaries proved to be so unreliable, even for an individual informant, that they have been accorded a relatively minor place in the analysis.

Rosch Heider (1972) makes a similar point, classing stimuli located away from focal regions of color space 'internominal', whilst Kay and McDaniel (1978) proposed that color categories be considered fuzzy sets.

On the other hand, much evidence suggests that color space is categorized more cleanly than the previous paragraph suggests (e.g. Boynton & Gordon 1965; and particularly Bornstein & Korda 1984). Similarly, Malkoç, Kay and Webster (2005) found that English speakers identified a boundary between blue and green categories more consistently than the best example of either color.

Such differences may be partially explicable in terms of differences in response categories available to participants and also by differences in the lightness and saturation of stimuli used in differing experiments. But variations in stimulus range used in differing studies of categorization might also help explain the different results obtained. Such an explanation, though, would only be valid if stimulus range can be shown to influence categorization.

Finally, the potential influence of stimulus range on color categorization relates to color categorical perception (CP). CP is the idea that, all other things being equal, discriminations between stimulus pairs belonging to different categories are made more reliably and/or faster than discriminations made between pairs belonging to the same category. Numerous studies have combined colorful stimuli and tasks such as target detection and visual search (e.g. Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies 2007; Gilbert, Regier, Kay & Ivry 2006; Roberson & Davidoff 2000). Results show that, although performance of these tasks would not appear to require explicit categorization of the stimuli used, categorization nevertheless seems to influence performance. Better understanding of the factors which may influence color categorization should lead to a deeper understanding of color CP. This, in turn, has a bearing on

theories of linguistic relativity (e.g. Whorf 1956), which suggest that differences in language lead to differences in thought and perception.

2. Experiments 1a, b and c

Participants in the three experiments reported here were native Turkish speakers. The experiments were 2-alternative-forced-choice tasks (2-AFC). In such experiments participants are required to decide which of two descriptors, such as 'green' or 'blue', most accurately describes a given stimulus. To manipulate stimulus range, each experiment used two conditions. Some stimuli were present in both conditions, others in only one or other of the conditions.

The three experiments differed primarily in the region of color space from which stimuli were drawn. Stimuli in Experiments 1a and b came from the region of color space named '*mavi*' and '*yesil*' by Turkish speakers. These correspond to English terms 'green' and 'blue' (Özgen & Davies, 1998). Stimuli in experiment 1c came from regions of color space named '*mavi*' and '*mor*', corresponding to English term 'purple' (Özgen & Davies 1998). For the sake of clarity, English color terms will be used when referring to stimuli used in the experiments.

2.1 Participants

There were a total of 131 participants divided almost equally among the three experiments. All had normal color vision, tested using pseudoisochromatic plates (Ishihara 2003). Table 1 gives details of the participant who took part in each of the experiments.

2.2 Experiment 1a: Apparatus, stimuli and design

The experiment was run using a personal computer and a sixteen inch LG 710S CRT monitor. Display was controlled using a GeForce 6200 LE graphics controller. Colorimetric measurements were made using a Cambridge Research Systems colorCAL.

Table 1. Response categories and participant details for experiments 1a, b and c. (Abbreviated column headings: Exp. = Experiment)

		Participants		
Exp.	Response Type: 1/2	Number in each condition	Mean age (S.D)	Sex
1a	green/blue	45 (C1 = 23, C2 = 22)	21 y. 9m. (33m.)	19F, 26M
1b	green/blue	45 (C1= 22, C2 = 23)	22y. 4m. (34 m.)	24F, 20M
1c	blue/purple	46 (23 in each condition)	21y. 1m. (37 m.)	26M, 20F

Conversions between CIE and Munsell color spaces were made using tables provided by Wyszecki and Styles (1982).

Stimuli were nine Munsell defined colors varying only in hue. Hues ranged from 7.5G to 7.5B in steps of 2.5 hue units and spanned the green–blue region of color space. Stimuli were of value 7 and chroma 8. Stimulus 7.5G was the greenest-appearing stimuli, 7.5B the bluest. Previous research has indicated that 7.5BG marks the boundary between blue and green categories (Bornstein & Korda 1984). Stimuli were presented as 36 mm squares in the center of the display corresponding to a visual angle of 4.1° from the viewing distance of 500 mm. Stimuli were shown singly against a gray background of identical luminance. Following the experiment the colorimetric properties of stimuli were rechecked. These measurements confirmed stimuli properties had remained stable.

2.2.1 *Experiment 1a: Procedure*

There were two conditions: 1 and 2. Each condition used seven stimuli. In condition 1 the stimuli were 7.5G, 10G, *2.5BG (1), 5BG (2), 7.5BG (3), 10BG (4)* and *2.5B (5)*. In condition 2 stimuli were *2.5BG (1), 5BG (2), 7.5BG (3), 10BG (4), 2.5B (5)*, 5B and 7.5B. Numbers in parentheses indicate labeling of stimuli in Tables 2 and 3. The five italicized stimuli were common to both conditions. Thus, in addition to the five stimuli common to both conditions, participants in condition 1 categorized two extra greener stimuli, those in condition 2 categorized two extra bluer stimuli.

Stimuli were presented for categorization singly and in a random order seven times each, making a total of forty-nine trials. Participants were instructed to categorize the stimuli as either 'green' (type 1 response), or 'blue' (type 2 response) using the left or right mouse buttons. Response keys were counterbalanced across participants. During stimulus presentation, two prompts, in size eighteen black font, appeared on the top left and right of display, indicating which mouse button corresponded to which response. Stimuli remained displayed until a response was recorded. A two second unfilled interval followed, after which the next stimulus was displayed. Participants sat approximately 500 mm from and at right-angles to the display in a small dark room. Participants were instructed to perform the task as rapidly and accurately as possible. For each trial, response type (1 or 2) and response time were recorded.

2.3 Experiments 1b and 1c: Apparatus, stimuli, design and procedure

Experiments 1b and 1c differed from experiment 1a only in the stimuli used. In Experiment 1b, stimuli were of the same hue as those in Experiment 1a, but of lower value (6) and saturation (6). In Experiment 1c, stimuli were of the same value and saturation as in Experiment 1a, but of different hues: 7.5B, 10B, *2.5PB (1), 5PB (2), 7.5PB (3), 10PB (4), 2.5P (5)*, 5P and 7.5P. Numbers in parentheses indicate labeling of stimuli in Tables 2 and 3. The five italicized stimuli were common to both conditions. Stimuli 7.5B and 10B were present in condition 1 only; stimuli 5P and 7.5P were

present in condition 2 only. Previous research suggests that the boundary between blue and purple categories lies around 7.5PB (Franklin & Davies 2004) or 10PB (Roberson, Davidoff & Braisby 1999).

In Experiment 1b, the forced choice response categories were the same as those used in Experiment 1a. In Experiment 1c, the response categories were 'blue' (type 1) and 'purple' (type 2), as shown in Table 1.

2.4 Results of experiments 1a, 1b and 1c

No participants reported being unable to categorize stimuli using the categories provided.

The analyses below are confined to data produced by the five stimuli that occurred in both conditions within each experiment, labeled 1 to 5 in Tables 2 and 3. Stimulus 3 represents the centrally located stimulus within the entire stimulus range used in each experiment. In Experiments 1a and 1b, this is the stimulus with hue of 7.5BG; in Experiment 1c, the corresponding stimulus hue is 7.5PB.

Table 2. Proportion type 2 responses made in Experiments 1a, b and c for stimuli 1 to 5. For each experiment, the average proportion of type 2 responses made by participants in conditions 1 and 2 is shown, as is the combined responses of participants across both conditions. The lowest three rows give data combined across all experiments, for conditions 1 and 2 separately (corresponding to Figure 1) and, in the bottom row, combined across all experiments and conditions. Standard deviations are in parentheses. (Abbreviated column headings: Exp. = experiment, Cond. = condition, Comb. = combined.)

		Stimulus					
Exp.	**Cond.**	**1**	**2**	**3**	**4**	**5**	**All**
a	1	0.03 (0.09)	0.29 (0.31)	0.84 (0.18)	0.97 (0.12)	0.97 (0.10)	0.62 (0.43)
	2	0.02 (0.06)	0.02 (0.09)	0.30 (0.36)	0.83 (0.21)	0.99 (0.03)	0.43 (0.46)
	Comb.	0.02 (0.08)	0.15 (0.26)	0.57 (0.40)	0.90 (0.23)	0.98 (0.07)	0.53 (0.45)
b	1	0.02 (0.05)	0.42 (0.34)	0.85 (0.19)	0.99 (0.04)	1.00 (0.00)	0.65 (0.42)
	2	0.02 (0.06)	0.06 (0.13)	0.29 (0.32)	0.79 (0.32)	0.96 (0.07)	0.42 (0.44)
	Comb.	0.02 (0.05)	0.23 (0.31)	0.56 (0.39)	0.89 (0.25)	0.98 (0.06)	0.54 (0.45)
c	1	0.00 (0.03)	0.06 (0.13)	0.69 (0.39)	0.94 (0.13)	0.98 (0.05)	0.42 (0.45)
	2	0.02 (0.05)	0.04 (0.06)	0.27 (0.34)	0.81 (0.34)	0.97 (0.09)	0.54 (0.47)
	Comb.	0.01 (0.04)	0.05 (0.10)	0.48 (0.42)	0.87 (0.27)	0.98 (0.08)	0.48 (0.46)
All	1	**0.02** (0.07)	**0.26** (0.31)	**0.80** (0.26)	**0.96** (0.11)	**0.98** (0.07)	0.60 (0.45)
	2	**0.02** (0.05)	**0.04** (0.10)	**0.29** (0.33)	**0.81** (0.33)	**0.98** (0.09)	0.43 (0.45)
	Comb.	0.02 (0.06)	0.14 (0.25)	0.48 (0.40)	0.89 (0.25)	0.98 (0.07)	0.51 (0.45)

Table 3. Response times (in milliseconds) made in Experiments 1a, b and c for stimuli 1 to 5. For each experiment, average participant response times in conditions 1 and 2 are shown separately, as are combined response times across both conditions. The lowest three rows give data combined across all experiments, for conditions 1 and 2 separately (corresponding to Figure 2) and, in the bottom row, combined across all experiments and conditions. Standard deviations are in parentheses. (Abbreviated column headings: Exp. = experiment, Cond. = condition, Comb. = combined)

		Stimulus					
Exp.	**Cond.**	**1**	**2**	**3**	**4**	**5**	**All**
a	1	844 (538)	1435 (865)	1292 (658)	760 (354)	717 (293)	965 (861)
	2	670 (105)	691 (217)	1189 (1292)	1462 (1252)	812 (436)	1010 (842)
	Comb.	755 (389)	1055 (722)	1239 (985)	1119 (984)	765 (373)	987 (761)
b	1	724 (231)	1331 (768)	1092 (1079)	700 (189)	693 (186)	950 (568)
	2	686 (122)	820 (517)	1339 (879)	1059 (456)	844 (370)	908 (656)
	Comb.	705 (183)	1069 (694)	1218 (979)	883 (392)	771 (301)	929 (619)
c	1	687 (162)	1203 (545)	1109 (672)	840 (448)	712 (125)	859 (526)
	2	645 (118)	650 (112)	1133 (850)	1085 (648)	780 (181)	911 (568)
	Comb.	666 (141)	915 (694)	1122 (761)	968 (568)	748 (159)	884 (554)
All	1	**752** (352)	**1323** (847)	**1164** (819)	**767** (346)	**708** (210)	942 (628)
	2	**667** (115)	**719** (331)	**1219** (990)	**1200** (860)	**812** (340)	923 (667)
	Comb.	708 (261)	1012 (702)	1192 (908)	990 (695)	761 (288)	933 (647)

For each participant, for each stimulus, the proportion of type 2 responses ('blue' for Experiments 1a and b, 'purple' for Experiment 1c) was calculated. Data generated were combined across participants within each experimental condition as shown in Table 2. Similarly, for each participant, median response times to each stimulus were calculated and then combined across participants within each experimental condition, as shown in Table 3. Figure 1 shows, combined across experiments, the mean number of type 2 responses made in separate conditions. Figure 2 gives corresponding data for response times. Examination of these figures suggests that, overall, there are different patterns of performance between conditions.

Data for categorical response times and categorical responses were analyzed separately in 2 (Condition: 1, 2) X 3 (Experiment: 1a, 1b, 1c) X 5 (Stimulus: 1, 2, 3, 4, 5) mixed ANOVAs. Bonferroni corrected t-tests were used for subsequent comparisons. The analyses below report only significant main effects and interactions.

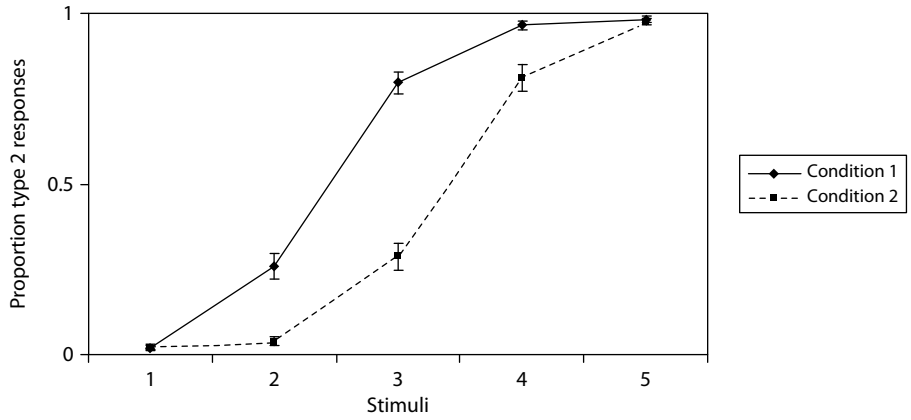

Figure 1. Combined data from experiment 1a, b and c showing proportion of type 2 ('blue' in experiments 1a and b, 'purple' in experiment 1c) responses (±1S.E.) in conditions 1 and 2. Data correspond to the numbers in bold in Table 2

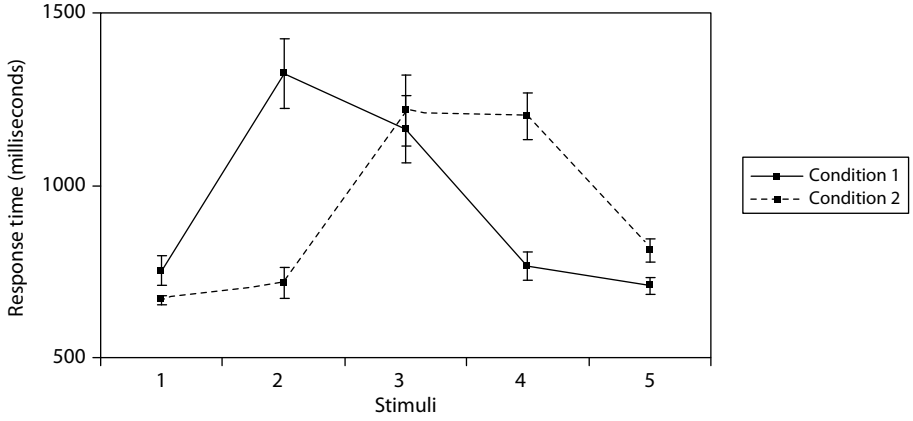

Figure 2. Combined data from Experiment 1a, b and c showing mean response times (±1S.E.) in conditions 1 and 2. Data correspond to the numbers in bold in Table 3

3. Categorical responses

3.1 Main effects

All the main effects were significant. A main effect of condition, F (1, 130) = 84.49, MSE = 262.83, $p < 0.001$, indicates participants in condition 2 gave significantly fewer type 2 responses than participants in condition 1. The main effect of experiment,

F (2, 130) = 3.73, MSE = 11.59, $p < 0.05$, indicates participants in Experiment 1c gave fewer type 2 responses than participants in Experiments 1a or 1b, min. t (89) = 3.21, max. $p < 0.05$. The main effect of stimulus, F (4, 520) = 717.45, MSE = 1222.78, $p < 0.001$, indicates significantly different response patterns between all stimuli pairs, min. t (135) = 3.74, max. $p < 0.01$, with stimulus 2 receiving more type 2 responses than stimulus 1, stimulus 3 receiving more type 2 responses than stimulus 2, and so on.

3.2 Condition by stimulus interaction.

A significant two-way interaction was found between condition and stimulus, F (4, 520) = 42.16, MSE = 71.85, $p < 0.001$. This reflects differences in responses to stimuli 2, 3 and 4 in different conditions, min. t (134) = 3.86, max. $p < 0.001$, with fewer type 2 responses to those stimuli being made by participants in condition 2.

3.3 Experiment by stimulus interaction.

A significant interaction found between experiment and stimulus, F (4, 520) = 2.23, MSE = 3.80, $p < 0.025$, appears due to stimulus 2 receiving type 2 responses less frequently in Experiment 1c than in either Experiment 1a or 1b, min t (89) = 1.34, max. $p < 0.001$.

4. Response times

4.1 Main effect

There was a significant main effect of stimulus, F (4, 520) = 17.85, MSE = 5358618, $p < 0.001$, with significant differences in response times between all stimuli, min. t (135) = 2.83, max. $p < 0.05$, except for the following stimulus pairs: 2 and 3, 2 and 4, and 1 and 5. For the significant differences, response times were always higher for stimuli closer to the center of the overall range used in the experiments, that is closer to the stimulus numbered 3 in Table 3.

4.2 Condition by stimulus interaction.

A significant two-way interaction between condition and stimulus, F (4, 520) = 16.20, MSE = 4861948, $p < 0.001$, reflects differences in response to stimuli 2 and 4 in different conditions, min. t (134) = 4.18, max. $p < 0.01$. Responses to stimulus 2 were slower in condition 1 (where that stimulus is closer to the center of the stimulus range), with the opposite pattern for stimulus 4.

5. Discussion

5.1 Summary of experiments and results

Experiments 1a, b and c were forced choice categorization experiments involving color stimuli. Each experiment involved two conditions, with participants in both conditions categorizing seven stimuli seven times each. In each experiment five stimuli were common to both conditions, the other two were unique to each condition.

Comparison of the stimuli common to both conditions in each experiment revealed differences between conditions in the patterns of categorization, visible in Figure 1. In Experiment 1a, for example, participants in condition 1 categorized the five stimuli common to both conditions as 'blue' more frequently than participants in condition 2. This difference in performance reflects the influence of the two extra greenish colored stimuli in the stimulus set named by participants in condition 1.

Response times to individual stimuli also differed depending on condition, as shown in Figure 2. In general, responses took longer for stimuli located closer to the center of each condition's stimulus range.

5.2 Stimulus range and color categorization

Stimulus range influences performance of forced choice color categorization experiments of the kind described here. The effects were found to be broadly similar in three differing regions of color space. Stimulus range influences not only the frequency with which particular categorical responses are made, but also the time required to produce responses. These influences manifest themselves over the course of only forty-nine trials. It seems probable that in experiments involving larger numbers of trials, range effects would be larger.

However, there are also significant differences between response patterns made in experiments 1a, b and c. That such differences exist shows, unsurprisingly, that task performance is influenced by factors besides stimulus range.

In the introduction, three reasons for investigating the effects of stimulus range on color categorization were mentioned. One concerned the failure of a previous experiment (Mitterer & de Ruiter 2008) to find such an effect. The second reason relates to an apparent paradox in the literature on color categorization. Whilst some researchers have concluded that the divisions between color categories are clear cut (e.g. Bornstein & Korda 1984), others (e.g. Berlin & Kay 1969) have drawn different conclusions. Finally, it was suggested that understanding the influences of range on color categorization can help us understand more about color CP.

There are several potential explanations for the differences between the results of Mitterer and de Ruiter's (2008) study and this one. As is mentioned above, differences in performance between the three experiments described here suggest that factors besides stimulus range influence categorization. Mitterer and de Ruiter (2008) used a

wider range of stimuli. Their stimulus range also included more prototypical stimuli – that is, stimuli considered to be the best examples of the categories they represented. These factors may be sufficient to eliminate the effects of stimulus range on categorization. Further experiments could determine the issue. However the results reported here confirm that psychological judgments about color are, like many other kinds of psychological judgments, influenced by stimulus range.

Influences of stimulus range can also help explain disagreements over the categorization of regions of color space away from category centers. The results of experiments described here seem to show that, in a 2-AFC task, changing the location of stimuli within a range can influence the consistency with which they are categorized.

If during a forced-choice-categorization experiment, the suspected location of a category boundary is located at the center of the stimulus range, then range effects are likely to influence the results. In particular, if the boundary stimulus is the one at the center of the stimulus range, then it is likely that range effects will enhance the apparent sharpness of a category boundary. Alternatively, range effects might also lead to a particular stimulus being categorized less consistently than others, and hence identified as the stimulus closest to the boundary. Using a different range, a different stimulus may likewise be identified as that closest to the boundary. Thus a stimulus identified as being closest to a boundary may only be identified as such in virtue of the context in which it is presented. Range effects may also mask individual differences in color categorization.

Consequently, disagreements over the categorization of colors located away from category centers may be partially explicable in terms of differences in the range of stimuli used by different researchers, as well as differences in experimental techniques (especially multiple versus single trials involving individual stimuli) which influence participant assessment of stimulus range.

Finally, studies of color CP often include a 2-AFC categorization task prior to a main task assessing CP (e.g. Gilbert et al. 2006; Roberson & Davidoff 2000), using a stimulus range that straddles the suspected category boundary. Some potential consequences of this procedure have just been mentioned. In the experimental phase, something similar happens, with participants being exposed to equal numbers of stimuli belonging to each of the previously established categories.

If, as is claimed (Gilbert et al. 2006; Roberson & Davidoff 2000), CP is underpinned by active classification of stimuli, then in research using this methodology, the strength of CP might be enhanced by range effects – because stimuli either side of the center of the range are categorized less ambiguously than if they are located at the center of the stimulus range.

On the other hand, time taken to categorize stimuli increases as stimuli are located closer to the center of the range. If CP is underpinned by classification of stimuli then range effects might be expected to reduce the effect of CP in situations where the category boundary is located at the center of the stimulus range and the experimental measure is the speed of discrimination. The reason is as follows. A CP effect is found

when discriminations between stimulus pairs belonging to different categories are made more reliably and/or faster than discriminations made between pairs belonging to the same category. But if stimuli comprising the across-category trials are drawn from close to the center of the stimulus range, as is usually the case, categorizing these stimuli should take longer than if they were located towards the ends of the stimulus range. Conversely within-category stimulus pairs are usually drawn from the ends of the stimulus range, locations where categorization is faster.

To investigate, experiments assessing CP could be carried out involving two conditions, one in which the suspected category boundary is located at the center of the stimulus range used, another in which the boundary is located away from the center of the stimulus range. Comparison of the results in each condition would aid assessment of the influence of range effects on color CP. This in turn can further understanding of the mechanisms driving CP.

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SECTION 5

Individual differences in colour vision

Preface to Section 5

The concept that there are large individual differences in colour vision abilities is familiar to many. We probably all know somebody (probably a male) who is (sic) 'colour blind', and sees colours differently from others. Of course, most 'colour blind' individuals are not completely blind to colour as such, but suffer from colour confusions due to genetic differences in the structure of their cone photoreceptor pigments. The chapter by Lillo et al. deals with this type of colour vision difference and explores the practical consequences of this condition. The remaining chapters in this section, however, explore individual differences in colour vision that are less commonly known.

Franklin and Sowden review recent literature on colour vision in Autism Spectrum Disorders (ASDs). ASDs are developmental disorders which are largely characterized in terms of difficulties with social interaction, but it is increasingly becoming clear that sensory processing differences are also a factor in this group of disorders. These sensory differences are not only potentially problematic for the individuals concerned but may also shed light on the neurological basis of ASDs.

Synaesthesia is a condition whereby individuals experience sensations in one sensory domain whilst being stimulated in another. One of the most common forms of this cross-modal perception involves colours evoked by, for example, verbal or textual presentations of words, letters or numbers. Simner's chapter reviews recent research on colour sensations in synaesthesia: a condition which her own research has suggested is much more common than previously thought. The chapter by Smith and co-authors explores a specific sub-domain of synaesthesia: colours induced by speech sounds. As with ASD, exploration of the specific manifestations of synaesthesia can help us to understand not only what might be the neural basis of this condition, but also how colour processing is organized with respect to other visual modalities (like text processing) and other sensory modalities (like audition).

In the final chapter in this section, Walter explores the controversial 'lens brunescence' hypothesis, whereby the ubiquity of the 'grue' colour category in studies of colour naming (i.e. a single colour term which is used to name objects/colours that are described as either green or blue by English speakers) is explained in terms of the yellowing of the lens of the eye due to excessive exposure to sunlight.

This section effectively demonstrates the wide range of colour-related phenomena which are experienced by different groups of individuals which not only inform us about the scientific basis of these differences but also have deep ramifications for our understanding of typical colour vision.

Colour and autism spectrum disorders

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There is converging evidence for atypical perception in those with Autism Spectrum Disorders (ASD). This chapter reviews a series of studies that have initiated the investigation of colour perception in ASD. Research is reviewed that identifies effects of colour on reading speed, visual discrimination and atypical behaviour in ASD. We also review research that suggests that encoding of colour is atypical in those with ASD, and studies that provide evidence for reduced chromatic discrimination in those with the disorder. The theoretical and practical implications of investigations of colour perception in ASD are highlighted. Avenues for further research are suggested that could clarify how those with ASD process and experience the world of colour.

1. Background

Autism Spectrum Disorders (ASD) are pervasive neuro-developmental disorders, varying in severity, that are characterized by impaired non-verbal and verbal communication, atypical social cognition, and the presence of repetitive and stereotyped behaviours. In addition to these defining characteristics there also appears to be atypical perceptual and sensory functioning in ASD, including atypical perception of motion, auditory perception, visual search and visuo-spatial perception (for reviews, see Dakin & Frith 2005; Simmons, Robertson, McKay, Toal, McAleer & Pollick 2009). Although perception and cognition in ASD has received a relatively large amount of research interest, up until recently the domain of colour had been largely neglected. This is surprising given widespread anecdotal evidence from those with ASD and their parents and carers, which suggests that colour is experienced differently by those with the disorder. For example, anecdotal evidence highlights the incidence of colour obsessions in those with ASD (such as only eating food of a particular colour) and heightened sensitivity or aversions to certain colours. A series of recent studies has initiated the experimental investigation into the experience of colour in ASD. These studies have investigated the impact of colour on reading speed, visual discrimination and atypical behaviour in ASD (Ludlow, Wilkins & Heaton 2006, 2008; Ludlow & Wilkins 2009), and have also considered whether perception and

discrimination of colour in ASD is enhanced or reduced (Heaton, Ludlow & Roberson 2008; Franklin, Sowden, Burley, Notman & Alder 2008; Franklin, Sowden, Notman, Gonzales-Dixon, West, Alexander, Loveday & White 2010). The aim of this chapter is to provide an overview of these initial studies, and also to highlight avenues for further research.

2. The impact of colour on reading speed, visual discrimination and atypical behaviour

Two studies have investigated the impact of colour on reading speed and discrimination of visual images in children with ASD (Ludlow et al. 2006, 2008). There is converging evidence that coloured lights, spectacles with coloured filters, or coloured overlays placed on text can reduce perceptual distortions and increase reading speed (e.g. Irlen 1991; Wilkins, Lewis, Smith & Rowland 2001). The use of coloured overlays can lead to a 5% increase in reading speed for around 20% of typically developing children (Wilkins et al. 2001), with similar rates of improvement for reading accuracy (Wilkins, Jeans, Pumfrey & Laskier 1996), and similar rates of improvement for adults (Evans & Joseph 2002). The benefits of coloured overlays appear to be even stronger in children with ASD, with the percentage of children who have a 5% increase in reading speed when using coloured overlays significantly higher in ASD than in typical development. For example, Ludlow et al. (2006) found that 79% of high-functioning children with autism improved their reading speed by at least 5% when using a coloured overlay, compared to 16% of a control group of typically developing children matched on age, gender, verbal ability and pre-overlay reading speed. These benefits are only found when the colour of the overlay is selected by the children with the aim of making reading easier, and are not found when the colour of the overlay is their favourite colour (Ludlow et al. 2008). A higher percentage of children with ASD than controls also have a 5% or more increase in speed when using an overlay on a matching-to-sample task using picture stimuli (Ludlow et al. 2008). There is also anecdotal evidence (e.g. Williams 1999) and a case study (Ludlow & Wilkins 2008) that argues that wearing of coloured filters in spectacles can reduce atypical behaviours in those with ASD. For example, a case study of J. G., a child with autism, claims that the child experienced fewer episodes of vomiting, that co-ordination, social skills and exam performance improved, and that the frequency of burn-out periods was reduced when wearing glasses with coloured filters. This is a fascinating case study, yet whether or not coloured filters can reliably reduce atypical behaviours of those with ASD awaits experimental investigation.

One theory of the effect of coloured filters and overlays on visual distortions is that those who benefit from them have hyperexcitability of certain regions of the cortex and that coloured filters and overlays reduce the hyperactivation by changing the distribution of cell firing across the cortex (e.g. Wilkins 2003). It is argued

that different colours reduce different regions of hyperactivation, and that this explains why individuals vary in which colour they choose for the filter or overlay (e.g. Ludlow et al. 2008). There is evidence for atypical activation of the cortex in ASD and over-functioning of neurons in the primary visual cortex (e.g. Villalobos, Mizuno, Dahl, Kemmotsu & Müller 2005), and there is also fMRI evidence to suggest that others who benefit from coloured filters or overlays (e.g. those with migraines: Huang, Cooper, Saatana, Kaufman & Cao 2003) have cortical hyperexcitability. However, direct evidence that indicates that coloured filters or overlays reduce cortical hyperexcitability has not yet been provided so at this stage the account is only speculative.

These studies on the effect of colour on reading speed and discrimination of visual images in children with ASD illustrate the potential for research on colour in ASD to lead to therapeutic interventions (as for J. G.), and also the potential to provide insight into the underlying neural mechanisms of the disorder. Further research into the underlying mechanisms of these effects, and also research which considers the other ways in which colour may affect other aspects of perception, cognition and behaviour in ASD will be beneficial. It is known that colour can affect perception, cognition and behaviour in many ways. For example, colour can affect local-global processing (e.g. Maier, Elliot & Lichtenfeld 2008; Mehta & Zhu 2009), cognitive performance (e.g. Elliot, Maier, Moller, Friedman & Meinhardt 2007), creativity (e.g. Mehta & Zhu 2009), performance in competitive sports (e.g., Hill & Barton 2005), and mood (e.g. Yildirim, Akalin-Baskaya & Hidayetoglu 2007). Little is known about these effects of colour during typical development, let alone whether or how these effects manifest themselves in atypical development and developmental disorders, so further research here could be beneficial.

3. Perception and discrimination of colour in ASD

Various theories, such as the Enhanced Perceptual Functioning theory (e.g. Mottron, Dawson, Soulières, Hubert & Burack 2006) suggest that perceptual processing and discrimination is atypical in ASD. So far, three studies have directly investigated colour perception and discrimination in ASD (Heaton et al. 2008; Franklin et al. 2008; Franklin et al. 2010). Heaton et al. tested a group of children with autism with associated learning disability, a typically developing (TD) control group matched on age, and a moderate learning disabilities (MLD) group matched on non-verbal cognitive ability. On a triads task the ASD group were less accurate than the typically developing group when selecting the hue that was different out of a set of three different hues. However, the MLD group also showed this disadvantage, indicating that the difficulty in selecting the different hue for the ASD group was not specific to ASD but was rather related to lower non-verbal cognitive ability. The lack of an identical control task that uses stimuli varying along a dimension other than hue also means that the

ASD group may have difficulty with the general task (choosing the odd-one-out) rather than the processing of colour. Another task, a colour association task, required participants to remember four pairings of colours and animal pictures. Participants were then given an animal and asked to identify the paired hue. Phase 1 asked participants to choose the hue from the original set of hues (red, green, blue, yellow). Phase 2 asked participants to choose the hue from a set of hues that were from the same category as the paired hue (e.g. red1, red2, red3). All groups of children were above chance in phase 1 (the TD group were best), yet only the ASD group were above chance for phase 2. It was reasoned that in phase 2, as the hues were all the same name, a verbal labeling strategy (remembering the associations using the names of the colours) could not be relied on, so only those using a perceptual strategy (remembering the shade of the colour) could succeed. In line with this, there was a negative association between verbal ability and phase 2 performance. Therefore, the success of the ASD group on phase 2 led Heaton et al. to argue that the children with autism "remembered the exact shades of the paired colours, rather than relying on the category name" (2008: 7).

The findings from the colour association task could suggest that those with ASD are more likely to encode colour perceptually than linguistically. However, caution is required. First, the ASD group had a significantly lower verbal mental age than both MLD and TD groups. Therefore, it is possible that it is verbal ability rather than ASD that is important here. Second, it needs to be established whether a potential bias to perceptual rather than linguistic encoding is specific to colour (or even colour association tasks), or whether it is actually a more general processing style that is found across perceptual domains. Finally, some of the findings do not appear to be consistent with the argument that the ASD group were encoding colour perceptually. If responding was entirely perceptual we may expect performance to be much better in phase 1 than in phase 2 of the experiment, as in phase 2 the set of colours to choose from was more perceptually similar. However, performance for the ASD group does not appear to be significantly different between the two phases. Whether or not colour is encoded atypically in ASD needs to be further explored in studies that will tease apart the different ways of encoding colour. Tasks that may be useful are triads tasks where the odd-one-out is linguistically or perceptually isolated or sorting tasks where multi-dimensional scaling can provide a map of perceptual space. In order to be able to attribute any group differences in linguistic or perceptual encoding of colour to autism, control groups matched on age, non-verbal and verbal cognitive ability would be needed. Likewise, in order to be able to attribute any group differences to differences in processing of colour, then identical control tasks where stimuli differ along a dimension other than colour should also be used.

Two other studies have investigated perceptual processing and discrimination of colour in ASD (Franklin et al. 2008; Franklin et al. 2010). Both of these tested high-functioning young adolescents with ASD and had a control group matched on age and non-verbal cognitive ability. Experiment 1 of the first study assessed

performance on recognition memory and visual search tasks, where targets and distractors were from the same colour category and varied in hue, saturation and lightness. The ASD group were less accurate at remembering the coloured target or identifying the coloured target out of a grid of coloured distractors than the TD group, yet were equally as good when stimuli differed in form rather than colour. Experiment 2 used a target detection task where the location of coloured targets had to be identified when shown on same or different category coloured backgrounds that differed in hue to the target (e.g. Franklin, Pilling & Davies 2005). As for Experiment 1, accuracy of target detection was worse for the ASD than the TD group, yet when accurate, those with ASD were as fast as the TD group. Additionally, the influence on discrimination of the categorical status of the target in relation to the background was equivalent for the ASD and TD groups, with both groups showing faster discrimination of targets on different- than same-category backgrounds. The lack of a control task in Experiment 2 means that we cannot be sure that the lower accuracy for the ASD group on the target detection task is due to a difficulty with colour rather than a general difficulty locating targets. However, the findings from Experiment 2 align with those in Experiment 1 (where a control task was used) which suggests that high-functioning adolescents with ASD have less accurate colour perception than in typical development. The equivalency of the categorical effect for the ASD and TD group suggests that, despite less accurate colour perception, the categorical structure of perceptual colour space in high-functioning ASD is intact.

A second study used two tasks that are traditionally used to directly measure chromatic discrimination (Franklin et al. 2010). Experiment 1 assessed performance on the Farnsworth-Munsell 100 hue test (Farnsworth 1943) which is a colour vision test widely used to identify disorders of colour vision. The test involves ordering a series of stimuli spanning the complete hue circle with small incremental hue differences between adjacent stimuli. The amount of error in ordering stimuli reflects the accuracy of chromatic discrimination and the amount of errors on 'red-green' and 'blue-yellow' axes of colour vision can also be computed (Smith, Pokorny & Pass 1985). A control task involved ordering an achromatic series of stimuli that varied from black to white. The ASD group made significantly more errors on the chromatic Farnsworth-Munsell 100 hue task than the TD group, and the poorer performance for the ASD group was found on both 'red-green' and 'blue-yellow' axes of colour vision. The number of errors for the TD group was in-line with the test norms for that age group (Kinnear & Sahraie 2002), yet the number of errors for the ASD group was closest to the test norms for children three years younger. The ASD group were as good as the TD group at ordering achromatic stimuli, suggesting that the poor performance on the hue task was not due to difficulty understanding task instructions or ordering stimuli. However, the achromatic task also appeared to be easier than the chromatic task, so the achromatic task does not adequately control for task difficulty.

Experiment 2 of Franklin et al. (2010) estimated chromatic thresholds using a psychophysical threshold discrimination task (Sowden, Davies, Notman, Alexander

& Özgen 2011). Participants had to decide the direction (left or right) of a colour defined boundary that was created by colouring two halves of a circle differently. The chromatic difference of the two halves of the circle was adjusted using a Zippy Sequential Testing (ZEST) algorithm (King-Smith, Grigsby, Vingrys, Benes & Supowit 1994) which is a procedure that sets the difficulty of the next trial on the basis of the participants' previous responses, and which homes in on a threshold at a pre-defined point on the psychometric function. Chromatic thresholds were estimated for stimuli varying only along the s axis of the MacLeod-Boynton (1979) colour space (variation in S-cone signal), and for stimuli varying only along the l and m axis of the MacLeod-Boynton (1979) colour space (variation in ratio of L- and M- cone signals). As a control task, luminance thresholds were also estimated using the same task and procedure, where the two halves of the circle were coloured but varied in luminance rather than hue. The ZEST procedure for both chromatic and luminance versions of the task was set to estimate thresholds at 82% correct performance, ensuring that task difficulty for the colour and control tasks was equivalent. The ASD group had significantly elevated chromatic thresholds compared to the TD group for both axes of the MacLeod-Boynton colour space (the average jnd [just-noticeable-difference] was 2.64ΔE units larger in CIE L*u*v*, 1976 space for the ASD than TD group). There were no significant differences between the ASD and TD groups in luminance thresholds, indicating that the elevated chromatic thresholds for the ASD group could be attributed to reduced chromatic discrimination rather than task difficulty or task demands.

The findings of Experiment 1 and Experiment 2 of Franklin et al. (2010) both suggest that high-functioning adolescents with ASD have, on average, reduced chromatic discrimination compared to typically developing adolescents matched on age and non-verbal cognitive ability. Although the control task for Experiment 1 was not adequately matched in difficulty to the colour task, the findings from Experiment 2, where control and colour tasks were matched in difficulty, validates the interpretation of the group differences as being due to reduced chromatic discrimination. The findings from both experiments suggest that reduced chromatic discrimination is due to a general reduction in chromatic sensitivity rather than a selective deficit in one of the underlying subsystems of colour vision. The finding of reduced chromatic discrimination is consistent with the reduced accuracy of the ASD group compared to the TD group on the colour memory, search and target detection tasks in Franklin et al. (2008). It therefore appears from these two studies that high-functioning adolescents with ASD, on average, have reduced chromatic discrimination that affects colour memory and colour search.

Neither of these studies assessed the verbal mental age (VMA) of participants, and it should be considered whether potential difference in VMA for ASD and control groups is the source of the apparent reduced chromatic discrimination (Simmons et al. 2009). The performance of the ASD groups cannot be due to a poorer understanding of task instructions or a different use of language on the tasks relative to controls, as the

control tasks, where there were no group differences in performance, had identical language demands. There is some evidence to suggest that colour terms can change perceptual sensitivity around chromatic, but also luminance defined, colour category boundaries (e.g. see Thierry, Athanasopolous, Wiggett, Dering & Kuipers 2009). One could argue that reduced chromatic discrimination in ASD is somehow linked to a reduced influence of colour terms on colour perception in ASD due to lower VMA. However, this account is difficult to reconcile with the data of the threshold discrimination task of Franklin et al. (2010) where discriminations were from the same colour category, and where stimuli for the luminance control were actually also coloured. We therefore do not consider verbal ability as a plausible explanation for the findings, yet it is agreed that, for future studies, assessing VMA would be useful to characterize the abilities of the samples. It is likewise important that future research, unlike all of the research conducted on colour and ASD so far, fully characterizes the clinical diagnoses of their samples, rather than only relying on DSM IV (American Psychological Association 1994) diagnoses (Simmons et al. 2009).

Reduced chromatic discrimination may seem surprising in the context of anecdotal reports of strong colour obsessions in some individuals with ASD. However, colour obsessions may be related to processes other than discrimination, such as the process of mapping experiences or emotions onto colours (Simmons 2011); for example, those with colour obsessions may have an atypically strong tendency to form colour associations with significant objects or events in their lives. Additionally, although there were significant group differences, there was still some individual variation. Therefore, not all high-functioning adolescents with ASD should be expected to have less accurate colour perception than in typical development, but it is possible that those individuals who have colour obsessions may indeed have hypersensitivity in particular regions. Further research is needed to explore these individual differences and also to investigate whether reduced chromatic discrimination is found for those with other forms of ASD, such as ASD with associated learning disability and Aspergers, which were not investigated in the previous research (Franklin et al. 2008, 2010). Also of interest is how chromatic discrimination varies across the lifespan in those with ASD. In typical development, chromatic sensitivity improves throughout childhood, peaking at late adolescence and reducing thereafter (e.g. Knoblauch, Vital-Durand & Barbur 2001). Reduced chromatic discrimination for those with ASD at the age that we tested may just represent a delay, with the peak in sensitivity occurring a little later. Alternatively, chromatic discrimination may be atypical throughout development.

It is also important to consider whether the size of the reduction in chromatic sensitivity for the ASD groups compared to the control groups has an impact on how colour is experienced in everyday life. For example, based on the Farnsworth-Munsell 100 Hue Test norms, the ASD group were delayed in chromatic discrimination by three years, and the difference in jnd in perceptual space on the chromatic discrimination task was fairly small (but nevertheless reliable). At present, it is unknown whether a

difference in chromatic sensitivity of this size will have a real impact on how those with ASD experience and process colour in everyday life, especially considering that there are often luminance and other cues present to support discrimination in our everyday experience of colour. However, further research that considers how those with ASD interact with colour in their everyday life is needed to explore the practical implications of reduced chromatic discrimination in ASD. For example, are educational interventions that rely on colour less effective for those with ASD than those without?

It is clear that much more research on chromatic discrimination in ASD is needed. As well as the potential educational and clinical implications of this research, the research could also provide insight into the neural basis of the disorder. As there is some knowledge of the neural basis of chromatic discrimination, identifying atypical chromatic discrimination could give insight into the types of neural disturbances found in ASD. The investigation of other types of perception in ASD has led to various neural models of ASD such as atypical magnocellular functioning (Milne, Swettenham, Hansen, Campell, Jeffries & Plaisted 2002), atypical dorsal stream processing (Spencer, O'Brien, Riggs, Braddick, Atkinson & Wattam-Bell 2000), overfunctioning of neurons at V1 and reduced synchrony with other cortical areas (Caron, Mottron, Bertiuame & Dawson 2006), and increased neural noise (Simmons, McKay, McAleer, Toal, Robertson & Pollick 2007; Simmons et al. 2009). Some of these theories cannot explain reduced chromatic discrimination in ASD (e.g. atypical magnocellular functioning), although the neural noise model could potentially explain both reduced chromatic discrimination and atypical perception in other domains. Further experimental and psychophysical research will be essential to test these theories further (see Simmons et al. 2009). In addition, the Event-Related Potential approach could be useful to establish the time course, and underlying mechanisms of atypical perception in ASD and fMRI will continue to give insight into the neural basis of atypical perception in ASD. All of these techniques should be useful in the further investigation of colour perception in ASD.

4. Conclusions

This chapter has provided an overview of research that has started to investigate how those with ASD process and experience colour. This research has shown that colour affects reading speed and visual discrimination in a greater proportion of children with ASD than in typical development (Ludlow et al. 2006; Ludlow et al. 2009), and a case study suggests that colour can be used as a behavioural intervention (Ludlow & Wilkins 2009). Several studies have suggested that colour perception is atypical in ASD (Heaton et al. 2008; Franklin et al. 2008, 2010), and two studies have demonstrated that colour discrimination, memory and search is reduced in high-functioning adolescents with the disorder relative to typically developing controls (Franklin et al. 2008; Franklin et al. 2010). The research on colour and ASD conducted so far makes

an important first step to understanding colour perception and cognition in ASD. However, much more research is needed to obtain a comprehensive account of how those with ASD experience the world of colour. This chapter has suggested avenues for further research that could have implications for educational and clinical practice, whilst also providing greater insight into the neural basis of the disorder.

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Red-Green dichromats' use of basic colour terms

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We describe Red-Green dichromats' use of basic colour terms and compare this with naming errors predicted by metameric equivalence derived from confusion lines in CIE (International Commission on Illumination) coordinates. After briefly reviewing previous work, the results from two tasks – prototype selection and colour term mapping – are presented. Dichromats' choice of prototype was surprisingly similar to that of typical observers, especially for primary BCTs. More errors were made in the mapping task by including stimuli that were similar in transformed lightness and that shared a confusion line with stimuli that typical observers included in the range of the given term. Additionally, evidence was obtained that use of BCTs was dependent on residual R–G (red-green) mechanism activity.

1. Background

Up until now there has been no research that provides an integrated view of how Basic Colour Terms (BCTs) are used by 'colour blind' people, i.e. those diagnosed as 'red-green dichromats'. Previous work, despite its limitations, has revealed the kind of information that dichromats' use to select a colour name, and we briefly review this work in the first part of this chapter. In the second part, we report the most relevant results from a recent study (Lillo, Moreira, Álvaro & Davies 2011) which avoided the limitations of earlier work. As will be shown, in some circumstances dichromats' use of BCTs is reasonably accurate, and confusions that are found in clinical diagnosis are rare under natural viewing.

Typical colour vision is trichromatic. The retina contains three different kinds of cone receptors that differ in their relative sensitivity to wavelength. They are usually known as L (long), M (medium) or S (short), referring to their peak wavelength sensitivity. Within the retina, these three kinds of cone signals are recombined into two chromatic channels and one luminance channel (see Wuerger & Parkes 2011). One chromatic channel – red-green (R-G) – signals the difference between L and M (L–M),

and the other – blue-yellow (B-Y) – signals the difference between the sum of L and M, and S ((L+M) – S). However, there is a relatively common form of inherited 'colour blindness' known as red-green dichromacy (R–G dichromacy) where either the L cone (protanopes) or the M cone (deuteranopes) is missing. The red-green channel now signals either (L-L) or (M-M), thus conveying no useful information. Consequently, there are sets of colours that are indistinguishable for red-green dichromats – they are 'metamers' – that are perceptually distinct for typical observers.[1]

Books on defective colour vision (e.g. Birch 2001) include chromaticity diagrams, such as Figure 1, showing dichromat 'confusion lines' that predict stimuli that should be metamers for dichromats but perceptually distinct for typical observers. All stimuli of similar lightness or brightness on a confusion line should be indiscriminable for a given type of dichromat (protanope or deuteranope).

For typical observers, brightness (aperture colours) and lightness (surface colours) depend on the responses of L and M cones. Consequently, these colour parameters are altered for people who, like the dichromats, lack a certain cone type. However, it is possible to infer dichromats' brightness-lightness perception level from the response in the cone type that they do have (L or M; see, for example, Lillo & Moreira 2005). In the rest of this paper we will refer to 'transformed brightness' and 'transformed lightness' (L_T*) to differentiate these inferred parameters from the CIE (International Commission on Illumination) standard ones.[2]

Figure 1 shows a subset of protanope confusion lines radiating from the confusion point (grey rhombus, u′ = .66; v′ = .50; a hypothetical stimulus that only produces

1. Stimuli that are physically different but perceptually identical are metamers (they produce the same colour experience). For example, typical observers see the same white in response to an isoenergetic stimulus (Stimulus 1, the same amount of energy in every wavelength) or to a mixture of two complementary lights (Stimulus 2, for example, a mixture of 480 nm and 580 monochromatic lights). Stimuli 1 and 2 are metamers because, being physically different, they produce the same perceptual experience (white).

2. According to CIE recommendations (Hunt 1998: 65), the following equation can be used to compute surface colour lightness (L*).

$$L^* = 116\left(\frac{Y}{Y}\right)^{1/3} - 16$$

Y and Y_n are the luminances of, respectively, the target stimulus and the reference white. For a typical observer, luminance values are determined by the weighted response of the L and M cones. Such responses can be inferred using standard luminance and chromatic coordinates (x and y). For protanopes, transformed luminance values (Y_T and Y_{nT}) depend only on the M-cones response. For deuteranopes, they depend only on the L-cones response. Transformed luminance values allow the computing of transformed lightness (L_T*).

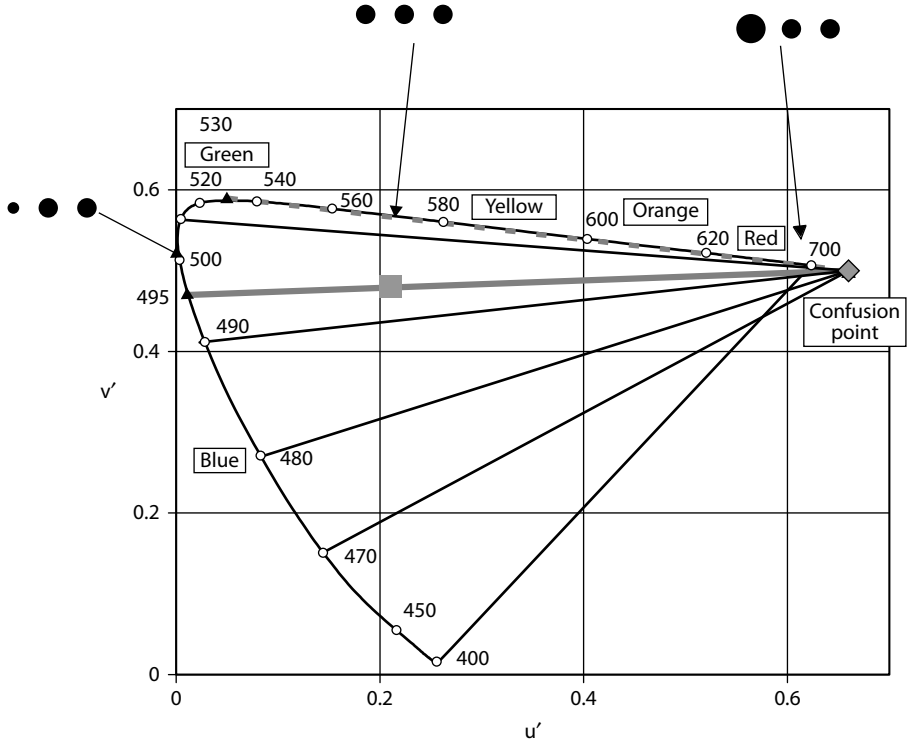

Figure 1. Protanope confusion lines. They all begin at the protanope confusion point (u′ = .66, v′ = .50; grey rhomboid). All the stimuli included on a confusion line differ only with regard to the relative protocone response

responses in the L cone). Consider the confusion line ending at 495 nm. Because it crosses the achromatic point (grey square, u′ = .21; v′ = .47), for a protanope all stimuli included on this line must be perceptually equivalent to an achromatic stimulus. For example, if the diagram is used to represent luminous stimuli (aperture colours), a 495-nm monochromatic light (bluish green) and a white or grey light should be metamers for a protanope.

Figure 1 uses groups of three black circles (triads) to represent relative cone responses. These triads show why stimuli on a protanope confusion line must be metamers for protanopes. The circle on the left of a triad represents the relative response strength of the L cone; the larger the circle, the greater the relative response. As can be seen, the three Figure 1 triads represent three stimuli that only differ in the L cone response. As, by definition, protanopes have no L cones, they cannot differentiate these stimuli.

Of particular interest is the confusion line ending at 530 nm (dashed line ending in black triangle) that overlaps with part of the perimeter – the spectrum locus. This

coincidence means that, for similar-intensity stimuli, protanopes cannot differentiate among the stimuli with wavelengths between 530–700 nm; one of these expected confusions forms the basis of the clinical diagnosis of protanopia with an anomaloscope.[3] A 589-nm stimulus (an orange yellow) can be made to match (become metameric) with any possible mixture of 546-nm (green) and 670 nm (red), by adjusting the intensity of the lights. The same is true for deuteranopes (dichromats lacking the M cone), although their confusion point differs from the protanope confusion point and is not shown in Figure 1.

Protanopes' and deuteranopes' confusion lines have been used to simulate the colours seen by these dichromats. There are computer programs that change colours to, allegedly, make them similar to the ones experienced by dichromats (Brettel, Viénot & Mollon 1997; Viénot, Brettel & Mollon 1999). Although there are some exceptions (Capilla, Díez-Ajenjo, Luque & Malo 2004), these simulations are based on the reanalysis of results from studies of monocular dichromats viewing monochromatic stimuli with the dichromatic eye (these people are dichromats when using only one eye but trichromats when using only the other eye).

When considering the difficulties that red-green dichromats may have in using BCTs, simulated colours could complement the predictions from confusion lines. If two BCTs include stimuli on the same lines and produce similar simulated colours, then these terms may be used interchangeably. But, as we shall show, dichromats make fewer naming mistakes than predicted on this basis.

2. R–G dichromats' use of BCTs: Partial information

2.1 Naming of surface colour prototypes

Several years ago, we designed a simple experiment in which 30 dichromats (12 protanopes, 18 deuteranopes) and 30 typical children participated (aged between 5–7 years; Lillo, Davies, Collado, Ponte & Vitini 2001). Their task was to name the eleven prototypes of Spanish BCTs (essentially identical to their English equivalents, see Lillo, Moreira, Vitini & Martín 2007). Considering that, when tested by anomaloscope, dichromats confuse some reds, oranges, yellows and greens, we expected frequent errors in dichromats' naming. Figure 2 indicates that they performed better than our expectations.

As expected, children with typical colour vision (black bars in Figure 2) scored over 90% correct for all BCTs. Surprisingly, dichromatic children scored over 80% for most primary BCTs (red, green, yellow, blue and white). How is it possible that the same children who were unable to differentiate a yellow from a red (or from a green,

3. The Nagel analytical anomaloscope is an apparatus used to diagnose defective colour vision. When using an anomaloscope dichromates match yellow lights with mixes of red and green different to the matches of normal people. See Birch (2001) for more details.

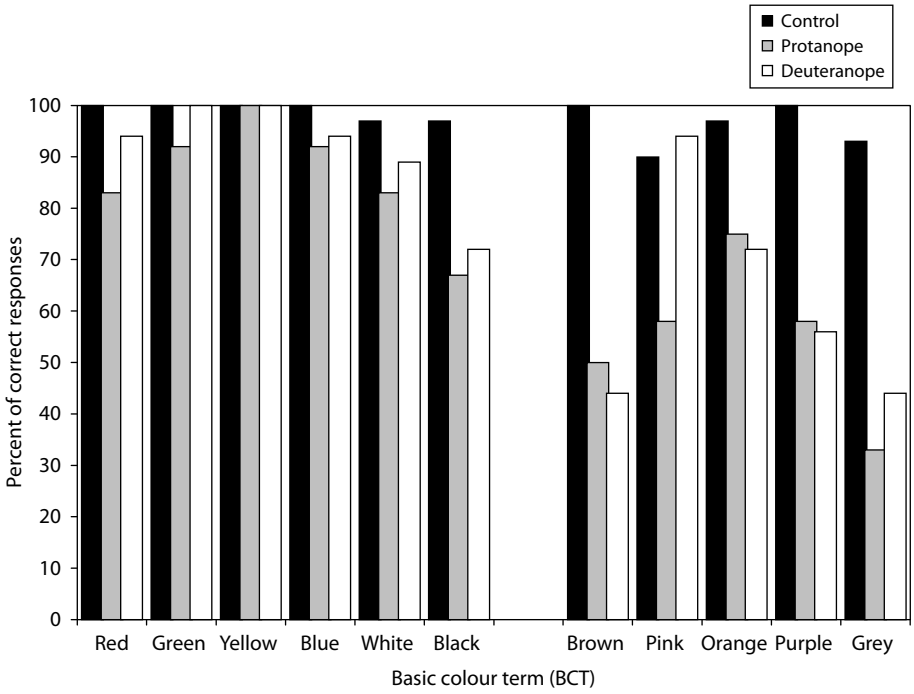

Figure 2. Percentage of correct responses in prototype naming task (based on Lillo et al. 2001: Table 3). Black bars = control group; grey bars = protanope group; white bars = deuteranope group

or an orange) in the anomaloscope named the yellow prototype without error? As we will see, the psychophysical characteristics of the stimuli used provide part of the explanation.

Anomaloscopes use luminous stimuli with no background (aperture colours) and it is easy to produce stimuli of similar transformed brightness, but different chromaticity (u′ v′) on any confusion line. In contrast, the stimuli in our naming experiment were surface colours, and with these, some hues are only realizable for a restricted transformed lightness range (Lillo, Moreira & Gómez 2002).

Surface transformed lightness depends on (1) what proportion of incident light is reflected, and (2) which wavelengths are predominantly reflected (cones are differentially sensitive to wavelength). Because of this, some saturated colours are only possible at some transformed lightnesses. For example, a saturated greenish blue must be darker than a white.

The error-free naming of the yellow prototype could be a consequence of these constraints on realizable surface colours. For aperture colours, the confusion line that includes the yellow prototype also includes some reds, greens and oranges, but for

surface colours there are no possible reds, greens or oranges with the same transformed lightness as the yellow.

Although the above constraints (psychophysical stimulus specificity) may partially explain the unexpected accuracy of dichromats' naming, they cannot explain everything. We will use the few confusions found between the green and red prototypes (Lillo, Davies, Collado, Ponte & Vitini 2001:Table 4) to show the reason for this.

Both for protanopes (Lillo et al. 2001:Figure 3) and deuteranopes, red and green prototypes fall very near confusion lines. For the protanopes, these stimuli have very different transformed lightness (red $L_T^* = 37.95$; green $L_T^* = 54.24$). This variation probably aids in the correct naming of both prototypes. But for the deuteranopes, these stimuli have similar transformed lightness (red $L_T^* = 53.10$; green $L_T^* = 59.30$), so how can we explain that they never confused the red and green prototypes (Lillo et al. 2001:Table 4)? As shown in Section 2.2, there is reason to believe that a factor ignored till now contributed to this result and, in general, to the relatively satisfactory naming displayed by protanopes and deuteranopes in the experiment of Lillo et al. (2001).

2.2 Are people diagnosed as dichromats true dichromats?

Nagel, who designed the anomaloscope type named after him, was the first to discover that protanopes and deuteranopes become anomalous trichromats when responding to large stimuli (Smith & Pokorny 1977). As noted by Smith and Pokorny, in 1905 Nagel published a paper in German entitled "Dichromatische Fovea, trichromatische Peripherie" (dichromatic fovea, trichromatic periphery), in which he described himself as deuteranope for small stimuli (less than 2°) and deuteranomalous for medium-size stimuli (10°). Nagel's works were forgotten and it was necessary to wait until the end of the 1960s to rediscover the residual activity of the red-green mechanism in people diagnosed as dichromats according to standard clinical procedures.

In an important series of experiments, Boynton and Scheibner (1967), Scheibner and Boynton (1968) showed that many so-called dichromats were not completely dichromatic. Tested with stimuli larger than anomaloscope stimuli (3°), some nominal dichromats behaved as though they had some activity in the supposedly missing R–G channel. They used just *red, yellow, green* and *blue* to name monochromatic stimuli with four levels of transformed luminance[4]. Some of the stimuli were in the range 530–630 nm (very similar to those used in anomaloscopes) and as these stimuli belong to the same confusion line (see discontinuous line in Figure 1), naming confusions among red, yellow and green should occur independently of the position on the confusion line. In contrast to this expectation, Scheibner and Boynton's (1968: 1153–1155)

4. Scheibner and Boynton used four transformed luminance values (1000, 500, 250 and 125 td). These values were established using as reference a 630 nm stimulus in a heterochromatic matching procedure (each dichromat adjusted each wavelength luminance to match the intensity perceived in the reference stimulus).

results showed that the use of a BCT was influenced by transformed lightness (low values increased naming of red) and also by wavelength values (red was used more frequently for higher wavelengths). As they behave like true dichromats in naming small stimuli that just fall on the central retina (the macular), but make fewer errors with large stimuli, the expression 'macular dichromat' may be appropriate (Nagy & Boynton 1979; Montag 1994; Wathtler, Dolman & Hertel 2004).

2.3 Some methodological considerations

To achieve a general view of dichromats' use of BCTs, research using naming responses (or equivalents) must fulfil the following requirements: (1) the stimuli should include exemplars of all BCTs; this implies the use of some low saturation stimuli, as for example *pink* is only used for such stimuli, and the use of varying transformed lightnesses; (2) observers must be allowed to use all the BCTs in their responses; (3) it must be possible to differentiate BCT use for the best exemplars (prototypes) and for non-prototypical exemplars.

Frequently, studies have not fulfilled all these requirements (Jameson & Hurvich 1978; Montag & Boynton 1987; Montag 1994; Lillo et al. 2001; Cole, Ka-Yee Lian, Sharpe & Lakkis 2006; Bonnardel 2006). Sometimes the stimuli have no (or very few) exemplars of *white*, *black* and *grey*, or there were insufficient low saturation stimuli. These two kinds of sample deficits make it impossible to get a general vision of macular dichromats' use of BCTs. These requirements also preclude the use of monochromatic lights as, for example, *black, grey* and *brown* can only be used to name surface colours. Thus as many previous studies used monochromatic lights (Nagy & Boynton 1979; Paramei, Bimler & Cavonious 1998; Wachtler, Dohrman & Hertel 2004) they can only provide partial information about the cues and mechanisms related to BCT use. Nevertheless, it seems likely that residual activity in the R–G mechanism (Schneiber & Boynton 1968) would affect naming of surface colours. Similarly, the finding that increasing the luminance (brightness) affects the naming of lights in dichromats more than in typical people (Paramei, Bimler & Cavonious 1998; Bimler & Paramei 2004) is likely to generalize to surface colours too.

The reason for the need to distinguish between prototype and non-prototype naming is that errors are less likely for the prototype than for other exemplars. Prototypes tend to have specific psychophysical properties, which reduces the likelihood of confusing them with stimuli from other categories (recall the lack of errors for the yellow prototype). Such specificity is less pronounced for non-prototypes. For example, although the green prototype is located on a specific confusion line and has a specific transformed lightness, *green* is used across a relatively large range of transformed lightnesses and confusion lines. This lack of specificity makes some greens more likely to become perceptually similar (metamers) to some members of other BCTs.

3. A global view of BCT use in macular dichromats

To achieve a general understanding of R–G dichromats' BCT use, we performed an investigation (Lillo, Moreira, Álvaro & Davies 2011) in which 17 dichromats (8 protanopes and 9 deuteranopes) and 15 typical observers participated. To obtain a representative sample of surface colours, we created a 102-stimuli set from the results provided by previous naming and measurement of the NCS atlas.[5] The set included prototypes of each BCT, 'boundary-stimuli' between BCTs defined by previous use of combined terms, such as *red-purple*, and stimuli halfway along the line in CIE L*u*v* between a prototype and each relevant boundary colour. This set was used to assess the choice of 'best example' of each BCT and to map the range of each BCT, similarly to Berlin and Kay's (1969) original study. More specifically, the mapping task required each observer to point out all the stimuli that could be named using each BCT. However, the best exemplar task required participants to point out the best representative of each BCT. The two tasks were performed at different moments. Half of the observers performed the mapping task first and then the best exemplar task. For the other half, the reverse order was used. The second task did not begin until all the BCTs of the first task had been used.

Based on previous work (Lillo et al. 2001; Cole et al. 2006), we expected dichromats to be very similar to typical observers in their best example choices, especially for primary BCTs. In contrast, we expected more errors (stimuli included as members of a BCT by dichromats but not by typical observers) in the mapping task. Where stimuli on the same confusion line fell in different BCTs, we expected errors to occur, but with two provisos. First, the stimuli were also of similar transformed lightness and second, because of the residual R–G mechanism activity mentioned above (Boynton & Scheibner 1967; Nagy & Boynton 1979; Montag 1994; Wachtler, Dolman & Hertel 2004), we expected the probability of error to decrease as R–G differential activity increased. We compared the location of occurring errors with predictions of likely errors based on category overlap in transformed lightness and shared confusion lines. We expected this to over-predict errors as it did not take residual R–G activity into account and the non-occurring errors should be those stimuli that produced high differential R–G activity.

3.1 Best exemplar task results

Figure 3 shows the percent of correct responses for each BCT and for each group. A response was considered correct when a stimulus was chosen by at least 50% of the control group in the mapping task. As expected, on this basis, the control group scores 100% for all the BCTs (black bars). This result was also obtained for five BCTs by the protanope group (grey bars: *green, yellow, blue, white* and *black*.) and for the deuteranope

5. NCS = Natural Colour System, a system similar to Munsell (Hunt 2001: ch.7)

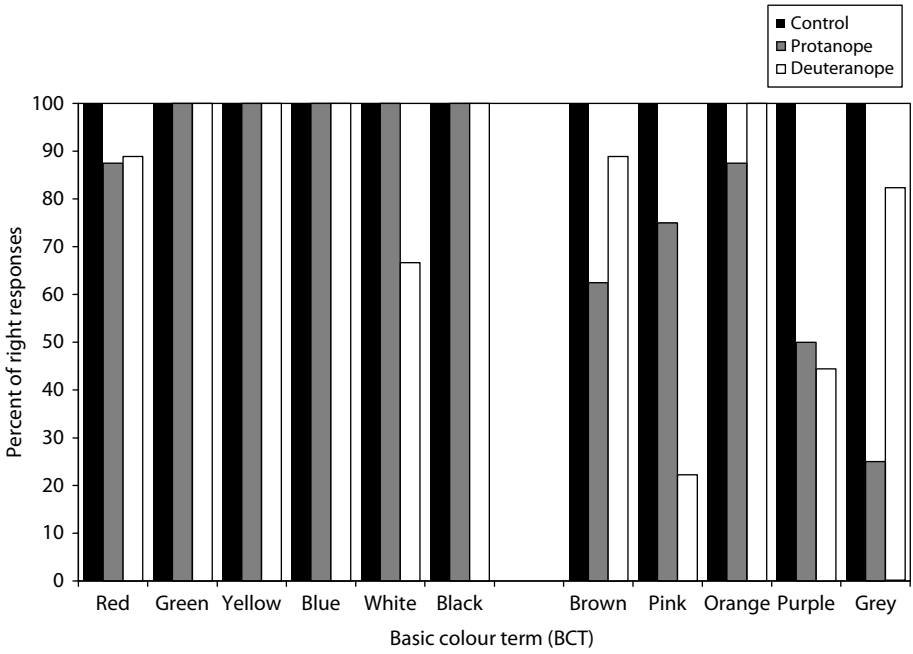

Figure 3. Percentage of correct responses in the best exemplar searching task (based on Lillo et al. 2011). Black bars = control group; grey bars = protanope group; white bars = deuteranope group

group (white bars: *green, yellow, blue, orange* and *black*). A series of Kruskal-Wallis analyses of variance indicated that there were no significant group differences ($n = 6$, $\chi^2[2] = 1.069$, $p = .586$) when the analysis was restricted to the primary categories, but differences were revealed when the analysis was applied to all the BCTs ($n = 11$, $\chi^2[2] = 7.374$, $p = .025$) or only to secondary BCTs ($n = 5$, $\chi^2[2] = 7.22$, $p = .027$). The corresponding Mann-Whitney U analysis showed ($p < .05$) for all the BCTs taken together and, for *purple, pink, orange* and *grey*, that typical observers obtained significantly more correct responses than the protanopes (grey bars) and the deuteranopes (white bars), but there were no significant differences between the dichromat groups.

3.2 Mapping task results

Table 1 shows the percentages of correct and incorrect responses in the mapping task for protanopes (a similar table for deuteranopes is presented in Lillo et al. 2011). Again, a response was considered correct when a stimulus was chosen by at least 50% of the control group in the mapping task. The first column gives the target category and the first row shows the response category (according to typical observers' responses). The percentages along the diagonal indicate correct selections; that is, trials where

Table 1. Mapping task results. First column indicates target BCT (protanopes had to find exemplars belonging to it). Each row of percentagess adds up to 100% (all responses produced when looking for exemplars of a BCT). Correct responses in the diagonal

	Red	**Green**	**Yellow**	**Blue**	**White**	**Black**	**Brown**	**Pink**	**Orange**	**Purple**	**Gray**	**Other**
Red	**58.0**						28.8		7.82			5.38
Green		**46.0**	8.24				36.85				5.77	3.14
Yellow		23.8	**75.0**									1.20
Blue		3.88		**60.0**				5.67		26.9	3.04	0.51
White		6.54			**67.31**			22.9			3.27	0.00
Black	3.81			5.71		**88.10**						2.38
Brown	3.37	22.23				5.94	**63.16**		4.49			0.81
Pink					7.23	3.42		**41.60**		23.91	20.10	3.74
Orange		6.42	26.35				13.41		**51.22**			2.60
Purple	3.15			33.7				5.51		**56.10**		1.54
Gray		23.69					4.41	12.2		4.89	**51.75**	3.06

dichromats selected a stimulus belonging to the target BCT. Table 1 shows, for example, that 58% of protanopes' red choices were correct. Errors were distributed among brown (28.8%), orange (7.8%), and other categories (5.38%). A series of Man-Whitney U tests indicated that protanopes and deuteranopes had similar proportions of correct responses ($p > .05$). On the other hand, both dichromat groups have fewer correct responses than typicals ($p < 0.5$).

The distribution of errors was examined in chromaticity diagrams for each BCT and for both kinds of dichromat. For example, Figure 4 shows deuteranope and control choices of *green* stimuli. Circles represent stimuli chosen by deuteranopes (the larger the circle, the more frequently a stimulus was selected) and crosses indicate typical observers' selections; the coincidence of crosses and circles indicates correct responses and circles without crosses indicate errors. The meaning of the squares will be explained shortly.

Figure 4 includes two confusion lines. The solid one corresponds to the median of the correct responses. The other line is the errors median. As commented on when Figure 1 was introduced, a confusion line includes stimuli that must be metamers for true dichromats, if they are similar in transformed lightness. Because of this, it is reasonable to expect that all the stimuli named with each BCT – errors and correct responses – must be similar in these two parameters. Contrary to these expectations, significant differences ($p < .05$) appeared for an important number of BCTs. Specifically, when comparing confusion lines (the slopes), there were significant differences in five categories for the protanopes (yellow, blue, white, orange and grey), and in three categories for the deuteranopes (yellow, blue and pink). With regard to transformed lightness, there were significant differences in five categories for the protanopes (green,

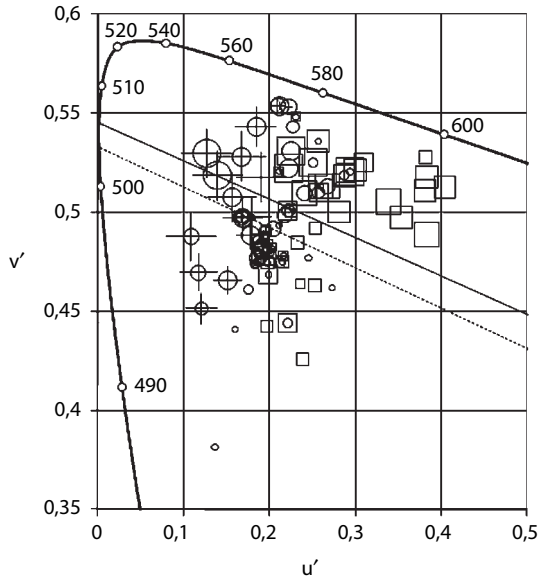

Figure 4. Mapping task results for green (deuteranope group). Crosses = typical observers' selections. Circles = dichromats' selections. Squares = expected errors. Continuous line = correct response median. Discontinuous line = error median

yellow, brown, orange and purple) and in two categories for the deuteranopes (orange and grey).

As shown below, psychophysical specificity partly explains the above-mentioned significant differences. Readers are reminded of our previous comments about the perfect naming of the yellow prototype in order to understand the reason for this. For this stimulus, and for some others, there are no stimuli belonging to other categories that are similar in transformed lightness and confusion line. Hence, there can be no confusion with other BCTs.

Let us now consider the squares appearing in Figure 4. They represent 'expected errors' (the larger the square, the greater their probability of being incorrectly pointed out as members of a category.; see Lillo et al. 2011 for full details). That is, they are stimuli that, because of their similarity to the correct responses (they were similar to the greens in transformed lightness and confusion lines), should have been pointed out by true dichromats as members of the BCT GREEN considered in the mapping task. Statistical analysis with the Mann-Witney U-test indicated that, when slopes and transformed lightness of real and expected errors were compared, significant differences ($p < .05$) only appeared for a very reduced number of BCTs, specifically, in the protanope group, for orange (slope and transformed lightness) and purple (transformed lightness) and in the deuteranope group, for brown and pink (slope), and for green and grey (transformed lightness).

Figure 4 indicates that some expected errors became real errors (coincidence of circles and squares) but also that these stimuli were frequently not pointed out as members of the target BCT (that is, some expected errors never occurred). Figure 4 also shows a geographic separation between these two situations: expected errors that became real errors (squares with circles) were nearer to correct responses (circles with crosses). Thus, distances in the chromaticity diagram were decisive in transforming expected errors into real ones.

For true dichromats, distances in the chromaticity diagram are irrelevant for differentiating between stimuli similar in transformed lightness and confusion line (no differentiation is possible!). However, for people with some activity in the red-green mechanism, greater distance in a confusion line means more perceptual differences. Figure 5 indicates that such differences were used to avoid errors when using BCTs. The abscissa of this figure represents the difference in the red-green mechanism activity (ΔRGres, distance on a confusion line) between a BCT prototype and a stimulus belonging to another BCT (for the control group). The ordinate indicates the proportion of empirical error. Black points correspond to stimuli identical to a prototype in

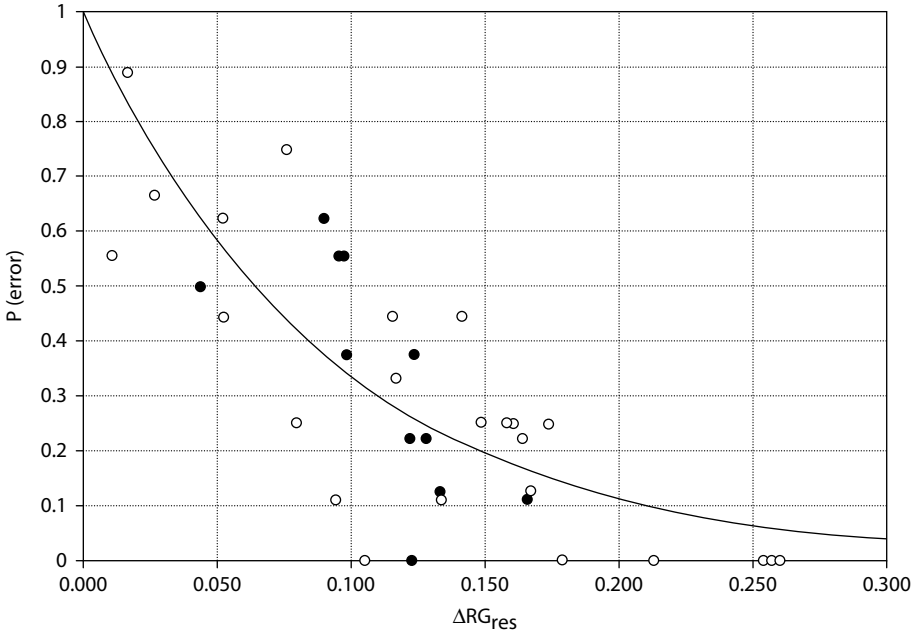

Figure 5. Error probability and residual red-green activity in protanopes and deuteranopes. ΔRGres (Red-Green residual variation. Distance between the target stimulus and a BCT prototype). Black points, stimuli identical to a prototype in transformed lightness and confusion line. White points, stimuli very similar to a prototype in both of these parameters

transformed lightness and confusion line. White points correspond to stimuli very similar to a prototype in both of these parameters. It is clear that increasing the differences in the red-green mechanism response reduced the probability of using a BCT inaccurately. Consequently, it can be concluded that our dichromats did not behave as expected for true dichromats.

4. Conclusions

Protanopes' and deutoranopes' confusions of anomaloscope stimuli do not allow us to predict the way these people use BCTs. According to the predictions based on confusion lines, when anomaloscope-type stimuli (aperture colours) are used, these people do not detect differences between stimuli that typical observers categorize as reds, oranges, greens or yellows.

However, when relatively large-size surface colours are used, people diagnosed as dichromats according to standard procedures use BCTs with some accuracy, especially for the best exemplars (prototypes) of BCTs. Such accuracy appears to be related to two factors: psychophysical specificity (some relative lightness and confusion line combinations are only possible for some BCTs) and the R–G mechanism residual activity. Because of this latter factor, it is appropriate to refer to 'macular dichromats'.

In the surface colour framework, the term R–G dichromats applied to people diagnosed as protanopes or deuteranopes is not very accurate. As shown in Table 1, confusions between red and green BCTs were scarce in the mapping task. Because of this, these people used to be surprised when informed that they may confuse some stimuli belonging to these BCTs (red and green). Every day they interact with surface colours without confusing reds and greens.

To say that macular dichromats do not confuse all the stimuli that are similar in terms of transformed lightness and confusion lines does not imply that these parameters are useless. As shown, most errors were made in stimuli similar to correct responses in these two parameters (great similarity was found between expected and empirical errors). Consequently, it can be concluded that use of each BCT is associated with some values in these parameters but, additionally and when possible, with the residual R–G mechanism activity.

Acknowledgements

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Synaesthesia in colour

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Synaesthesia is an inherited condition that can give rise to a 'merging of the senses'. People with synaesthesia experience unusual perceptions (e.g. colours, tastes) when engaged in everyday activities like reading, speaking, listening to music, and so on. Synaesthetic perceptions of colour can be triggered by a range of stimuli, including sounds, tastes, smells, touches, and even linguistic stimuli such as letters, numbers and words. In this paper, I describe work on colour synaesthesia from the *Synaesthesia and Sensory Integration Lab* at Edinburgh University, where we examine the cognitive, linguistic, and developmental basis of this unusual condition. These data contribute to the emerging view that synaesthetes and non-synaesthetes lie on a continuum of cross-sensory association, but one where neuro-developmental differences allow synaesthetes to experience these colour associations at a conscious level.

1. Introduction

For a small portion of the population, the experience of colour can arise without the usual external stimulation. Some of these individuals have a condition known as synaesthesia. For synaesthetes, everyday activities (e.g. listening to music, reading) trigger exceptional experiences (e.g. of colour, taste). Synaesthetes might see colours when they hear sounds, for example (*music-colour synaesthesia*; Ward, Huckstep & Tsakanikos 2006) or experience tastes in the mouth when they read words (*lexical-gustatory synaesthesia*; Simner & Ward 2006; Ward & Simner 2003) and so on. The condition is characterized by the pairing of a particular trigger (or *inducer*) with a particular experience (or *concurrent*; Grossenbacher 1997) and so music-colour synaesthetes, for example, respond to music (inducer) by seeing colours (concurrent).

A large-scale prevalence study conducted by our lab has shown that synaesthesia is found in approximately 4.4% of the population (Simner, Mulvenna, Sagiv, Tsakanikos, Witherby, Fraser, Scott & Ward 2006b). In this study, nearly 2000 members of the general population were individually assessed for synaesthesia with objective tests of genuineness, and approximately 1 in 23 people had one (or more) variants of the condition. Indeed, nine different variants were found in this sample overall. The

most commonly experienced synaesthetic concurrents were for sensations of colour (as opposed to taste, touch, smell, etc.) and the most commonly found triggering-stimuli were linguistic units such as words, graphemes (letters or numerals) and phonemes (see also Simner 2007). Indeed, approximately 88% of all synaesthesias were triggered by language, and 95% gave rise to colour experiences. Although certain variants were not tested for at that time (because they were identified in later studies, e.g. sequence-personality synaesthesia, Simner & Holenstein 2007; Simner & Hubbard 2006) the number of synaesthesias triggering colour would still remain by far the largest category overall.

In prevalence testing, synaesthesia showed no clear gender differences; there were approximately the same number of female synaesthetes compared to male. This contrasts with earlier studies that had reported a 6:1 female-to-male ratio of synaesthetes (e.g. Baron-Cohen, Burt, Smith-Laittan, Harrison & Bolton 1996). However, these earlier figures were based on studies counting synaesthetes who had come forward to self-refer, and so were likely contaminated by a self-referral confound. In other words, as in other areas of self-referral (Dindia & Allen 1992), male synaesthetes may simply be less likely to come forward to report their atypical experiences. When studies assess prevalence without relying on self-report (e.g. Simner et al. 2006b) no strong gender differences are revealed. Nonetheless, there may yet be a slight trend for marginally more female synaesthetes overall, given a meta-analysis of all existing robust studies (see Simner, Harrold, Creed, Monro & Foulkes 2009 for discussion).

Synaesthesia is known to run through families, and work in our lab has traced the familial inheritance patterns through large numbers of family groups (Ward & Simner 2005). More recent studies have confirmed that synaesthesia has a genetic basis, using whole-genome scans that reveal evidence of linkage to chromosomes 2q24, 5q33, 6p12, and 12p12 (Asher, Lamb, Brocklebank, Cazier, Maestrini, Addis, Sen, Baron-Cohen & Monaco 2009). This inheritance is assumed to give rise to neuro-developmental differences in the brains of synaesthetes, and, indeed, a number of brain imaging studies on adult synaesthetes now reveal differences in both function and structure. Studies using functional magnetic resonance imaging (fMRI) show that synaesthetic perceptions of colour activate the same regions that support veridical colour perception. For example, *grapheme-colour synaesthetes*, who experience synaesthetic colours from letters, numbers and words, show fMRI activation in areas that are normally associated with colour perception for external stimuli (i.e. human areas V1 (left) V4 and/or V8; for a review, see Hubbard & Ramachandran 2005). Imaging studies have also shown that synaesthetic experiences have anatomical roots. A recent study exploiting diffusion tensor imaging (DTI) has shown increased structural connectivity in the brains of synaesthetes (Rouw & Scholte 2007). This methodology tracks the diffusion of water molecules in the brain, and indicates areas of increased white matter tracts as regions where the diffusion of water is restricted in certain directions (and the degree of this restriction is indicated by the *fractional anisotropy*, FA). Grapheme-colour

synaesthetes demonstrated greater FA in the right fusiform gyrus (among other areas) compared to controls, in regions close to areas involved in word and colour processing. This suggests increased white matter connectivity compared with the same regions in control brains. This hyper-connectivity appears to lie at the roots of synaesthetic experiences, and studies in our lab are testing this hypothesis further with other forms of synaesthesia.

Synaesthesia research has enjoyed a renaissance in recent years, and significant advances have been made in our understanding of common variants such as grapheme-colour synaesthesia (e.g. Simner, Glover & Mowat 2006a). A number of rarer variants have now also come under scrutiny (e.g. lexical-gustatory synaesthesia; Simner & Ward 2006; Ward & Simner 2003) although some work remains in cataloguing and classifying all 50+ manifestations thus far identified (Day 2005; Cytowic 1993). Below I describe work from the Synaesthesia and Sensory Integration Lab at the University of Edinburgh, where we examine the roots of this unusual phenomenon, and the relationship between synaesthesia and cross-modal associations in all people. I will focus particularly on variants of synaesthesia that trigger colour, but also of interest to the visual scientist might be those variants that trigger visuo-spatial perceptions of shapes in space (and for this, I direct the reader to a recent review of this latter manifestation; Simner 2009).

2. Phenomenonology of colour synaesthesia

For synaesthetes, input to one modality (e.g. seeing the letter *a*) consistently and automatically evokes a percept in another modality (e.g. tasting onions), or in a different aspect within the same modality (e.g. seeing the colour red). In a phenomenological sense, synaesthetic colour sensations are experienced either as colours projected into space (as is the case for *projector synaesthetes*) or as an overwhelming impression of colour in the 'mind's eye' (for *associator synaesthetes*; Dixon, Smilek & Merikle 2004). When colours are triggered by speech, they can sometimes appear as externally visualized coloured text (Cytowic 2002). This experience, phenomenologically speaking, is something akin to viewing coloured sub-titles accompanying the spoken word, and is known as *ticker-tape synaesthesia* (Linn, Hancock, Simner & Akeroyd 2008). When triggered by reading, synaesthetic colours might be superimposed onto the typeface (e.g. Dixon, Smilek, Cudahy & Merikle, 2000; Witthoft & Winawer 2006). When colours are triggered by non-linguistic sounds, like music or environmental noise, colours can again be projected or associated, and can again take spatial locations (e.g. at top left-hand physical or mental space) and/or assume specific forms (spirals, circles, waves, etc.).

In all cases, behavioural evidence demonstrates that synaesthetes are highly consistent and specific in their associations, which they experience automatically (e.g. Ward et al. 2006). For example, a synaesthete might describe the sound of middle C on the piano as a silver-grey ball seen in left-hand space, while one note higher might be a slightly rotated purple ellipse with green edging. Importantly, these descriptions

remain highly consistent over time, and are considerably more consistent than analogical associations made by controls. For example, Simner and Logie (2007) describe the case of lexical-gustatory synaesthete JIW, who experiences tastes in the mouth when hearing, reading, or saying words. JIW described the flavours triggered by a set of words, and then reproduced those exact associations 27 years later with 100% accuracy. In contrast, when age-matched controls were given the same word-list and asked to generate analogous associations, they were only 47% consistent when retested only 10 seconds later. Simner and Logie's study shows that their synaesthetes' long-term consistency of word-taste pairings falls well outside the usual constraints of normal explicit, episodic memory recall. Indeed, synaesthetes report that they are not 'remembering' their flavour associations at all, but rather that they are experiencing them at a perceptual level each time a word is encountered. Similar consistency has also been shown for synaesthetes experiencing a range of concurrents, including colour (e.g. from letters, Simner et al. 2006a; Ward, Simner & Auyeung 2005).

3. The continuity hypothesis of synaesthesia

Recent work has examined the similarities, rather than differences, between synaesthetes and non-synaesthetes and has asked whether these two groups are qualititatively different, or whether they differ just quantitatively. These studies, including a number from our own lab, investigate whether there is a common mechanism accounting for cross-modal associations in both synaesthetes and non-synaesthetes, and whether this mechanism may simply be *more pronounced* in synaesthetes. Several arguments speak for this idea. First, psychoactive drug use can evoke synaesthesia in non-synaesthetes, suggesting that cross-modal perceptual experiences may lie dormant in all of us (Delay, Gerard & Racamier 1951; Simpson & McKellar 1955). Second, even without pharmaceutical stimulation, all people, not only synaesthetes, have cross-modal associations that unite ostensibly different qualia across the senses. Third, and most importantly, these cross-modal associations in both synaesthetes and non-synaesthetes appear to be mediated by the same mechanisms. For example, sound-colour synaesthetes experience colours with increasing lightness as the pitch of the sound increases. Importantly, this same correlation between luminance and pitch is also seen in non-synaesthetes making sound-colour associations by intuition (e.g. Ward et al. 2006). Furthermore, both synaesthetes and non-synaesthetes choose more saturated colours for certain types of timbre (e.g. strings versus pure tones). The synaesthetes in the study by Ward and colleagues differed from non-synaesthetes in experiencing their colours at a conscious level, and in being more consistent in their associations over time. Despite this, their qualitative data shows similar patterns of cross-modal associations, and this suggests that the same mechanisms may be present in both populations. Two further domains where our own lab has shown similarities between synaesthetes and non-synaesthetes in cross-modal colour mappings are described in more detail below.

3.1 Experiencing colours when reading

A number of studies conducted by our research group have suggested that both synaesthetes and non-synaesthetes share similar mechanisms for cross-modal matching, with the key difference being the extent to which such associations are available to conscious inspection. For example, Simner, Ward, Lanz, Jansari, Noonan, Glover & Oakley (2005) examined colour associations to linguistic stimuli such as letters by examining a large group of (n = 70) grapheme-colour synaesthetes. Simner et al. aimed to discover whether their letter-colour associations are simply random, or whether they reflect any type of rule-based system. Historically, it had been assumed that the experiences of grapheme-colour synaesthetes were highly idiosyncratic, since pairs of synaesthetes often disagreed on the colours for their letters, even if they were both members of the same family. However, Simner et al. were able to compare a *very large number* of synaesthetes, in order to identify any underlying trends. Synaesthetes provided the colours for each of their 26 letters of the alphabet (e.g., *a* = crimson red; *b* = aquamarine; *c* = mustard yellow, etc.) and analyses showed that associations were not random. Instead, synaesthetes showed an underlying similarity in their choice of colours. For example, although synaesthetes could experience any colour at all for the letter *a*, they were significantly overall likely to experience shades of the colour red. For *b* they were likely to experience blue, for *c* they were likely to experience yellow, and so on. Moreover, Simner et al. were able to show a set of 'rules' guiding these choices (e.g. synaesthetes tended to pair high frequency letters, such as *a*, with high frequency colour terms, such as red). Of great interest, however, is that Simner et al. also elicited colours from a large group of (n = 400) non-synaesthetes. This group were also asked to provide colours for each letter, based on instinct alone. Perhaps most surprisingly, this group, too, tended to share their preferences for the colours of each letter, and these choices were similar to those made by synaesthetes. For example, for both populations, *a* tended to be red, *s* to be yellow, and so on. Other subsequent studies (e.g. Beeli, Esslen & Jäncke 2008; Smilek, Carriere, Dixon & Merikle 2007) have shown that both synaesthetes and non-synaesthetes pair higher frequency graphemes to more luminant colours, and these data combine to suggest, once again, that synaesthetes and non-synaesthetes possess shared mechanisms for cross-modal colour attribution, although synaesthetes are able to experience these colours to a conscious level.

3.2 Experiencing colours from touch

Other studies (Simner & Ludwig 2009; Ward, Banissy & Jonas in press) have shown that commonalities also exist between synaesthetes and non-synaesthetes in the way they pair colours to sensations of touch. There is some history to the notion that vision and touch may be associated by a cross-modal mechanism, even in the general population. Lederman and Abbott (1981) showed that non-synaesthetes assess the tactile quality of stimuli on the basis of both touch and vision. When subjects were estimating the

roughness of an abrasive surface, their estimation was affected by giving them false visual feedback. Specifically, when subjects touched a surface that was different to a viewed surface they *believed* they were touching, they estimated the roughness of the stimulus as lying midway between the discrepant information conveyed by touch and vision.

Simner and Ludwig (2009) investigated how people associate touch sensations with colours, and previous examples of touch-colour mappings have already been established in the peer-reviewed literature. Martino and Marks (2000) showed that non-synaesthetes can make touch-colour associations depending on the vibration-frequency of a touch sensation, and on the luminance of the colour. When participants categorized vibrotactile sensations as fast or slow (i.e. high vs. low frequency), they were faster to categorise high frequencies when accompanied by a white visual stimulus, and faster to identify low frequencies shown with a black stimulus, than when presented in reverse (Martino & Marks 2000). This suggests that high frequency vibrotactile sensations on the skin correspond to white, whereas low frequency vibrotactile sensations match with black. A second study demonstrated matching between colours and the sensations of heat at different temperatures, pairing certain colours (e.g. red, yellow) with warm temperatures, and others (e.g. blue, green) with colder temperatures (Morgan, Goodson & Jones 1975). Simner and Ludwig extended this literature by systematically varying tactile scales in terms of roughness, hardness, and roundness, and asking participants to match colours to the sensations.

Simner and Ludwig (2009) tested three female synaesthetes, and over 200 non-synaesthetes, comprising both children (5–11 years) and adults (12+ years). Participants were tested individually and each was asked to palpate 18 objects hidden behind a screen one by one, and to "choose a colour that seems to fit the way each object feels". Participants made choices by operating a mouse with their right hand while simultaneously feeling the stimulus with their left hand. Colours were selected from a colour wheel, with a separated bar to change the lightness/darkness. Participants were told they should not try to guess the real colour of the objects, but should attend to what the objects felt like, and choose a colour that fits each feeling.

Materials comprised three sets of objects varying from rough to smooth, hard to soft, and pointed to round. The rough-smooth objects were six surfaces (23 x 28cm) ranging from smooth to rough, where roughness was quantified by an ISO grit value, denoting the number of grains bonded to each inch of the surface. Their soft-hard gradient comprised six cubes of foam (150cm x 100cm x 75cm), ranging from soft to hard, where hardness was measured in Newtons per square metre. Finally, their smooth-pointed stimuli were six wooden 3D shapes (10cm high) ranging from pointed to round, where shape was determined mathematically on an increment that altered the shape from pointed to round.

After confirming each colour choice by a button press, participants moved a slider to indicate how certain they were about each decision. Simner and Ludwig then assessed the specific colour chosen for each stimulus-set according to its hue, saturation and luminance. They found strong cross-modal correspondences between touch and

colour in both synaesthetes and non-synaesthetes. In non-synaesthetes, they found significant correlations between the tactile quality of the touch-stimuli, and the luminance and saturation of the colour. Specifically, smoother, softer and rounder shapes were significantly lighter than rougher, harder and more pointed shapes. Moreover, smoother, softer shapes were more saturated. Simner and Ludwig (2009) also found significant age effects. For example, the relation of smoothness to saturation was strongest in younger age groups. Moreover, they found, too, that synaesthetes had comparable associations between visual and tactile qualities, in that smoothness and softness tended to correlate with lightness and saturation choices, as it did for non-synaesthetes, although in some cases the direction of the trends differed between individual synaesthetes and the group of non-synaesthetes. For example, softness positively correlated with lightness for non-synaesthetes, and the same was true for one of our synaesthetes, although another synaesthete had the same significant effect, but in the opposite direction (i.e., softer shapes were darker; see also Ward et al., in press, for comparable findings with this same participant).

Once again, then, synaesthetes and non-synaesthetes are experiencing similar cross-modal correspondences for colour, albeit to different levels of awareness. Synaesthetes perceived their colour associations at a conscious level, while non-synaesthetes made their associations on intuition alone. The synaesthetes in Simner and Ludwig's study were significantly more certain about each of their colour choices compared to non-synaesthetes, and they reported significantly greater consistency in their colours over time. In both touch and language domains, therefore, both synaesthetes and non-synaesthetes make non-random cross-modal colour associations, and both share the underlying mechanisms on which these pairings are based.

4. Conclusions

An increasing interest in synaesthesia over the past decade has significantly improved our understanding of this unusual phenomenon. It affects people in far greater numbers than previously assumed, but appears to be based on mechanisms shared, in part, by the broader population. The data described here contribute to an emerging view that synaesthetic experiences reflect mechanisms found in all people, albeit to a different level of awareness. Both synaesthetes and non-synaesthetes have similar systematic cross-modal experiences for colour, triggered by qualities of sound, touch, and other sensory stimuli, as well as by linguistic units such as letters, numbers and words. In some cases, these cross-modal associations in non-synaesthetes are present even from an early age. Future research into the mechanisms underlying this phenomenon might reveal new information about the relationships between synaesthetes and non-synaesthetes, and about the development of cross-modal perception and cognition more generally.

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Towards a phonetically-rich account of speech-sound → colour synaesthesia

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This paper explores the contribution that phonetics can make to research into certain types of synaesthesia: those which have speech sounds as the 'inducer' or trigger for the synaesthetic experience, and colour as the 'concurrent' or triggered experience. These variants are under-researched relative to other variants. We first discuss the complex inter-relationship between speech sounds and graphemes as synaesthetic inducers, then review recent findings concerning the parameters of speech that can evoke impressions of colour. These findings suggest systematic relationships, but a more detailed phonetic approach is needed to better understand the mappings.

1. Introduction

This paper explores the contribution that phonetics can make to research into certain types of synaesthesia. Synaesthesia is a neurological condition in which stimuli in one sensory modality automatically trigger experiences in a different modality. Certain variants of the condition have speech sounds as the 'inducer' or trigger for the synaesthetic experience, and colour as the 'concurrent' or triggered experience, but they are under-researched relative to other variants. We review relevant literature on this type of synaesthesia and outline factors that make it intriguing and challenging.

Various terms have been used for relationships between speech sounds and colour, especially 'coloured hearing', and 'phoneme-colour synaesthesia'. We refer to 'speech-sound → colour synaesthesia' because 'coloured hearing' can include non-speech sounds and is too general for our purposes, while 'phoneme-colour synaesthesia' makes an untested assumption, namely that only one particular unit of linguistic analysis, the phoneme, is relevant to the condition.

The fullest discussion of speech-sound → colour synaesthesia is by Marks (1975) who analyzes historical case reports in relation to phonetic parameters. Although the

reports lack the methodological controls for genuineness that modern studies consider essential, Marks's review suggests that the colour percepts evoked by particular spoken vowels show a degree of commonality across synaesthetes. Speech sound → colour relationships may even have a wider currency. Phonetics counts among its technical terms various visual analogues for sounds, such as 'clear', 'dark' and 'bright,' and, while it is unclear whether these have anything in common with synaesthesia *per se*, it is striking that they seem to make intuitive sense to most learners of phonetics.

Little is known about the prevalence of speech-sound → colour synaesthesia. Day (2005: 15) gives the prevalence of phoneme-colour synaesthesia as 10.5% of all synaesthesias in a database of 572 cases (drawn from the historical literature and the author's own work as editor of a synaesthesia email forum). This is a lower prevalence than synaesthesias involving letters, time units, and other musical or non-musical sounds, but higher than most other types. Yet Day gives no definitional criteria and, in general, this type of synaesthesia is under-explored (Simner 2006). Voices have also been reported as an inducer (Simner, personal communication) but, likewise, little studied.

The main challenge in understanding speech-sound → colour synaesthesia lies in the multidimensional nature of speech. Speech exists in a complex relation to writing, and can be described using many different parameters, units, and levels of abstraction. Only a few possible candidates have been systematically investigated. Below, we make the case for casting the net more widely.

2. Existence and prevalence of speech-sound → colour synaesthesia in relation to grapheme-colour synaesthesia

The organization of speech into units of sound is distinct from the organization of writing into letters. A language like English exhibits notoriously opaque correspondences between phonemes (one type of abstract sound unit) and graphemes (abstract letter units). For example, a single vowel phoneme, /i/, in Standard Southern British English can be represented by the graphemes ⟨e⟩ (*we*), ⟨ea⟩ (*bead*), ⟨ee⟩ (*seed*), ⟨e.e⟩ (*effete*), ⟨ei⟩ (*ceiling*), ⟨ey⟩ (*key*), ⟨ie⟩ (*chief*), ⟨y⟩ (*happy*). Conversely, a single grapheme, e.g. ⟨o⟩, can be associated with the vowel phonemes /ɒ/ (*long*), /u/ (*do*), /ʌ/ (*won*), /ə/ (*observe*), /əʊ/ (*so*), /ɪ/ (*women*), /ʊ/ (*woman*). The correspondences depend on the accent of English. To make matters still more complicated, phonemes are not always pronounced in exactly the same way, but variably according to the phonetic context in which they occur.

Teasing apart graphemic and speech-sound-based types of synaesthesia is complicated. Most lay people believe that letters 'are' the sounds of speech and do not think much about how phonology differs from orthography. Yet graphemic and phonological representations in fact exert a mutual and intertwined influence on both speech

perception and reading (e.g. Van Orden 1987). In consequence, if a case of synaesthesia is induced by spoken language this does not necessarily make it a speech-sound → colour synaesthesia: it might be induced by (spoken) graphemes. To clarify the nature of the inducer, researchers test synaesthetes on words with shared initial graphemes but not phonemes, and vice versa: e.g. if *christen* and *crease* have the same colour, that colour is presumably induced by the phoneme /k/; but if *christen* and *cheese* have the same colour, it is presumably induced by the grapheme ⟨ch⟩.

Studies using this method have revealed a much greater prevalence of grapheme-colour than phoneme-colour synaesthesia: for example Baron-Cohen, Harrison, Goldstein and Wyke's (1993) study of nine word-colour synaesthetes identified all as grapheme-colour rather than phoneme-colour synaesthetes. The large prevalence study of Simner, Mulvenna, Sagiv, Tsakanikos, Witherby, Fraser, Scott and Ward (2006) identified no phoneme-colour synaesthetes (but nine grapheme-colour synaesthetes and two word-colour synaesthetes) in a sample of 500 university students.

Recently, a neurological account has been proposed that explains the prevalence patterns in terms of proximity of grapheme and colour processing areas within the left fusiform gyrus (Ramachandran & Hubbard 2001). If neuroanatomical adjacency between primary perceptual regions were necessary to synaesthesia, then we might expect that speech-sound → colour synaesthesia would be rare or non-existent, at least among literate people, and that most apparent cases of speech-sound → colour synaesthesia would turn out to be grapheme-colour synaesthesia in disguise.

The adjacency hypothesis is controversial from a neurological point of view, however, and there are at least two further reasons to suspect that speech-sound → colour synaesthesia has an independent existence. First, studies that have a phonetic focus have identified some systematic colour associations that are different from those for graphemes. For example, in a large study of grapheme-colour synaesthesia, Simner, Ward, Lanz, Jansari, Noonan, Glover and Oakley (2005) find ⟨o⟩ to be predominantly white, though sometimes black. In contrast, Marks (1975) studied case reports of sound-colour synaesthesia with a focus on phonological vowels, and found the vowels [o] and [u] (often corresponding with orthographic ⟨o⟩ or ⟨oo⟩) to be associated with dark colours. (Certain associations are, however, shared among graphemes and speech sounds, e.g. ⟨a⟩ and [a] with red.)

Second, it remains to be demonstrated that grapheme-colour and speech-sound → colour synaesthesias are pure, separable variants of the condition, as opposed to points along a continuum. Baron-Cohen et al. (1993) categorized their subjects as having phoneme-colour or grapheme-colour synaesthesia based on *majority* response pattern, which suggests a mixture of influences. Simner, Glover and Mowat (2006) showed that lexical stress influences the colour of both spoken and written words in a group of grapheme-colour synaesthetes whose words are coloured predominantly according to their vowels. Although we access a word's stress pattern when we read, stress is not usually represented in written language, and is in origin a phonological

property. Therefore, the influence of stress on grapheme-colour synaesthesia suggests an intertwining of phonetic and graphemic influences.

Recent work has sought to explain systematicities in grapheme-colour correspondence patterns by correlating properties of graphemes with external predictors. Simner et al. (2005) and Simner and Ward (2008) demonstrated that synaesthetes tend to associate frequently-occurring graphemes with frequently-occurring colour terms. However, it is not usual for analyses to incorporate phonetic predictors in addition to graphemic or frequency-based ones, in order to test for the possibility of combined influences. To do this requires the development of clear hypotheses about speech-colour mappings, the issue discussed in the next section.

3. Which parameters of speech are involved in speech-colour mappings?

3.1 Parameters in the analysis of speech

Although most work on speech-colour synaesthesia has been framed in terms of sound segments such as phonemes, the reality of speech is captured better by examining the physical parameters that make it up. These include both articulatory and acoustic parameters, which are related in systematic (though complex) ways (e.g. Stevens 1997). Both are potentially relevant in synaesthesia; we focus on the acoustic level, which has received somewhat more attention.

Speech consists of acoustic energy across a wide frequency spectrum. The relative amount, or amplitude, of acoustic energy at each frequency fluctuates rapidly over time, reflecting the rapid movements of the vocal organs in the flow of speech. The time-varying speech spectrum conveys a wide range of linguistic and non-linguistic information about the particular vowels or consonants being articulated, their place within larger linguistic units (such as words, phrases, or turns in conversation), and the speaker's personal and social characteristics.

A number of parameters of the speech spectrum are considered to be particularly informative. First, the *fundamental frequency*, or f0, is the lowest frequency component of the speech wave, with overtones (harmonics) at regular intervals above it. The fundamental frequency reflects vibration of the speaker's vocal folds, and corresponds to the perceived pitch of the voice. It is affected by speaker characteristics (e.g., on average, f0 is higher for females than males), and also rises and falls in linguistically meaningful ways related to the intonation of speech. The harmonics above the fundamental frequency are affected by details of the way in which the vocal folds are vibrating, which reflects other aspects of individual vocal quality or timbre such as breathiness, harshness, creakiness, and falsetto.

Second, the *formant frequencies* are the resonant frequencies of the cavities of the mouth, nose and throat. They change over time, reflecting the changing shape of these cavities during the articulation of sounds, as well as attributes of the speaker such as

the size of the cavities, and the habitual articulatory posture. Different vowel qualities are distinguished by their different formant frequencies, e.g. the [i] vowel in *beat* versus the [a] vowel in *bat* versus the [ɔ] vowel in *paw*.

A third important acoustic parameter, *aperiodic noise,* is present especially in certain types of consonant sound (e.g. 'pops' in stop consonants like [p] [t] [k] and 'hisses' in fricative consonants like [f] [s] [ʃ]='sh'). The acoustic properties of these types of noise are determined by the resonant frequencies of particular configurations of the vocal cavities.

The issue for speech-colour synaesthesia is thus which of these aspects of the speech spectrum are important in determining colour percepts. In principle, any or all could play a role, independently or in interaction with one another, perhaps to differing degrees for different synaesthetes.

3.2 Vowels

The most systematic investigation of speech sound → colour synaesthesia has been conducted for vowel quality. Jakobson (1962) posits various general relationships between colours and vowels, whose empirical basis is unclear: they appear to be derived from a combination of synaesthetes' case reports and phonetic insight. Jakobson considers two axes of colour, light-dark, and chromatic-achromatic, and relates these to the phonetician's traditional vowel triangle or quadrilateral (see Figure 1), which is a means of representing phonetic distinctions among vowels that reflects both articulatory and acoustic criteria. Jakobson proposes that chromaticity relates mainly to the vertical dimension of the vowel quadrilateral, which corresponds in articulatory terms

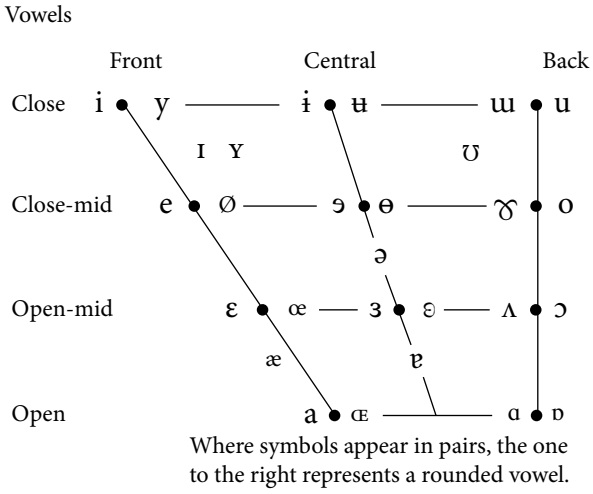

Figure 1. Vowel chart of the International Phonetic Alphabet. Reprinted with permission from the International Phonetic Association, http://www.langsci.ucl.ac.uk/ipa/

to the degree of jaw opening and tongue lowering, and in acoustic terms to 'compactness' (concentration of intense acoustic energy in a narrow, central region of the spectrum). Maximally open, or compact, vowels such as [a] are proposed to be maximally chromatic. The light-dark axis relates primarily to the front-back dimension of vowels, which corresponds in articulatory terms to the position of the highest point of the tongue in the mouth cavity, and in acoustic terms to the frequency of the second formant. Front vowels such as [i] are proposed to be lighter than back vowels such as [u]. As chromaticity decreases (i.e. for phonetically close vowels), the importance of the light-dark opposition is said to increase.

Marks (1975) reports a meta-analysis relating trends in a large number of synaesthetic case reports to average acoustic and/or perceptual properties of vowels. He observes that: (1) the black-white dimension is related to vowel 'pitch', by which he appears to mean a perceptual impression that is based on formant frequencies, but can be correlated with the pitch of pure tones; (2) the red-green dimension is related to vocalic compactness, defined here as the ratio of the second to first formant frequencies. Thus, vowels with a higher 'pitch', e.g. [i], [e], are whiter than those with a lower 'pitch', e.g. [o], [u]; and vowels with a higher ratio of second to first formant, e.g. [i], [e], are greener than those with a lower ratio, e.g. [a]. The correspondences with Jakobson's hypotheses are striking. Marks's 'pitch' dimension is related to Jakobson's front-back dimension because the 'pitch' differences are related to the frequency of the second formant (low in back vowels, high in front vowels). Both authors identify compactness as relevant, although Jakobson associates it with chromaticity *per se*, and Marks with red-green.

Marks's study has methodological limitations, especially the impossibility of reconstructing from case reports the actual vowel qualities involved. However, recent evidence from experiments with non-synaesthetes broadly supports Marks's findings. Wrembel and colleagues tested non-synaesthete Polish subjects with Polish vowels (Wrembel 2007) and English vowels (Wrembel & Rataj 2009). Subjects matched vowels to a palette of eleven 'basic' colours. Close front vowels (English /i/ and Polish /i/) were associated with yellow and green, and mid front /e/ in both languages with greens and blues. More central vowels tended to elicit grey hues. Open vowels (English /æ/ and /ɑ/ and Polish /a/) tended to elicit red hues, while back vowels tended to elicit dark colour associations: browns, blacks, greys and blues.

In a preliminary study, the authors tested ten English-speaking non-synaesthetes on fifteen [h] + vowel syllables. The vowels were produced by a male phonetician as exemplars of categories from the International Phonetic Alphabet, rather than as English vowels, though some were close in quality to vowels of English. Participants heard each syllable up to five times, then matched it to a colour chosen freely from a 149-choice colour wheel. Colours were specified in terms of Hue, Saturation and Brightness values (range 0 – 255) as determined in the colour picker tool of Microsoft Office. Whilst a formal calibration of the colours was not performed to allow conversion to CIE or other standard colour space, these numbers do give a broad indication of the colour and brightness content of the stimuli chosen.

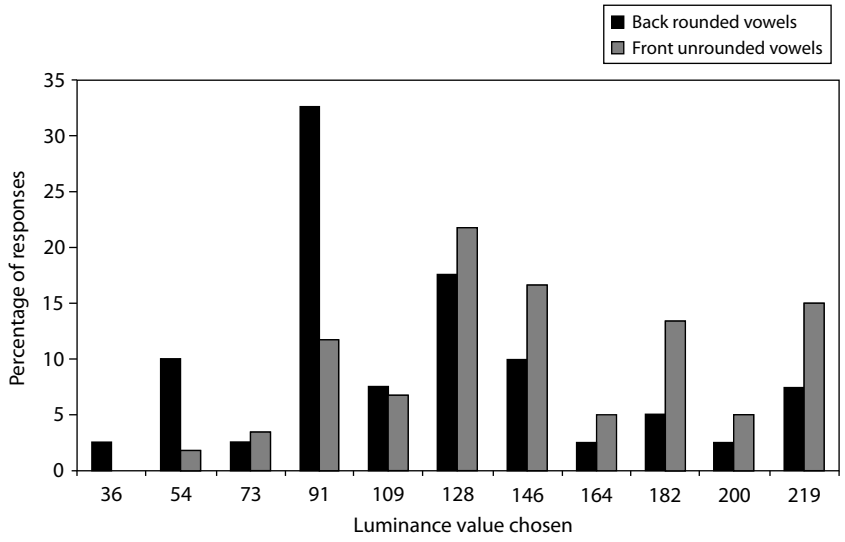

Figure 2. Luminance values chosen for back-rounded and front-unrounded vowels

Three main trends emerged from this experiment. First, the open vowels [aː] and [ɑː] showed high consistency across participants: 30% and 40% respectively responded with maximally saturated red hues (hue 255, saturation 255). Second, front-unrounded vowels elicited higher luminance values than back-rounded vowels (Figure 2). Tentative evidence was also found for a role for hue, with blues and purples chosen for back-rounded vowels more frequently than for front-unrounded vowels (Figure 3).

The striking thing about these studies is their consistency in spite of different methodologies, subject cohorts and even languages: in particular, the findings of high luminance values for front-unrounded vowels, reds for open vowels, and dark hues for back-rounded vowels. More work is needed to tease out the combinations of acoustic parameters and dimensions of colour that best explain the patterning in the data, and also to test how sensitive the patterns are to fine-grained variation in vowel quality, such as slightly different realisations of the 'same' vowel produced by different speakers, or by the same speaker in different phonetic contexts.

3.3 Consonants and larger speech units

Consonant segments might also evoke coloured concurrents, but very little work addresses this possibility. Jakobson (1962: 488) predicts, on the basis of the spectral features of consonants, (1) that consonants are relatively achromatic compared to vowels; (2) that dental/alveolar consonants (e.g. [t], [d], [s]) are lighter than labial or velar consonants (e.g. [p], [b], [m], [k], [g]); (3) that acoustically *diffuse* consonants (labials and dentals) are maximally achromatic (black – white), while acoustically *compact*

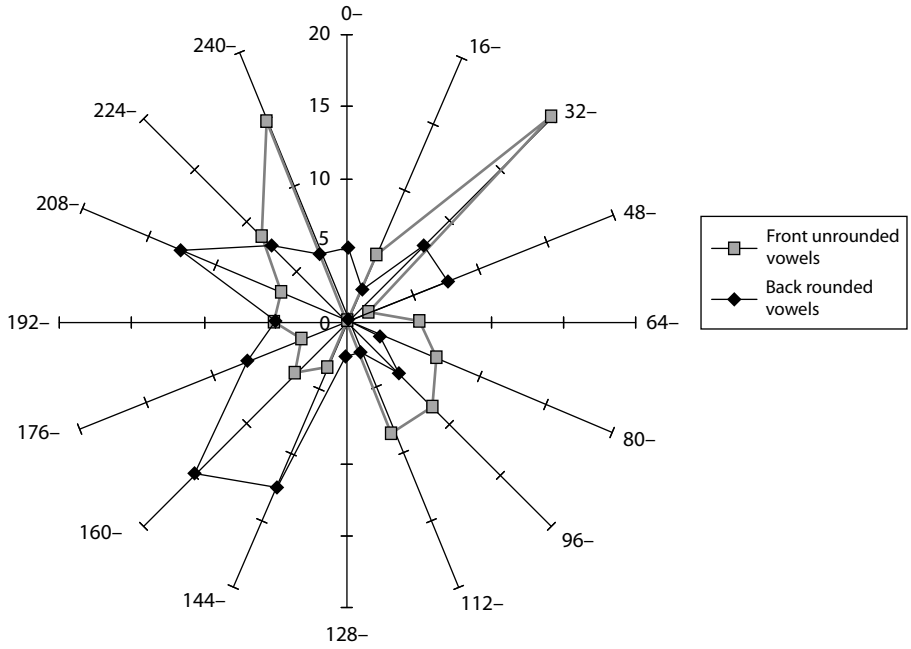

Figure 3. Hue values chosen for back-rounded and front-unrounded vowels. Hues 16-48 are oranges, yellows; hues 64-112 are greens; hues 144-208 are blues, purples; hues 224-255 (=0) are pinks, reds

consonants (palatals and velars) exhibit attenuated achromaticity (grey). To our knowledge, Jakobson's predictions have not been systematically tested.

In normal speech, consonants and vowels influence each other mutually through the phenomenon of coarticulation, e.g. /k/ is pronounced slightly differently in *key* vs *caw*. Individual sounds occur within larger units such as syllables, words, and phrases, and a sound's place in these larger structures affects the details of how it is pronounced. In ordinary speech perception, listeners are exquisitely sensitive to these types of context-dependent pronunciation variability. However, there is no evidence as to whether any of these processes might affect synaesthetic concurrents.

3.4 Voice characteristics

There has been no systematic investigation of the possibility that vocal characteristics – such as the pitch of the voice, reflected in fundamental frequency (f0) – act as synaesthetic inducers. Comparable properties of musical sounds have, though, been investigated. Musical sounds, like speech, have a pitch or fundamental frequency, and this can act as an inducer with colour as concurrent. Ward, Huckstep and Tsakanikos (2006) showed that sounds with high f0 tend to be associated with lighter colours and those

with low f0 with darker colours, for both synaesthetes and non-synaesthetes. Additionally, Ward et al. compared instrumental notes, which have f0 and harmonic overtones, with pure tones (computer-generated sounds that have energy only at one frequency, their f0). Instrumental notes were perceived as more colourful than pure tones.

Questionnaire results suggest that for some synaesthetes, individual voices do act as inducer (Simner, personal communication). A study of lay 'labels' for voice qualities (Laver 1974) also suggests that visual analogues for voices are quite common, in terms of colour or texture or both, e.g. 'golden', 'metallic', 'colourless', 'dark brown', 'treacly' or 'pink' voices.

4. Conclusion

The extant studies of speech-sound → colour synaesthesia differ widely in terms of degree of methodological control and subject population, and the topic remains under-researched compared to grapheme-colour synaesthesia and music-colour synaesthesia. Converging evidence across studies suggests, however, that systematic, phonetically-motivated correspondences do exist between spoken vowels and colours, for both synaesthetes and non-synaesthetes. There are intriguing points of overlap and divergence with, on the one hand, grapheme-colour synaesthesia, and on the other, music-colour synaesthesia. Further work on these parallels and divergences has the potential to shed light on the neurological basis of the condition.

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Perceiving "grue"

Filter simulations of aged lenses support the Lens-Brunescence hypothesis and reveal individual categorization types

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Many languages have only one term for "green" and "blue", generally called "grue". Since they are especially spoken near the equator, Lindsay and Brown (2002) suggested that "grue" categories are caused by lens-brunescence, resulting from chronic exposure to high amounts of UV radiation. Due to increased lens aging bluish colours should appear greenish. Monitor-simulation experiments supported this hypothesis. However, the distribution of "grue" foci (Regier & Kay 2004) and the adaptation to lens yellowing in older observers (Hardy, Frederick, Kay & Werner 2005) contradicted the lens-brunescence hypothesis.
This study reinvestigated the possible influence of aged, brunescent lenses on colour categorization, simulating aged lenses by means of filters. The filter simulation shows important differences to previous monitor simulations, and defuses arguments that were put forward against the lens-brunescence hypothesis.

1. Introduction

Many languages make no distinction between "green" and "blue". They have only one term for these colours, generally called "grue". A significantly higher number of "grue" languages are spoken by people living in areas near the equator, while "blue/green" languages tend to be spoken at higher latitudes (Bornstein 1973; Lindsey & Brown 2002). In their lens-brunescence hypothesis Lindsey and Brown (2002) suggested that, in equator-near areas with high UV insolation, the lens might undergo a much faster aging process than in low-UV areas, resulting in a high optical density and thereby blue insensitivity at relatively young ages.

In a computer-simulation experiment they tested whether lens- brunescence alters colour categorization in a way that corresponds to the categorization patterns of "grue"

languages. By changing the colour of test patches according to the increasing density of the lens with age, they simulated densities of 50 to 100-year-old Europeans. Lindsey and Brown calculated that a 100-year-old European's lenses might correspond to the faster-aged lenses of a 30-year-old or even younger inhabitant of a high-UV area.

Most of the chromaticities that were normally categorized "blue" by the observers were mainly categorized "green" for the highest simulated optical density. Lindsey and Brown interpreted their results as a confirmation for a relation between lens-brunescence and the usage of a "grue" term. Yet, this did not stand uncontradicted.

Regier and Kay (2004) argued that lens-brunescence would not explain why the best examples of "grue" tend to peak at English focal "green" and focal "blue". Hardy, Frederick, Kay and Werner (2005) tested the effect of naturally-aged lenses on colour naming and found only minor differences between older and younger observers. They concluded that long-term adaptation mechanisms are able to compensate for increase of optical density with age. Thus, a connection between lens-brunescence and "grue" languages should be improbable.

In the present study the experimental design was changed. Lindsey and Brown (2002), and Hardy et al. (2005) tested only rather highly-saturated stimuli.[1] This study tested different saturations because investigations of aged observers (e.g. Kraft & Werner 1999) suggested that saturation might be an important factor. Additionally, instead of manipulating the colours of test patch and monitor background, observers looked through yellow-orange filters. The filters caused a chromatic change for the whole visible environment, whereas the local simulation on the monitor occupied only a rather small part (29°) of the visual field.

2. Materials and methods

2.1 Participants, stimuli and display

All participants (7 males, 11 females, 19 to 35 years old, average age 24) were native German speakers and were tested to guarantee normal colour vision. They had to name the colours of 417 circular patches of 2°, presented one at a time on a CRT monitor (8° x 11°) with a neutral-grey background. The room's illuminated walls had the same chromaticity as the monitor's background. Technical devices and setup were identical to those of Hansen, Walter and Gegenfurtner (2007).

The chromaticities of the isoluminant stimuli were specified in the DKL colourspace (Krauskopf 1999) and distributed regularly across the available gamut. In DKL space an isoluminant plane is spanned by two chromatic axes, intersecting at angles of

1. In what follows, the citations from Lindsey and Brown, and Hardy et al. will refer to their articles from 2002 and 2005, respectively, if not indicated differently.

90° at the central white point (corresponding to neutral grey). The 0°-180° axis runs from red to blue-green, the 90°-270° axis from green-yellow to bluish purple. Within the isoluminant plane the angle of a position defines the hue, and its distance from the white point the saturation.

The chromaticity of the white point was x = 0.31 and y = 0.32 in CIE coordinates, with a luminance of 32 cd/m^2.

2.2 Categories

The colour names were given in German: "*grau*" (grey), "*gelb*" (yellow), "*orange*" (orange), "*rot*" (red), "*violett*" (purple), "*blau*" (blue), "*tuerkis*" (turquoise) and "*gruen*" (green). In the following text the corresponding English names will be used to refer to these colour categories. Throughout the text, colour terms in quotation marks indicate subjective, named colour categories, and colour terms without quotation marks indicate objective directions or positions in colour space.

Since the colours were shown at one medium luminance level, other basic colour terms (Berlin & Kay 1969) which are differentiated from the colours above by brightness were excluded. The category "turquoise" was included because "grue" combines blue and green colours and it could be expected that "grue" corresponds best with an intermediate category between "green" and "blue". In German the status of "turquoise" is very similar to that of a basic colour term (Zimmer 1982; Zollinger 1984).

2.3 Filters

To simulate aged lenses, observers looked through filters of different densities. They wore opaque black goggles with square front-openings (4 x 4 cm). In filter conditions, the front openings were covered with Kodak Wratten filters. The weak-filter condition simulated a European's theoretical age of approximately 105 years (2 Kodak 85 + 1 Kodak CC40Y), the strong-filter condition approximately 165 years (4 Kodak 85 + 2 Kodak CC40Y), calculated after the linearly extended lens-aging model of Pokorny, Smith and Lutze (1987).

2.4 Data analysis

Only the chromatic range from 90° to 270° of DKL colour-space was considered, comprising 218 tested colour-space positions. This range corresponds to Munsell hues from GY (yellow-green) to BP (purple-blue) and is nearly identical with the normally "green", "turquoise" or "blue" categorized range (Hansen, Walter & Gegenfurtner, 2007).

To compare the results with those of the previous lens-brunescence simulations, the proportion of the different colour categories for the different tested hues was

analyzed. Within ranges of 5° of DKL space the respective categorizations of all observers for a certain colour category were added up.

Additionally, individual replacement patterns for "green", "turquoise" and "blue" were determined, comparing the categorizations for standard and strong filter condition. For each category the wins and losses from and to the two other analyzed categories were added up, thus calculating the total gain for that category in relation to the respective other categories. The results of the different observers were analyzed by Principal Component Analyses (PCA).

3. Results and comparison with previous simulation experiments

3.1 Colour-naming frequency

In Figure 1 the proportion of "blue", "turquoise", "green", "grey" and "purple" responses is given as a function of angle in DKL colour-space in steps of 5°. The different stimuli within such a 5° range are of approximately the same hue, but have different saturations. The corresponding Munsell hues are also indicated. Further categories are left out because their portion of categorizations is clearly below 5% for all conditions.

Grey vertical bars mark the positions of the "green" and "blue" curves' intersection points, where the majority of categorizations per hue changed from "green" to "blue". Arrows indicate the approximate positions of "green"-"blue" intersections for previous monitor simulations by Lindsey and Brown, and Hardy et al. (abbreviations LB and H), numbers give the simulated age (cf. Lindsey & Brown 2002, Figures 4 and 5; Hardy et al. 2005, Figures 2 and 3).

3.1.1 *"Green"-"blue" intersection points*

The results of the weak-filter condition, simulating a 105-year-old European, show a small shift of the "blue"-"green" intersection towards blue. The slightness of the shift is in clear contrast to the results of Lindsey and Brown, and Hardy et al. Lindsey and Brown observed a shift of similar magnitude for their simulation of 50 years of age. Thus, whereas the age simulated with weak filters corresponds to the highest age simulated by Lindsey and Brown, the shift corresponds to their lowest simulated age.

For strong filters, the magnitude of the "green"-"blue" intersection's shift towards blue is much stronger, about four times that for weak filters. This shift for filters simulating 165 years of age corresponds nearly exactly to the shift that was reported by Lindsey and Brown for their simulation of 100 years.

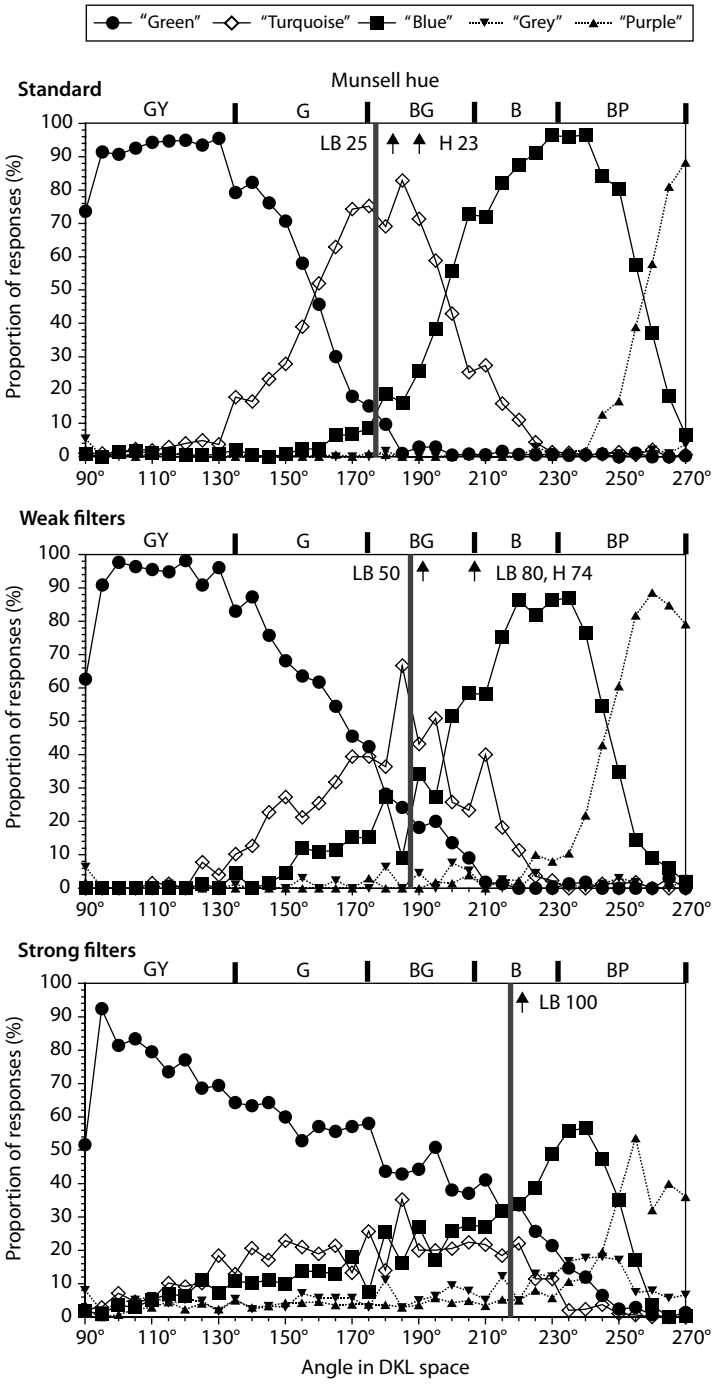

Figure 1. Proportion of colour-name responses

3.1.2 *Curve progressions*

3.1.2.1 *"Blue" and "turquoise" peaks*. Comparing the regions with the highest agreement for "blue" and "turquoise", we find only small deviations of their respective angular positions between the three conditions of the present study.

However, especially in the strong-filter condition, the maximal portions for "blue" and "turquoise" remain below those of the standard condition, mainly because of more frequent "green" categorizations for the respective hues. Primarily in the peak region, "blue" is also in part replaced by "grey". These results for strong filters correspond well with the findings of Lindsey and Brown for simulated 100 years.

3.1.2.2 *"Green"-"blue" ratio*. Monitor simulations showed an agreement of categorizations above 90% for the majority of the dominantly "green" categorized range in standard and aged conditions. In aged conditions, the point where the portion of "green" categorizations falls below 90% and "blue" starts to rise above 10% was shifted parallel with the "green"-"blue" intersection towards blue.

While the present study's standard condition shows very similar results, those for filter conditions are clearly different from monitor simulations (see Figure 1). Despite the large shift of the "green"-"blue" intersection towards blue for strong filters, the standard condition's plateau of above 90% for "green" is not extended, but reduced to a single peak near yellow. The number of "green" categorizations decreases from this peak towards blue. Simultaneously, the number of "blue" categorizations starts to increase. The portion of "blue" categorizations is above 10% for the majority of the dominantly "green" categorized range.

3.1.2.3 *Replacement of "turquoise"*. Lindsey and Brown's assumption that normally "greenish-blue" or "turquoise" hues should appear "green" with strong brunescent lenses was confirmed by their simulations: within the Munsell BG range, even stimuli that were named "blue" by more than 90% in the standard condition were named "green" by more than 90% for the monitor simulation of 100 years.

With filters, the proportion of "green" categorizations altogether rises for hues that are categorized mainly as "turquoise" in the standard condition, but the proportion of "blue" categorizations rises as well. And even for strong filters the "turquoise" proportion still extends to 35%. Furthermore, the range with "turquoise" categorizations above 10% slightly expands, towards blue as well as towards green. Such differences to the standard condition are rather small for weak filters, but pronounced for strong filters.

Thus, whereas Lindsey and Brown, and Hardy et al. observed a unilateral replacement of "blue" by "green", and obtained for all conditions a relatively sharp separation of "green" and "blue", this study shows a comparably clear separation only for the standard condition. For weak filters a more continuous transition between categories is already recognizable. For strong filters that separation is distinctly weakened.

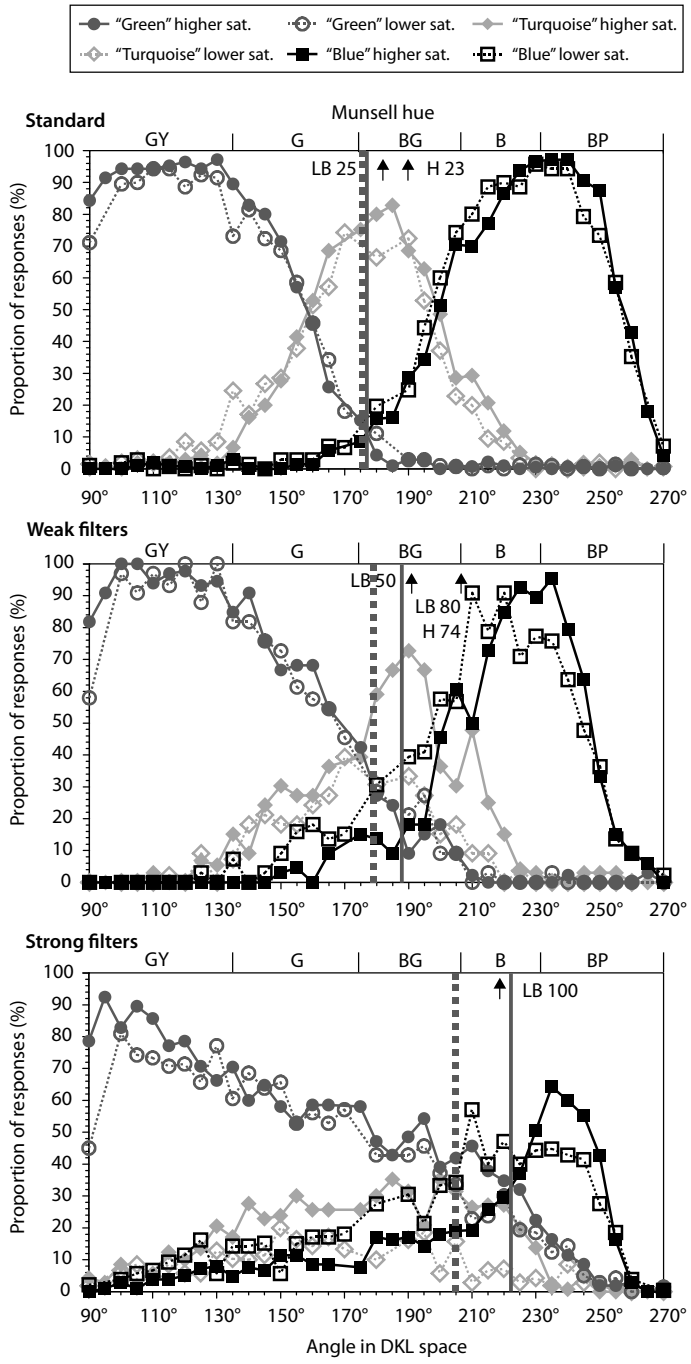

Figure 2. Proportion of colour-name responses for higher and lower saturated stimuli respectively

3.1.3 *Influence of saturation*

Since the observed differences to the monitor simulations might be a consequence of the additionally tested lower saturations, we will now analyze the results for higher and lower saturations separately.

Figure 2 gives the proportion of "blue", "turquoise" and "green" responses for the higher saturated (filled symbols, continuous lines) and the lower saturated (open symbols, broken lines) half of the stimuli. The higher saturations correspond approximately to the monitor simulations' degree of saturation. Grey vertical bars mark the intersection points of the "green" and "blue" curves (continuous bar for higher saturations, broken bar for lower saturations).

The results for the standard condition show virtually no difference between higher and lower saturation, but clear differences appear with filters.

The shift of the "green"-"blue" intersection towards blue is – unlike the situation expected by Lindsey and Brown – clearly smaller for lower saturations than for higher saturations. However, the results for higher saturations show that the difference described above to monitor simulations cannot be merely a result of the additionally tested less-saturated chromaticities: with weak filters, the shift observed for high saturations is still similar to the shift observed by Lindsey and Brown for the simulation of 50-year-old Europeans. In the strong-filter condition the "green"-"blue" intersection's shift is not very much larger than in Lindsey and Brown's simulation of 100-year-old Europeans.

The separate inspection of the results for higher and lower saturated stimuli shows also that higher proportions of "blue" categorizations for green-yellow and green hues in filter conditions mainly appear for lower saturations. This might explain why monitor simulations did not show such an effect.

3.1.4 *Individual replacement patterns and categorization types*

Individual replacement patterns were determined by analyzing how many of the standard condition's "green", "turquoise" or "blue" stimuli were categorized differently in the strong filter condition.

Figure 3 shows the result of a PCA (the first two axes explain 75% of the data's variance; first axis 52%, second axis 23%). The replacement patterns can be grouped into three main types, indicated by the grey ellipses: "green", "turquoise" and "blue" expanders, i.e. observers who show the highest total gain (more wins than losses for that category) for "green", "turquoise" or "blue", respectively. The biggest group (61%) are observers who primarily expand their "green" category. 22% of observers predominantly expand "turquoise", and 17% "blue". This grouping is supported by cluster analysis.

While most observers show a total gain for only one category, 22% also show a total gain for a second category: two "green" expanders also expand "blue", one "blue" expander also expands "turquoise", and one "turquoise" expander also expands "green". In some cases, the expanding category is extremely enlarged, so that it covers nearly the whole tested area of colour space. Figure 4 shows individual categorization examples for the different main types. Observer *su* is a moderate "green" expander; note also

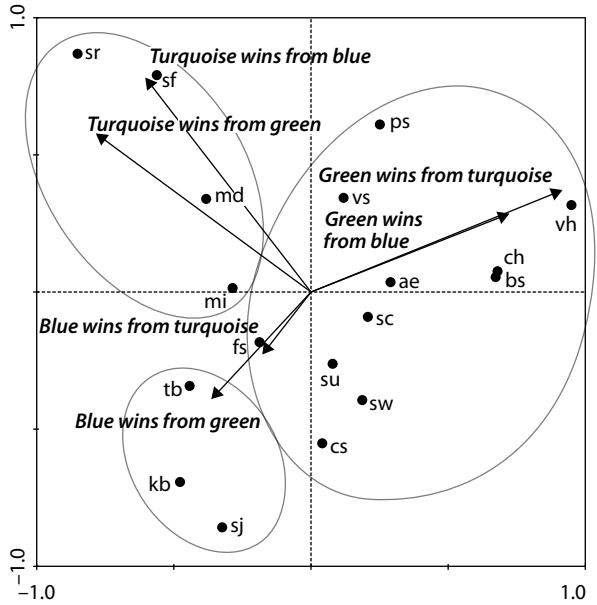

Figure 3. PCA of individual categorization replacements for "green", "turquoise" and "blue" (standard versus strong filter condition)

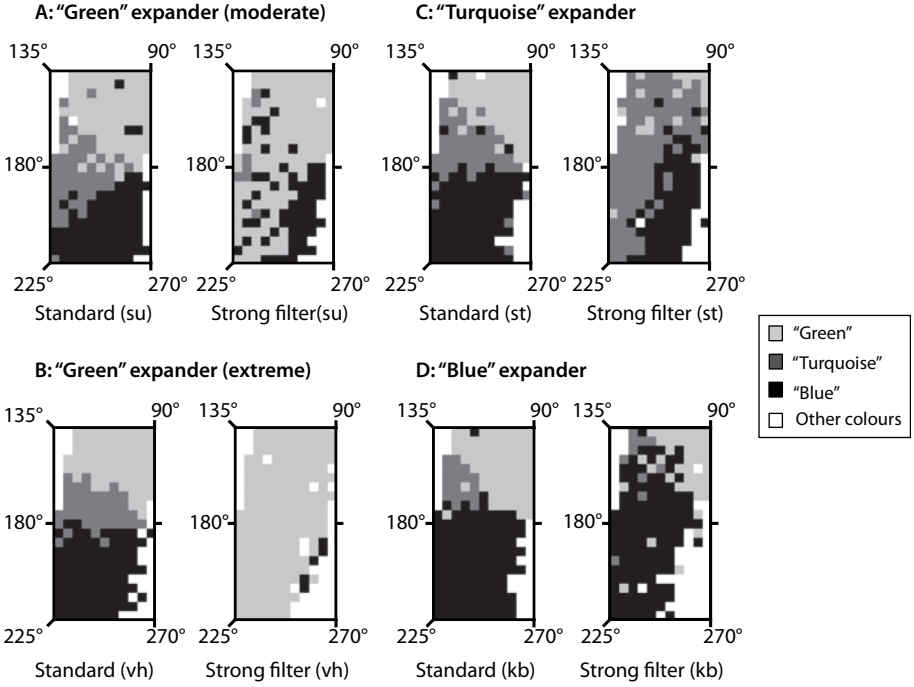

Figure 4. Individual categorization-patterns (standard and strong filter condition)

the extended range of "blue" categorizations for strong filters. An example of an extreme "green" expander is observer *vh*. Observers *sf* and *kb* are examples of "turquoise" and "blue" expanders respectively.

Apparently, the tested observers perceive chromaticities of the green-blue range through strong filters in different ways. Whereas for some of the observers the colours mainly become greener, for others the perceived colours predominantly appear rather as turquoise or even bluer.

4. Discussion

4.1 Filter results are consistent with previous investigations on aged observers

4.1.1 *Weaker brunescence is compensated by adaptation mechanisms*

While the simulation with weak filters led to results which are distinctly different from the simulations by Lindsey and Brown, and Hardy et al., they are consistent with another finding by Hardy et al. In addition to the simulation of aged lenses for young observers, they also tested a group of (on average) 74-year-old observers with naturally increased optical density. Old observers categorized the stimuli in virtually the same way as younger observers in the standard condition, despite the optical-density differences.

To explain the difference between computer-simulated 74-year-olds and naturally-aged observers, Hardy et al. proposed that, in the visual system of older observers, long-term operating adaptation mechanisms compensated for the changes.

Regarding the rather small differences in colour appearance for weak filters, it does not come as a surprise that Hardy et al. did not find significant differences between their older sample and the younger sample for the standard condition. The older observers who participated in their experiment were on average still 30 years younger than the age of 105 years, simulated in the weak-filter condition. Obviously, short-term operating mechanisms are able to compensate for most of the changes due to an even stronger increased optical density than that investigated by Hardy et al.

4.1.2 *Explanation for adaptation differences between filter and monitor simulations*

An explanation for the low adaptation in monitor simulations in contrast to the high adaptation in the filter simulation and old observers is probably the fact that the monitor simulation covered only a part of the observer's visual field, whereas the filter changed the perceived light for the whole visible environment just as aged lenses do. Other experiments already showed that colour-constancy mechanisms are quite effective and not very much information is needed to reach nearly perfect constancy despite extreme changes in the spectral composition of the perceived light (e.g. Kraft & Brainard 1999; Hansen, Walter & Gegenfurtner 2007).

4.1.3 *Adaptation is only partial for strong natural aging processes*

Referring to the visual system's adaptation to increasing optical density, Hardy et al. concluded that UV-induced lens-brunescence is unlikely to change colour appearance in the way proposed by Lindsey and Brown.

However, several investigations reported altered hue perception for observers of comparable age (Verriest 1963; Smith, Pokorny & Pass 1985; Knoblauch, Saunders, Kusuda, Hynes, Podgor, Higgins & de Monasterio 1987). Older observers who were tested with the Farnsworth-Munsell 100-hue test showed significantly reduced discrimination abilities, especially for blue and blue-green hues, similar to a tritan deficiency. Davies, Laws, Corbett and Jerrett (1998) found no colour vision deficiencies for British observers of ages up to 65, but frequent tritan errors for an older sample (mean age 77).

These findings for older observers suggest that adaptation is able to fully compensate for weaker age-related changes, but not for stronger changes.

4.2 Filter simulations support the lens-brunescence hypothesis

4.2.1 *Filter-simulated brunescence makes discrimination between "green", "blue" and "turquoise" more difficult*

Lindsey and Brown assumed that desaturated or greenish blues (like pale blue and turquoise) would appear "green" to old observers. And indeed, stimuli previously named "blue" were named "green" in their simulated aged conditions.

Also, for the average results of the filter simulations, we find that the "green" category expands towards blue. Yet "blue" also expands towards green, and even for strong filters "turquoise" categorizations do not vanish. Their range expands towards blue and green as well. Strong filters do not only make a high number of the bluish chromaticities appear greener, but also greenish chromaticities appear bluer. Thus, from a certain level of optical density the difficulties in differentiating hues of the green-blue range increase strongly.

Additionally, the observed different individual categorization patterns indicate that even observers with similarly brunescent lenses do not perceive chromaticities of the green-blue range in the same way. This complicates the common use of a "green/blue"-categorization.

It makes sense then not to separate these hues into different linguistic categories, but to use a single term instead, namely "grue".

4.2.2 *Filter-simulated brunescence does not imply the necessity of a single focus for "grue"*

Regier and Kay's (2004) objection to the lens-brunescence hypothesis started from the assumption that higher ocular density would cause a unilateral reduction of "blue" percepts in favour of "green". Then "grue" could be understood as an enlarged "green" category – which was supported by the results of Lindsey and Brown's

simulation experiment. Regier and Kay (2004) concluded that, corresponding to the single focus for "green", there should then be a single focus for "grue". With the expanding "green", this focus should be shifted to a position between "green" focus and "blue" focus. Yet most "grue" foci do not peak at an intermediate position, but near English focal "green" and focal "blue", as Lindsey and Brown had already pointed out. Regier and Kay (2004) argued that therefore the lens-brunescence hypothesis must be incorrect.

In this study – as in the simulations of Lindsey and Brown, and Hardy et al. – data on category foci were not collected. However, the assumption of a general unilateral expansion of "green" towards blue, on which Regier and Kay's objection was based, is not confirmed. On average, filter-simulated stronger brunescent lenses do not only make "green" extend to blue, as previously thought, but even, though to a lesser extent, "blue" to green.

A single central "grue"-focus might also be expected if "grue" was comparable to a common extended intermediate "blue-green" or "turquoise" category. However, according to filter results, this does not seem to apply for lens-brunescence. If a lens-brunescence induced "grue" was a true common intermediate category, derived from "green" and "blue", a general domination of "turquoise" categorizations should have been observed. This is not the case.

Furthermore, comparing the different conditions, no shift of the highest results per category to an intermediate position is observable. These facts do not support the previously postulated necessity of a general focus shift.

4.2.3 *Results of the filter-simulations are consistent with distribution of "grue" foci*

Lindsey and Brown (2004) re-examined the World Colour Survey data and confirmed that, for speakers of "grue" languages, most foci are found near the foci for "green" and "blue". However, the peak in green is much higher than the peak in blue, in contrast to the distribution of foci for speakers of "blue/green" languages. Unlike the sharp separation of "green" from "blue" foci in "blue/green" languages, there exists a remarkable number of foci between these peaks for "grue" languages (cf. Lindsey & Brown 2004, Figure 2).

A distinctly lower peak for "blue" as compared to "green", and a more continuous transition from "green" to "blue", are consistent with the mean categorization patterns observed in the present study for strong filters.

The observed individual categorization types suggest that individual colour-perception differences influence whether the "grue" focus is placed in blue or in green or in between. While most observers for strong filters preferentially extend the number of "green" categorizations, there exist also observers who preferentially extend "blue" or "turquoise". A higher proportion of observers with a dominant "green" category, and smaller proportions with a dominance of "blue" or "turquoise", fits very well with the observed distribution of "grue" foci.

4.3 Plausibility of lens-brunescence-effect appearance during lifetime

The results of this study suggest that lens-brunescence can cause changes in colour appearance which might explain the use of a "grue" category. Yet the optical density which is necessary to cause a distinct effect on colour naming seems to be higher than previously thought. Could such high densities be reached in equator-near regions at a plausible age?

First of all, the corresponding ages indicated here for filters are most likely too high because they assume a linear density increase with age, whereas the natural aging process shows an accelerated density increase (Pokorny, Smith & Lutze 1987).

In some regions of the tropics the mean UV-B exposure is more than five times higher than in central Europe (cf. Lindsey & Brown 2002, Figure 2). If we assume a linear progression for the density increase, the strong filter simulation might then correspond to only about 30 years of age, and weak filters to about 20 years.

The lens-brunescence's effect on colour vision might also be enhanced by light-induced sensitivity loss of the especially vulnerable short wavelength-sensitive receptors (Sperling 1991).

If hues are separated into different basic categories by a language, speakers of that language are able to distinguish them better than speakers of a language that does not make such differences (Winawer, Witthoft, Frank, Wu, Wade & Boroditsky 2007). Thus, for "grue" speakers the confusion of "green" and "blue" should already appear for a less intense brunescence as compared to "green/blue" speakers.

Finally, the differences in lifestyle between the tested members of an industrialized urban society and "grue"-speaking populations of rural farmers must be taken into account. In agrarian societies, people certainly spend a greater amount of time outdoors, and eyes are not protected by sunglasses, resulting in longer exposure to sunlight over a lifetime. Indeed, field studies found clearly higher rates of defective colour vision in areas of higher UV insolation (Davies et al. 1998; Nacer & Al-Abdulmunem 2001).

5. Conclusion

All in all, the lens-brunescence hypothesis still seems to be a reasonable explanation for the distribution of "grue" languages. Certainly, lens-brunescence is not the only factor generating "grue" languages, but it might strongly influence the development of a language, making a common use of "green" and "blue" categories within a speech community more difficult.

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SECTION 6

Colour preference and colour meaning

Preface to Section 6

There is a sense in which the scientific study of colour preference and meaning has been pioneered by the PICS series of conferences. Whilst many might argue on the basis of anecdotal evidence that there is so much individual variation in our reactions to colours that scientific study is pointless, those who have persisted in this endeavour have conclusively demonstrated that there is a considerable and surprising amount of agreement between individuals on these matters, especially when certain obvious factors like age, gender and culture are taken into account and the visual stimuli are carefully calibrated and controlled.

Accordingly, Ling and Hurlbert follow up their chapter on colour preference in our previous volume (Ling, Hurlbert & Robinson 2006) with a further study looking at the effects of age on colour preference in the UK. Ling and Hurlbert's favoured evolutionary explanation of colour preference differences is questioned by Palmer and Schloss, who describe their new 'Ecological Valence Theory' of colour preferences, which argues that our colour preferences are largely determined by the colours of fav-oured (or disfavoured) objects to which we are exposed during development. Pitchford and co-workers explore this theme further by arguing for a strong role of colour preference in how young children learn to name colours. Prado-Leon and Rosales-Cinco add a cross-cultural dimension to the mix by looking at the specific colour associations made by young adult Mexicans.

Simmons explores in more detail the link between colours and the emotions they evoke. This, again, is a topic on which many people have opinions based on anecdotal evidence, but which shows surprising levels of agreement between culturally homogenous individuals when studied scientifically and systematically. The concluding chapter of this section, by Plebe and co-authors, explores the link between colours and the adjectives used to describe them, using an artificial neural network which mimics primate physiology.

This section of the book illustrates how the field of colour 'aesthetic science' has matured in recent years, by developing a theoretical basis which will form the hypotheses for future experiments to test. Furthermore, whilst the origin of this research effort is largely in psychology, it is clear that the field is truly inter-disciplinary, drawing on neuroscience, linguistics, computing science and art history, among other fields, in endeavouring to explain why we like (or dislike) the colours we do, and what this can tell us about colour perception and cognition in general.

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Age-dependence of colour preference in the U.K. population

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In our previous study of hue preference for young Chinese and British adults in Newcastle upon Tyne, we found that individual hue preference patterns may be described by the weighted sum of the two universal cone-contrast channels (S-(L+M) and L–M contrast) (Hurlbert & Ling 2007). Therefore, each individual's hue preference may be reduced to two factors, representing preference along the 'blue'-'yellow' and 'red'-'green' dimensions correspondingly. We also found robust differences between sex and culture, represented by differential weighting on these components. Here we extend the study by investigating colour preference across ages in the U.K. population. A portable experimental box was developed to conduct the study outside the lab. Stimuli were displayed on a calibrated laptop screen fixed at the back of the box. A chin-rest fixed the distance from which observers viewed the stimuli, and their heads were covered by a black curtain to exclude external light from view. The observer had to select, as rapidly as possible, his or her preferred colour from each of a series of pairs of stimuli on a grey background, above and below the centre of the screen. We tested 4 age groups, children (8–9 years old and 11–12 years old), young adults (18–24 years), and elderly adults (61–88 years). The results reveal robust sex and age differences in colour preference for the U.K. population, which are described by our preference model. Implications of these differences are discussed.

1. Introduction

There is a long and rich interest in the nature and origins of colour preference, and quantitative studies on this topic date back to a century ago (Chandler 1934). Yet, early studies of colour preference often employed ill-defined stimulus and illumination conditions, as well as unreliable methods of quantifying preference (Chandler 1934; Dorcus 1926), making their results difficult to analysze or generalize (McManus, Jones & Cottrell 1981). The results of better-controlled studies in the last

half-century are still difficult to extrapolate because of their complexity: most studies have been carried out independently and at different times from each other, using different experimental stimuli and methods for different subject groups. All of these factors may influence colour preference results, and without a universally applicable quantitative system of colour preference it is difficult to summarize preference variations across different populations and experimental conditions. In our recent studies, we proposed a novel model of colour preference which enables us to quantify colour preference in terms of a small number of factors directly linked to the underlying neural components of colour encoding (Hurlbert & Ling 2007; Ling, Hurlbert & Robinson 2006). We found that this preference model is comparable across studies using different experimental stimuli and paradigms (Ling & Hurlbert 2007), thus permitting us to analyze the influence of various factors such as sex, culture and age on colour preference. Here we report our findings of colour preference across ages in the U.K. population.

2. Quantitative studies of colour preference

There are four main methods of assessing colour preference quantitatively. Note that here we exclude studies without controlled visual stimuli (e.g. verbal questionnaires asking "what is your most favourite colour?"). The first and also the simplest method is to ask the observers to select their favourite colour (or the first few favourites) from a set of test alternatives. The advantage of this method is its simplicity and speed, which allows the experimenter to test large subject samples in a short period of time (Camgoz, Yener & Guvenc 2002; Saito 1981, 1996). Nevertheless this method provides limited information on individual colour preference patterns, and is only suitable for studies comparing large populations. The second method is to ask the observers to arrange a series of colours in the order of their preference (Eysenck 1941; Gelineau 1981; Granger 1955). This method, although more informative than the first one, suffers the same drawback, and allows only limited quantitative analysis on individual data. The third method is to instruct the observers to rate the pleasantness for each colour, which will generate a numeric representation of colour preference for all the tested colours (Guilford & Smith 1959; Helson & Lansford 1970; Ling & Hurlbert 2007; Reddy & Bennett 1985; Palmer & Schloss 2011). The fourth method, the most time-consuming, is to perform pair-wise comparisons for a group of colours (Choungourian 1968; Ling et al. 2006; McManus et al. 1981; Ou, Luo, Woodcock & Wright 2004). This method, similar to the third one, generates a numeric colour preference curve for each individual subject, but provides more accurate preference results. (The above list deliberately neglects the host of other studies which effectively treat preference as only one dimension in a complex space of emotional responses to colour. Such studies may indirectly measure preference by assessing the 'pleasure' or other positive associations of colours, again using a range of techniques including individual

ratings (e.g. Valdez & Mehrabian 1994) or forced-choice comparisons (e.g. Simmons, this volume).

The exact method employed by an experiment depends on several factors, such as the research question, the available time and resources, the age and accessibility of the population, etc. Pair-wise comparison, for example, has the advantage of high accuracy, but, because it is time-consuming, often tests only a limited number of colours (Choungourian 1968; Ling et al. 2006; McManus et al. 1981; Ou et al. 2004). The first two methods, by contrast, ensure speed by sacrificing accuracy and do not indicate the exact degree of attractiveness for each tested colour. The third method is often considered the "best compromise", as it reports more exact colour preference than the first two but is faster than the fourth.

Using these described methods, past studies have revealed certain major characteristics of colour preference. For most people, preferences are highest in the region of blue and lowest in the region of yellow and yellow-green. Early discoveries of a general order of preference – blue, red, green, purple, orange and yellow (Eysenck 1941) – have been largely supported by subsequent studies (Camgoz et al. 2002; Granger 1952, 1955; Guilford & Smith 1959; Helson & Lansford 1970; McManus et al. 1981; Ou et al. 2004). This seeming universality of colour preference has prompted researchers to propose a mathematical formula which predicts the preference value of a given colour based only on its chromaticity coordinates (Ou et al. 2004). Nevertheless, the idea of a single mathematical formula which encapsulates colour preference for all subjects has a fundamental flaw, in that it assumes that every individual behaves in the same way. Various studies have shown that individual colour preference is far from uni-modal, and is also affected not only by sex (Eysenck 1941; Helson & Lansford 1970; McManus et al. 1981) and age (Adams 1987; Bonnardel, Harper, Duffie & Bimler 2006; Dittmar 2001; Pereverzeva & Teller 2004), but also by geographical origin (Choungourian 1968; Reddy & Bennett 1985; Saito 1981, 1996). An ideal preference system should thus incorporate both the individual variability and the universal similarities of colour preference.

3. A new colour preference model

In our previous studies of hue preference (Hurlbert & Ling 2007; Ling et al. 2006), we proposed a novel mathematical model in which individual hue preference is described as the weighted sum of two cone-opponent contrast components: S-(L+M) ('blue-yellow') and L–M ('red-green') contrast. Therefore, each individual's hue preference may be reduced to a set of two weights, representing individual preferences for the blue-yellow and red-green components respectively. This model is based on the fundamental neuronal mechanisms which encode colour, and is universal for all observers, while allowing individual differences in hue preference to be represented by the differential weighting on these components.

In a follow-up study, we tested the model's performance for different stimulus sets and experimental methods (Ling & Hurlbert 2007). Here we selected three groups of stimuli: a set of 90 Munsell colours which best samples the entire colour space; 20 NCS colours which include more typical colours, based on a previous study by Ou et al. (2004); and 24 colours with controlled lightness, hue and saturation values, based on our own studies (Ling et al. 2006). We also used two different experimental methods: the direct rating of pleasantness for each colour, and the pair-wise comparison method. Each observer completed the tasks for all stimulus groups using both methods, and for each stimulus group and experimental method combination we obtained an independent colour preference curve for each individual subject. These results were then processed by the preference model, and an independent set of preference weights was obtained.

Our results demonstrated that the individual preference weights obtained from different stimulus sets and experimental methods correlate highly with each other ($p < 0.00001$), indicating that our preference model is robust across experimental conditions, and can serve as an ideal platform from which (1) to extrapolate results from different studies which were previously incompatible; and (2) to probe systematically factors affecting individual colour preference.

4. Preference across ages

Although colour preferences of both young adults (Camgoz et al. 2002; Choungourian 1968; Eysenck 1941; Granger 1955; Reddy & Bennett 1985; Saito 1981) and infants (Adams 1987; Franklin, Pitchford, Mahony, & Davies 2006; Pereverzeva & Teller 2004) have been extensively tested in previous studies, few have explicitly compared colour preference across multiple age groups. The notable exceptions are described below.

In a comparative study of colour preference of younger and older native Germans, Dittmar (2001) asked the observers to choose their most and least favourite colours out of four given names (blue, green, red and yellow). The results illustrated that, although blue was universally preferred by all ages, the preference for blue decreased steadily with advancing age and the popularity of green and red increased. Bonnardel et al. (2006) examined colour preference of 21 Munsell samples, for 20–30 and 60–70 year-old subjects, using the method-of-triads (i.e. to indicate the preferred colour among three samples in a series of presentations). They found that the gender differences in colour preference were significantly reduced for elderly subjects compared with young adults.

4.1 Aim of this study

The two studies above compared only young adults with elderly subjects (Bonnardel et al. 2006; Dittmar 2001). To our knowledge, no previous study of colour preference has

systematically compared colour preferences of children, young adults and the elderly. Our aim in the experiments reported here was to employ our previously established methodology to perform a systematic examination of preference across a wide range of ages. We thus collected hue preference data from each of four different age groups in the U.K. population, and analyzed the variation in preference across these groups.

4.2 Method

4.2.1 *Participants*

We tested four different age groups in the U.K. over a period of 2.5 years, as follows: Group 1, 19 female and 17 male school children aged 8–9 years; Group 2, 18 female and 18 male school children aged 11–12: Group 3, 28 female and 25 male university students aged 18–22; Group 4, 19 female and 10 male elderly subjects aged 61–88. The 8–9 year-old group was tested in a local primary school in Newcastle upon Tyne in 2005; the 11–12 year-old group was tested in a Gateshead school in 2007; the university students were tested at Newcastle University in 2004; and the elderly subjects in social clubs for the elderly in 3 towns/villages near Newcastle in 2007. Group 3 subjects were tested in the laboratory; all other age groups were tested using the portable experimental box described below.

4.2.2 *Experimental setup*

We used two types of setup to collect data within and outside the laboratory. In the laboratory setup, the colour stimuli were presented on a calibrated CRT monitor in an otherwise dark room. Observers viewed the monitor from a distance of 57cm, their heads fixed in a chin rest while they used a mouse to perform the experimental task.

We also constructed a portable experimental box to conduct the study outside the lab (see Figure 1). Here the colour stimuli were presented on a calibrated laptop screen (LCD) located at the back of the box. Observers viewed the stimuli from a distance of 110 cm, positioned on a chin-rest at the front of the box, with their heads covered by a black curtain to exclude external light from view. A mouse connected to the laptop was positioned at the side of the box and used by the observer to perform the experimental task.

4.2.3 *Experimental stimuli*

We selected three stimulus sets, all including the same set of eight colours with varying hue but constant lightness and saturation. Set 1 was used for the 8–9 year-old group in the portable box, and Set 2 for the 18–22 year-old group in the laboratory setup. Note that these sets are identical in CIE Luv hue, saturation and lightness (HSL) coordinates, but because of the difference in the adaptation background (Y = 40 for the portable box because of the limited colour gamut of the laptop screen, and Y = 50 for the laboratory), the CIE Y, x, y coordinates are not exactly the same (see Table 1). Set 3 contains two additional hue values as well as the basic eight, to provide a denser sampling of the

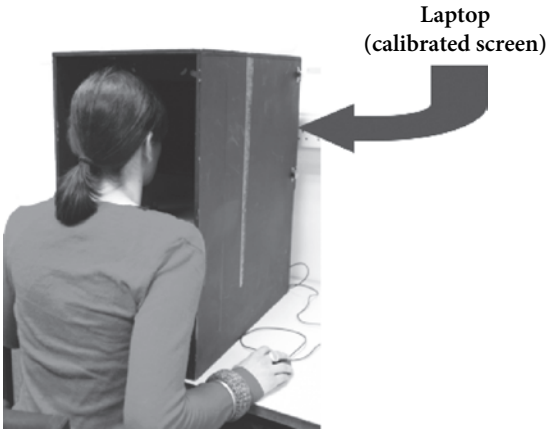

Figure 1. Subject using the portable experimental box. Note that in the actual experiment, the observer's head was covered by a black curtain to exclude external light from view

hue space. This set was employed to test the 11–12 and 61–88 year-old groups (see Table 1). Because the HSL values are the same across sets, we are able to extrapolate and compare preference patterns directly across the different sets.

4.2.4 *Procedure*

We employed the same experimental procedure for all subject groups, with a few minor variations depending on the setup. The colour stimuli were presented on the calibrated screen (CRT laboratory; LCD portable box) as pairs of rectangular patches (2x3 degrees laboratory; 1x2 degrees portable box) above and below the central fixation point on a uniform background (2 degrees eccentricity laboratory; 1 degree eccentricity portable box). Subjects initially adapted to the neutral colour (CIEx = 0.321, y = 0.337, Y = 50 laboratory; [0.3127 0.329], Y = 40 portable box) of the uniform background for one minute. Immediately after the adaptation phase, the pair-wise comparison trials began. On each trial, the subject's task was to move the mouse pointer to select which of the two colour patches he preferred, after which the next pair would appear almost immediately. There was no time limit on responses, but subjects were explicitly instructed to choose as quickly as possible, without cogitation and particularly without reference to any possible use of the colours (e.g. clothes, wall colours, etc.). All the possible pairs within each stimulus set were compared the same number of times (twice in the laboratory setup, and once in the portable box).

5. Results

Because each colour within a stimulus set appears an equal number of times, we may thus obtain a hue preference curve for that set by plotting the proportion of trials

Table 1. Specifications for all the experimental stimuli. Lightness, hue and saturation values derived from CIELuv colour space

Stimulus Set 1 (adaptation background Yxy=[40 0.3127 0.329])						
Stimulus No.	**CIEY**	**CIEx**	**CIEy**	**Lightness**	**Hue**	**Saturation**
1	22.67	0.3679	0.3337	80	0.284	0.5
2	22.67	0.3432	0.4009	80	1.705	0.5
3	22.67	0.2821	0.3725	80	2.68	0.5
4	22.67	0.2667	0.3512	80	3.017	0.5
5	22.67	0.2566	0.3243	80	3.424	0.5
6	22.67	0.2883	0.2717	80	4.844	0.5
7	22.67	0.3385	0.2923	80	5.821	0.5
8	22.67	0.3541	0.3091	80	6.16	0.5
Stimulus Set 2 (adaptation background Yxy=[50 0.321 0.337])						
Stimulus No.	**CIEY**	**CIEx**	**CIEy**	**Lightness**	**Hue**	**Saturation**
1	28.34	0.3768	0.3417	80	0.284	0.5
2	28.34	0.3530	0.4109	80	1.705	0.5
3	28.34	0.2908	0.3819	80	2.68	0.5
4	28.34	0.2748	0.3599	80	3.017	0.5
5	28.34	0.2642	0.3323	80	3.424	0.5
6	28.34	0.2954	0.2782	80	4.844	0.5
7	28.34	0.3465	0.2992	80	5.821	0.5
8	28.34	0.3624	0.3165	80	6.16	0.5
Stimulus Set 3 (adaptation background Yxy=[40 0.3127 0.329])						
Stimulus No.	**CIEY**	**CIEx**	**CIEy**	**Lightness**	**Hue**	**Saturation**
1	22.67	0.3679	0.3337	80	0.284	0.5
2	22.67	0.3713	0.3773	80	0.991	0.5
3	22.67	0.3432	0.4009	80	1.705	0.5
4	22.67	0.2821	0.3725	80	2.68	0.5
5	22.67	0.2667	0.3512	80	3.017	0.5
6	22.67	0.2566	0.3243	80	3.424	0.5
7	22.67	0.2602	0.2892	80	4.07	0.5
8	22.67	0.2883	0.2717	80	4.844	0.5
9	22.67	0.3385	0.2923	80	5.821	0.5
10	22.67	0.3541	0.3091	80	6.16	0.5

where each colour was chosen as the preferred colour as a function of its hue. Figure 2 illustrates the mean hue preference curves for all age groups. The results indicate that at 8–9 years of age there are already significant sex differences in hue preference, with the girls having higher preference in the 'purple' region than the boys, and boys having

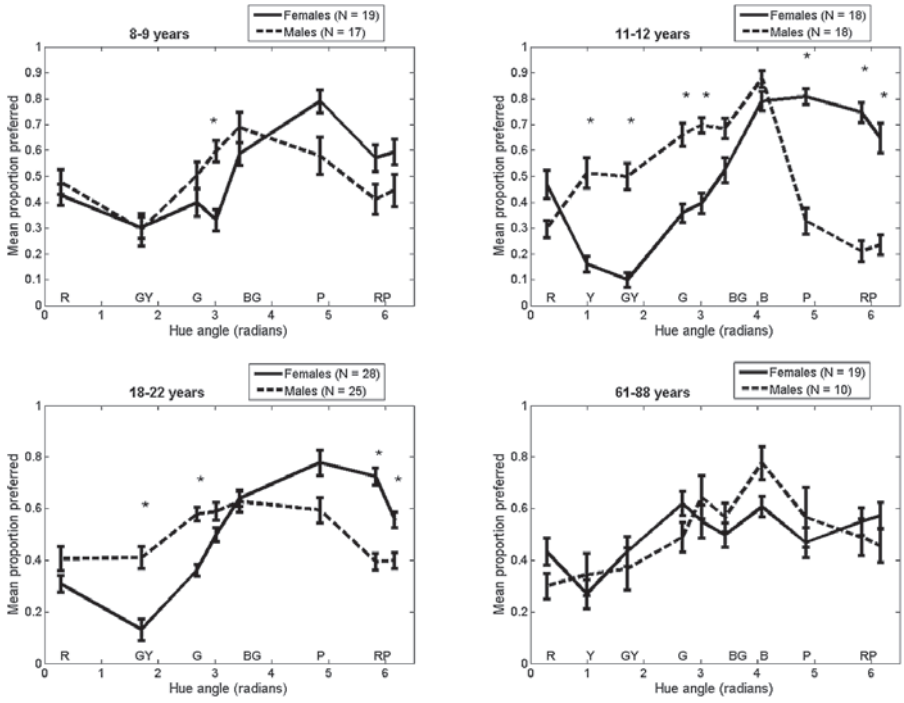

Figure 2. Mean hue preference curves for all age groups. Top left: 8-9 years; top right: 11-12 years; bottom left: 18-22 years; bottom right: 61-88 years. Females: solid line; males: dashed line. Error bars indicate standard error of the mean. The labels at the bottom of each panel indicate the nearest-matching Munsell hue names of the hue angle, for illustration purposes only. Asterisks indicate the hues for which sex differences are significant at p=0.05 with Bonferroni correction

higher preference in the 'green' region than the girls. For 11–12 year-olds, this sex difference is significantly increased, with girls having higher preference in the 'purple' and 'red-purple' region than the 8–9 year-olds, and boys having a larger dip there. The sex differences in the 'green' region are also widened, and while 8–9 year-old children exhibit no sex differences in the 'green-yellow' region, significant sex differences are found here for the 11–12 year-old children. The large sex differences at 11–12 years are reduced at 18–22 years, but still notable both for 'purple' and 'red-purple' regions, and for 'green' and 'green-yellow' regions. These differences effectively vanish for the 61–88 year-old group, although a weak trend towards an increased preference of females for 'red-purple' is visible.

The results in Figure 2 demonstrate clearly that age and sex affect hue preference. We therefore employ our hue preference model (Hurlbert & Ling 2007; Ling et al. 2006) to quantify better these effects. Using the model, each individual hue preference is reduced to a set of two weights: the first weight represents the subject's preference for

L–M ('red'-'green') contrast, and the second represents the subject's preference along the S-(L+M) ('blue'-'yellow') contrast component. The model's performance is consistent across different age groups, and explains 51–80% of individual hue preferences here, as shown in Table 2. The table also demonstrates that different components explain different amounts of variation in hue preference. For the females, except for the elderly subjects, the majority of the hue preference patterns are explained by preference for S-(L+M) ('blue'-'yellow') components, whereas for the males, again except for the elderly subjects, the L–M ('red'-'green') component accounts for greater variance in hue preference.

Figure 3 demonstrates the mean preference weights obtained from the model for each subject group. Compared with males, females always place higher weight on the L–M component, indicating a higher preference for 'reddish' contrasts than males. The

Table 2. Amount of variation explained (R^2) by the predicted hue preference model ('All'), and by individual L–M and S-(L+M) components respectively, for different age groups

Age Group	Females			Males		
	All	L–M	S-(L+M)	All	L–M	S-(L+M)
8-9 Years	0.6057	0.1712	0.4277	0.6720	0.3595	0.3090
11-12 Years	0.7842	0.1036	0.5793	0.6830	0.5273	0.1128
18-22 Years	0.7968	0.1117	0.6817	0.7453	0.4566	0.2936
61-88 Years	0.5116	0.2734	0.2122	0.6203	0.2661	0.3059

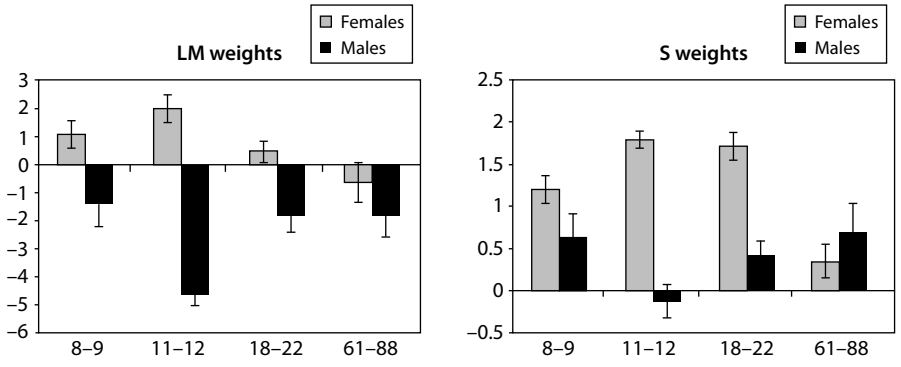

Figure 3. Mean weights on the L-M and S-(L+M) cone contrast components of the individual hue preference curves, for all age groups. Error bars indicate standard error of the mean

extent of this sex difference on the L–M component varies, with the largest sex differences apparent at 11–12 years old. The sex differences on the S-(L+M) component weights also vary, and, again, 11–12 year-olds exhibit the largest difference. These effects of age and sex on hue preference are confirmed by multiple ANOVA analysis. There are main effects of sex for variation in both L–M and S-(L+M) weights ($F(1,146) = 49.42$, $p < 0.00001$, L–M weights; $F(1,146) = 33.83$, $p < 0.0001$, S-(L+M) weights). Although there is no main effect of age ($F(3,146) = 1.33$, $p = 0.2675$, L–M weights; $F(3,146) = 2.21$, $p = 0.0896$, S-(L+M) weights), there are significant interactions between sex and age for variation in L–M ($F(3,153) = 7.25$, $p < 0.0001$) and S-(L+M) weights ($F(3,153) = 9.81$, $p < 0.00001$).

6. Discussion

In this study, we employed our colour preference model, previously established by testing young adults, to examine hue preferences for both children and elderly adults. Our results verify the model across ages – the two weights explain over 65% of individual variance in hue preference for five out of eight tested subject groups, and over 50% for all tested subject groups.

We also found significant effects of sex, and significant interactions between age and sex, in the variation of hue preference weights. Among these, two effects stand out the most. The first is the sharp peak of sex differences in hue preference at 11–12 years old, compared with 8–9 years old. At an average of only three years' age difference, the extent of sex differences in hue preference changes significantly. The hue preference patterns of 11–12 year-olds (see Figure 2) strongly suggest the interpretation that, at this age, girls are intensely attracted to colours in the 'purple' and 'red-purple' regions, while the boys spurn these, instead favouring the 'green' and 'yellow-green' regions. The large differences between 8–9 year-old and 11–12 year-old children are, on one hand, not surprising. 11–12 years of age marks the beginning of adolescence, with a surge in sex hormone production and associated physical and psychological changes (Wolman 1988). It is also the age when children begin to be more concerned with how they appear to others and to view their peer groups as more important (Wolman 1988). Given the pervasive notion that "pink is for girls" in Western culture, and the peer pressure for boys to appear more masculine and girls to appear more feminine at 11–12 years old, it is unsurprising for children at this age to exhibit the extreme sexually dimorphic hue preferences we report here.

The second main effect is the change in hue preference for the elderly subjects. While our study is consistent with results from previous studies in the U.K. and Germany (Bonnardel et al. 2006; Dittmar 2001), the explanation of the reduction in sex difference is not so straightforward. The most obvious factor to consider is the effect of aging on visual function. Previous research has shown that, although the human visual system is rather stable over much of the lifespan, there are losses in most of

its functions at older ages (Owsley & Sloane 1990). For colour vision, specifically, there is evidence of changes in the spectral characteristics of the lens (Pokorny & Smith 1987; Sagawa & Takahashi 2001), which cause poorer colour discrimination and alter colour categorization in old age (Knoblauch, Vital-Durand & Barbur 2001; see also Walter 2011). These changes in visual function may induce changes in colour preference. For example, with poorer colour discrimination, the elderly subjects may perceive certain colour stimuli as less distinctive compared with younger subjects, and as a result, exhibit less marked colour preferences.

Nevertheless, there is no evidence thus far to suggest that these age-related changes in colour vision are sexually dimorphic. Moreover, we found significant interactions between sex and age but no significant effect of age on hue preference weights (see Section 5). These results imply that the decline of visual function cannot fully explain the sharp decrease of sex differences for the elderly subjects.

Another possible explanation is that the changes in hue preference for the elderly subjects, as for the effect at 11–12 years, may be influenced by the changes of sex hormone levels across ages. All women will experience a dramatic drop in circulating estrogens after menopause transition (Morrison, Brinton, Schmidt & Gore 2006), whereas men experience a more gradual decline in testosterone levels from the age of 30–40 years onward (Simon, Preziosi, Barrett-Connor, Roger, Saint-Paul, Nahoul et al. 1992; Moffat 2005; Yeap 2009). If hue preferences are influenced by sex hormone levels, we may expect females to show a larger change in hue preference from young adults to elderly than males, as we found. A two-sample t-test of the preference weights confirmed that while females' hue preference patterns differ significantly between 18–22 and 61–88 years of age (L–M weight: $p < 0.00001$, S-(L+M) weight: $p = 0.1610$), males exhibit no significant difference between the two age groups (L–M weight: $p = 0.7918$; S-(L+M) weight: $p = 0.4053$).

Social and cultural factors may also play an important role in the development of hue preference across ages. Different ages in the present may have been subject to different social and cultural influences, both in the past and at present. For example, while today's children are certainly subjected to sex-specific colour coding in society, the elderly subjects will not have had the same cultural experience when they were young. Also, before the invention of colour TV and the prevalence of coloured prints, it is plausible that the elderly may have encountered fewer artificially coloured objects and images overall. These social and cultural factors will certainly affect individual colour preferences; the difficulty is how to disentangle these biological and social factors in the current results.

As we have previously argued (Ling et al. 2006; Ling & Hurlbert 2007), we assume that colour vision evolved for a purpose, whether this be finding food, evaluating mates or reading social signals, or some combination of these. The use of colour to find desirable fruits or mates would then drive a preference for the colours of the most desirable objects, abstracted from the objects themselves. Thus, preference for reddish fruits would emerge as an abstract preference for reddish colours (Hurlbert & Ling

2007). This assumption has been elaborated explicitly on the ontogenetic level as the Ecological Valence Theory, which states that current individual preferences for particular objects should correlate with preferences for the colours of these objects, and directly tested by Palmer and Schloss (2011). The theory thus provides an additional possible explanation for the effects of age on colour preference: if object preferences vary with age, preferences for the colours associated with these objects will also vary. In fact, these individual factors may also be strongly entangled with the biological, social and cultural factors, in that predispositions to favour certain colours at certain ages may be reinforced by social or cultural manipulations, the most obvious example being the "pink is for girls" dictate in Western culture.

As we did not explicitly follow one particular group of subjects over their lifespan, we cannot draw a solid conclusion on developmental changes in colour preference from this single study. Nevertheless, our results have demonstrated a reliable methodology to probe the effect of various factors on colour preference, and also show significant interactions between age and sex in hue preference, serving as a cornerstone for future studies.

7. Conclusion

In this study, we tested hue preference for four different age groups within the U.K. population. Using our previously developed model of hue preference, we reduced each individual hue preference curve to a set of 2 weights, indicating the extent of preference for the 'red'-'green' and 'blue'-'yellow' component of hues. Multiple ANOVA analyses on individual preference weights revealed a significant effect of sex and a significant interaction of sex and age on hue preference. While females show higher preference for both the 'red'-'green' and the 'blue'-'yellow' components, the sex differences vary across ages, with the 11–12 year-old children exhibiting the largest sex difference in hue preference and the elderly subjects the least. These effects may be influenced by age-related changes in sex hormones as well as social and cultural factors.

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Ecological valence and human color preference

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Aesthetic response to color is an important aspect of human experience, but little is known about why people like some colors more than others. Previous research suggested explanations based on sensory physiology and color-emotions. In this chapter we propose an ecological valence theory based on the hypothesis that color preferences are caused by people's average affective responses to color-associated objects. That is, people like colors that are strongly associated with objects they like (e.g. blues with clear skies and clean water) and dislike colors strongly associated with objects they dislike (e.g. browns with feces and rotten fruit). We report data that strongly support this claim: the ecological valence theory not only predicts average color preferences better than three alternative theories containing more free parameters, but it provides a plausible explanation of why color preferences exist and how they arise.

1. Introduction

For reasons that are not entirely obvious, most people have relatively strong and pervasive aesthetic preferences among colors. More people name blue as their favorite color than any other (e.g. Eysenck 1941; Granger 1955; Guilford & Smith 1959), but it seems that, for any given color, one can always find some people for whom it is their favorite. Despite this variability – or perhaps because of it – color preferences are important for understanding human behavior. Indeed, it is hard to overestimate the impact of color preference on the choices people make and the enjoyment they get in buying and viewing clothes, art, home décor, graphic designs and personal electronics.

A century of scientific investigation has taught us a great deal about *which* colors people like, but very little is known about *why* they like them. After briefly discussing two recent theories, we present a new one. This *ecological valence theory* (*EVT*) is based on the assumption that people's color preferences result from an evolutionary process whose net effect is to 'steer' them toward beneficial objects and situations and away

from detrimental ones. We then present color preference data from a comprehensive study of human color perception and use them to test among four theories. We find that, consistent with the EVT, how much people like color-associated objects accounts for 80% of the variance in average color preferences, substantially more than any of the other three theories (Palmer & Schloss 2010). These results constitute a potential breakthrough in understanding why color preferences exist and how they arise.

2. The ecological valence theory

Surprisingly little has been written about the causes of color preference. Most of the literature consists of psychophysical measurements that describe preferences without explaining them (e.g. Eysenck 1941; Granger 1955; Guilford and Smith 1959). One potential explanation comes from Humphrey (1976), who proposed that color preferences have developed through the signals colors convey in nature. For example, colors can send 'approach' signals (e.g. the colors of flowers attract pollinating bees), and 'avoid' signals (e.g. the colors of poisonous toads deterring predators). A related idea is picked up in Hurlbert and Ling's evolutionary/behaviorally-adaptive theory in which they suggest that human color preferences are based on hard-wired cone opponent mechanisms in the human visual system that arose from evolutionary selection (Ling, Hurlbert & Robinson 2006; Hurlbert & Ling 2007; Ling & Hurlbert 2009; Ling & Hurlbert 2011). Hurlbert and Ling (2007) reported that 70 percent of the variance in their preference data was explained by linear combinations of the three cone types' outputs. Both men's and women's preferences weighted highly positively on the **S-(L+M)** axis, with colors that were more violet preferred to colors that were more yellow-green. On the **L–M** axis, however, females weighted somewhat positively, preferring redder colors, whereas males weighted somewhat negatively, preferring colors that were more blue-green.[1] Hurlbert and Ling attributed this difference to evolutionary adaptation within 'hunter-gatherer' societies: females like redder colors because their visual systems were selected for finding ripe fruit against green foliage. They did not speculate, however, on why males prefer colors that are more blue-green or why both genders prefer colors that were more violet to colors that were more yellow-green.

Ou, Luo, Woodcock & Wright (2004a, 2004b) proposed an account based on 'color-emotions', which they defined as "feelings evoked by either colours or colour combinations" (2004a: 232). Their theoretical framework suggests that the valence (positivity-negativity) of the emotions evoked by colors determines people's preference for them. Sixty-six percent of the variance in their preference data could be

1. This gender difference was reported in Hurlbert and Ling's (2007) initial study of color preferences, but a subsequent experiment failed to replicate it, as both males and females weighted negatively on the **L–M** axis, preferring colors that were more blue-green than red (Ling & Hurlbert 2009). They did still find that females weighted *less negatively* than males on this axis, however.

predicted from three factor-analytic dimensions of color-emotions: *active-passive*, *heavy-light*, and *warm-cool*. They did not explain how color-emotions arise, however, or why some color-emotions predict preferences better than others.

We propose the EVT as a framework that unites and extends these previous approaches. It is based on both the evolutionary premise that color preferences are adaptive and an emotional premise that affective valences underlie them. In general terms, the EVT posits that people are better equipped to survive and reproduce if they are attracted to things whose colors 'look good' to them and avoid things whose colors 'look bad' to them. We view this implicit 'steering' function of color preferences to be roughly analogous to the steering function of taste preferences: people are better equipped to survive and reproduce if they eat things that 'taste good' and avoid eating things that 'taste bad'.[2] This ecological heuristic underlying the EVT will be adaptive if how 'good' vs. 'bad' colors look to people correlates with (and thus can serve as an effective surrogate for) the degree to which things that characteristically have those colors are evolutionarily advantageous vs. disadvantageous to the organism.

The EVT implies that the average preference for any given color over a representative sample of people should be largely predictable from their average affective responses to correspondingly colored objects. That is, people should be attracted to colors associated with salient objects that generally elicit positive affective reactions (e.g. blues and cyans with positively valued clear sky and clean water) and repulsed by colors associated with salient objects that generally elicit negative reactions (e.g. browns and olives with negatively valued feces and rotting food). We test this central prediction of the EVT in Experiment 2 and compare its predictions for color preferences with the predictions of theories based on cone contrasts, color-emotions and color appearance.

Environmental feedback from the outcomes of color-relevant experiences can influence evolutionary adaptation in at least two ways. First, it could shape genetically-based preferences for evolutionarily advantageous colors over evolutionarily disadvantageous ones. These would presumably reflect universal biases in the ecological statistics of color for the relevant species (e.g. blue skies and brown feces). Second, environmental feedback could produce and modify innate learning mechanisms that tune an organism's color preferences during its lifetime to its particular physical and social environment such that it comes to like advantageous colors and dislike disadvantageous ones. To the extent that people prefer more advantageous outcomes, they should learn to prefer the colors associated with those outcomes.

The best evidence for innate color preferences in humans comes from measurements of looking preferences in infants: how much time infants spent looking at each color within each possible pair of colors during fixed-duration trials. Figure 1A shows

2. Biederman and Vessel have adapted the eating analogy in another direction, positing that humans are 'inforvores' whose enjoyment of experiences is "connected to an innate hunger for information" (2007: 249). This does not seem related to the EVT unless color preferences are ultimately understood as being informational.

data adapted from Teller, Civan and Bronson-Castain (2004) for 12-week-old infants viewing pairs of six high-saturation colors. The general shape of this function, with a peak at blue and valley around yellow-green, is surprisingly similar to the average hue preferences we find in adults for high-saturation colors (Figures 1B and 1C). It is also

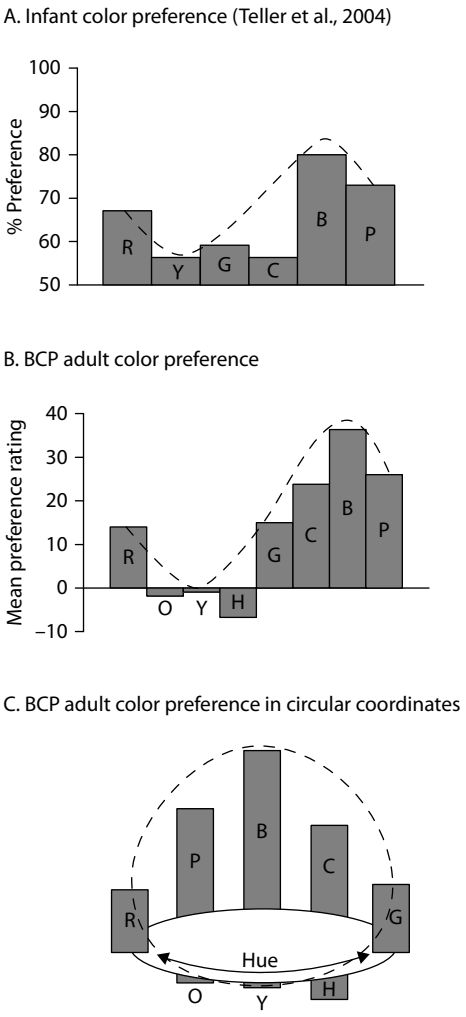

Figure 1. Hue preference functions for saturated colors in infants and adults. (A) Infants most prefer looking at blue and least prefer looking at yellow (Teller et al. 2004). (B) Preference patterns in aesthetic ratings for saturated colors by adults in the BCP. (C) Data in B plotted in circular coordinates to highlight the difference between *blue-yellow* vs. *red-green* dimensions. Dashed curves indicate the overall similarity of the functions (A and B) and how they translate into circular coordinates (C)

similar to the pattern that Valdez and Mehrabian (1994) and Simmons (2011) found for adults' evaluations of pleasure and pleasantness, respectively. Although the infant preference function may reflect learning during the first 12 weeks of life, it may well include a strong innate component.

The EVT assumes that learning mechanisms modify color preferences from this starting point, leading eventually to adult preference functions that reflect many diverse influences. By interacting with the world, people learn valences for particular objects depending on whether experiences with them are pleasant or unpleasant. To the extent that the consequences of interacting with an object are rewarding (e.g. biting into a delicious red apple or diving into a refreshing blue lake), an increment of positive affect accrues to the corresponding color. To the extent that they are punishing (e.g. smelling feces or tasting rotten fruit), the associated color accrues a decrement in affect. Corresponding colors thus accumulate increments and decrements in aesthetic valence by association with the corresponding objects, such that color preferences come to reflect the overall desirability of things associated with that color.

The EVT implies there may be several levels of factors influencing color preferences. First, average color preferences for large, diverse samples of people across the world should generally reflect universal trends in colored object valences: for example, nearly everyone presumably likes clear sky and dislikes rotten food. Second, systematic deviations in cross-cultural studies of color preferences should co-vary with corresponding cultural differences in color-object associations and/or object valences. Third, systematic sub-cultural influences should also arise from individuals' affinities with various special-interest societal groups having strong color associations, such as sports teams, universities, religions, and/or gangs. Fourth, truly idiosyncratic influences should also be present. The color of a child's bedroom, for example, might have a noticeably positive impact on his/her liking of that color if it were experienced during pleasant summer vacations, but a negative impact if it were experienced during an acrimonious parental divorce. Some people may also favor colors that complement their skin, hair, and eye color, and dislike those that they feel 'clash' with their coloring. It would be impossible to tease apart all such idiosyncratic influences, but some of them could be effectively isolated and studied.

In addition, there may be systematic changes in color preferences over time, from weeks to years, within individuals, and even longer periods within cultures. Color fashions in the modern clothing industry change seasonally in fairly consistent ways and annually in less predictable ways. Even more dramatic are cultural changes that have occurred in color preferences over many decades and even centuries. Perhaps the best example is the history of blue, as documented by Pastoureau (2001) in a fascinating monograph. He traces the trajectory of blue from its nadir in ancient Rome, where it was the least favored color, to its current zenith, analyzing the complex changes in cultural associations that were responsible for the dramatic increase in its popularity. Briefly, it appears that the Romans hated blue primarily because it was so favored by

Rome's enemies, particularly the Celts to the north, who even painted themselves in ferocious blue symbols to prepare for battle.

One of the great virtues of the EVT is that all of these factors – universal, cultural, sub-cultural, idiosyncratic, and even dynamic – can potentially be accommodated within its scope. Moreover, carefully selected subsets of these factors can be tested using variants of the psychophysical techniques we describe below (see also Palmer & Schloss 2010) with properly chosen categories of individuals.

3. The Berkeley Color Project

The Berkeley Color Project (BCP) is a large, systematic study aimed at understanding color preferences within the context of color perception. The BCP is primarily defined by three key features: its massive repeated measures design, its sampling of participants, and its systematic, perceptually motivated sampling of colors.

3.1 MRM design

The first important feature of the BCP is its massive repeated measures (MRM) design, wherein the same observers provide data on many different tasks. We have studied 48 participants in 30 different tasks, requiring 12+ hours of data collection per participant. MRM designs allow the results for any given task to be related to results from the same observers and colors for any other task. For example, to understand how people's color preferences relate to their color-emotion associations, one needs data of both sorts from the same participants. This logic applies to any number of different aspects of people's preferences for individual colors and color combinations.

The following BCP measurements are most relevant to the present chapter: aesthetic preference ratings for individual colors, psychophysical ratings of color appearance (*red-green*, *blue-yellow*, *light-dark*, *high-low saturation*), and ratings of Ou et al.'s 'color-emotion' dimensions (*active-passive*, *warm-cool*, *heavy-light*). MRM designs are generally desirable for studying any domain in which large individual differences are present, and color preferences certainly qualify by this criterion.

3.2 Participant sample

A second feature of the BCP is the nature of our participants. We present data collected in Berkeley, California, from 48 adults equally divided between men and women whose color sophistication ranges from high (professional artists and designers) to low (untrained novices). This enabled us to study not only gender differences, but also effects of training and expertise. We are currently in the process of repeating many of these measurements in Tokyo, Japan, and Guadalajara, Mexico, to obtain information

about universal vs. culturally specific features of performance on color-related tasks. We also plan to collect preference data developmentally with infants, young children and adolescents in the Berkeley community. We even hope to study preference for the same 32 colors comparatively in rhesus monkeys.

3.3 Color sample

The third key feature of the BCP is the set of 32 colors we used which were systematically sampled over the three most salient dimensions of color appearance: hue, saturation and brightness (see Figure 2). We effectively based our sampling on the structure of the Natural Color System (Hård & Sivik 1981), although we actually selected the colors from the glossy series of Munsell chips. As described in Palmer and Schloss (2010), the sample included highly saturated colors of the four Hering primaries approximating the unique hues:[3] red (R), green (G), blue (B), and yellow (Y) (Munsell hues 5R, 5Y, 3.75G,[4] and 10B, respectively). We also included four well-balanced binary hues that contained approximately equal amounts of the adjacent pair of unique hues: orange (O) between Y and R, purple (P) between R and B, cyan (C) between B and G, and chartreuse (H) between G and Y (Munsell hues 5YR, 5GY, 5BG, and 5P, respectively). We then defined four 'cuts' through color space that differed in their saturation and lightness levels, as follows. Colors in the 'saturated' (S) cut were defined

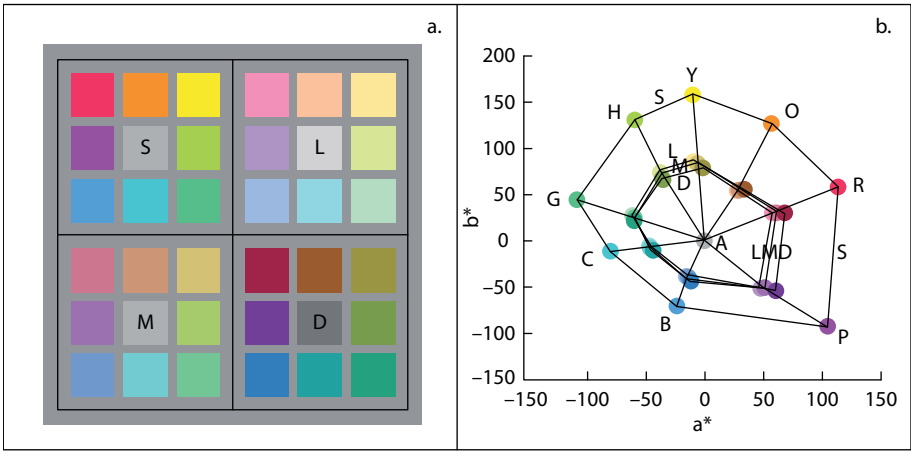

Figure 2. The colors of the BCP. (A) The 32 colors of the BCP. (B) The projections of these colors onto an isoluminant plane in CIELAB color-space.

3. Unique hues are those hues that contain one and only one of the four chromatic primary hues: red, green, blue, or yellow (see Wuerger & Parks 2011).

4. 3.75G was calculated by interpolating between 2.5G and 5G in the Munsell Renotation Table.

as the most saturated color of each of the eight hues that could be produced on our monitor. Eight colors in the 'muted' (M) cut were those that were approximately halfway between the S color and the Munsell value of 5 and chroma of 1 for the same hue. Eight colors in the 'light' (L*)* cut were those that were approximately halfway between each S color and the Munsell value of 9 and chroma of 1 for the same hue. Eight colors in the 'dark' (D) cut were those that were approximately halfway between each S cut and Munsell value of 1 and chroma of 1 for the same hue. The L, M, and D colors within each Munsell hue were equivalent in Munsell chroma (saturation). This set comprised the 32 chromatic colors that were studied. We also included five achromatic (A) colors – white, black, and the three grays whose luminance was approximately the average luminance of the eight hues in the L, M and D cuts – although we report results for just the 32 chromatic colors in this chapter.

Colors within cuts were not chosen to be constant in saturation and luminance, as Ling and Hurlbert had done, because we wanted to include highly saturated colors of the four unique hues, which are not equivalent in luminance or saturation. The most saturated examples of unique yellow and blue, for example, vary drastically in luminance, with unique yellow being much lighter. Moreover, our observers made psychophysical ratings of lightness and saturation, and we have the coordinates of the colors in Munsell and other color spaces, so that we could examine the effects of lightness and saturation that varied within cuts, if required.

4. Experiment 1: BCP color preference ratings

4.1 Color preferences

In the first and last (eighth) testing sessions, each participant rated all 32 colors for aesthetic preference using a line-mark task (–200 to +200 pixels) with a neutral point in the center. The data were normalized to range from –100 to +100 in Figures 3–5. All colors were presented in a different random order for each participant (for this task as well as all other tasks). The correlation between the average ratings in these two sessions indicated high reliability ($r = 0.92$, $p < .0001$). All subsequent analyses were performed on the data from just the 32 chromatic colors in Session 1, because it provides the purer measure. Average preference ratings showed relatively strong effects of hue in the S, L and M colors ($F(7,329) = 9.75$, $p < .001$), producing approximately parallel hue functions with peaks at blue and troughs at chartreuse (Figure 3). S colors were preferred to L and M colors ($F(1,47) = 9.20$, $p < .01$), which did not differ ($F < 1$). Hue and cut did not interact across S, M, and L cuts ($F(14, 658) = 1.66$, $p > .05$), but they did interact for the D cut versus the other three cuts ($F(7,329) = 17.87$, $p < .001$). Dark-orange (brown) and dark-yellow (olive) were significantly less preferred than other oranges and yellows ($F(1,47) = 11.74, 41.06$, $p < .001$, respectively), whereas dark-red and dark-green were more preferred than other reds and greens ($F(1,47) = 15.41, 6.37$, $p < .001, .05$, respectively).

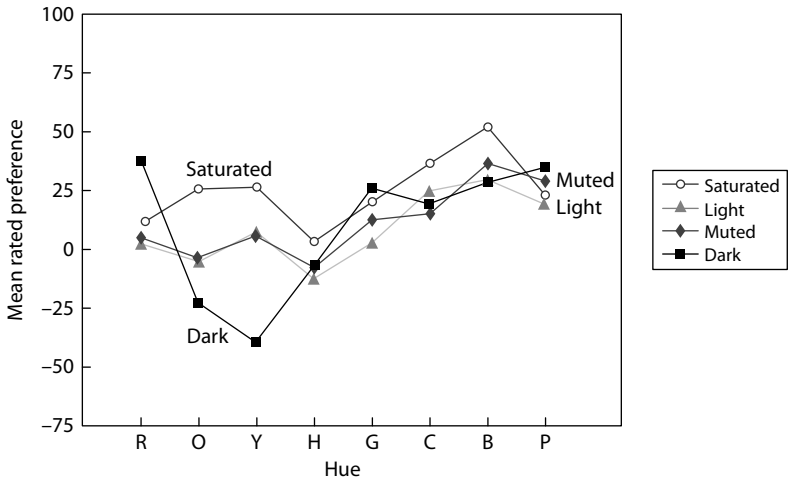

Figure 3. Color preference ratings as a function of hue for saturated, light, dark, and muted colors

4.2 Gender and expertise effects

The 48 participants were balanced in gender and color sophistication (as assessed by questionnaire), with 12 individuals in each cell of this 2x2 between-subjects design. Figure 4 shows the average preference ratings divided by gender. No reliable differences were present between males and females for the L and D colors ($F < 1$). A reliable interaction did emerge between males and females for the S and M cuts, however ($F(1,46) = 11.42$, $p < .01$): males preferred S colors to M colors ($F(1,23) = 24.18$, $p < .001$), whereas females trended in the opposite direction.

The cause of this gender difference is not obvious but is compatible with a cultural interpretation: S colors are bolder and more assertive than M colors, fitting the cultural stereotype for males. Supporting this interpretation, the 32 gender difference scores (male ratings minus female ratings for each chromatic color) were highly correlated with the 32 *active-passive* ratings ($r=.73$, $p < .001$), accounting for 53% of the variance. Some readers may wonder at the seeming conflict between these preference ratings and the way that males and females tend to dress, males in more muted colors and females in more saturated colors. The data make perfect sense, however, when one realizes that most males and females are dressing to attract members of the opposite sex.[5]

5. If the color preferences of gay men and lesbians are similar to those of straight men and women, respectively, then it would be consistent with our interpretation of the relation between dressing patterns and color preferences if gay men tended to wear more saturated colors (because they are dressing to attract other men) and if lesbians tended to wear more muted colors (because they are dressing to attract other women).

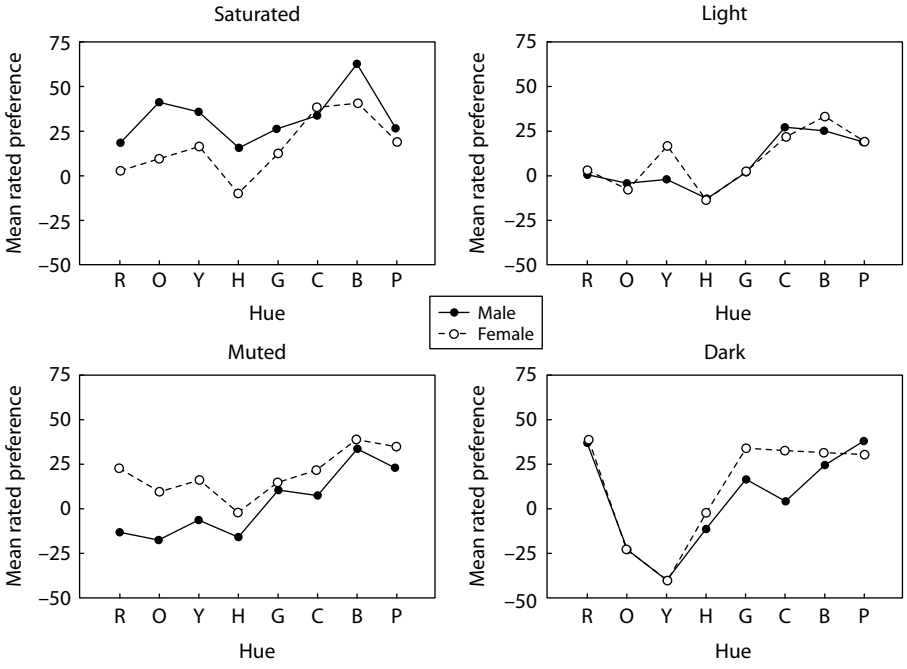

Figure 4. Gender differences in color preference ratings as a function of hue for saturated, light, dark, and muted colors

Figure 5 shows the hue preference functions from Session 1 for the low and high chromatic sophistication subgroups. The more sophisticated participants liked chromatic colors more than did their less sophisticated counterparts ($F(1,44) = 6.22$, $p < .05$). No such difference was present for the achromatic colors ($F < 1$), discounting the possibility that the two groups simply used the rating scale differently. Interestingly, there was an interaction between session (first vs. last) and artistic experience ($F(1,44) = 11.87$, $p < .01$). The difference in preference for chromatic colors found in Session 1 disappeared by Session 8, even though there was still no difference in achromatic preferences ($F < 1$). Preference for chromatic colors increased somewhat over time for the chromatic novices ($F(1,23) = 6.38$, $p < .05$) and decreased somewhat for the chromatic sophisticates ($F(1,23) = 5.84$, $p < .05$), such that they were not statistically different by Session 8 ($F < 1$). These changes are roughly consistent with Berlyne's (1971) inverted-U function of aesthetic dynamics, provided that the chromatic novices are initially at the low end of the aesthetic exposure spectrum, where their aesthetic appreciation would be expected to increase with exposure, and chromatic sophisticates are initially in the middle-to-high end of the spectrum, where their appreciation would be expected to decrease.

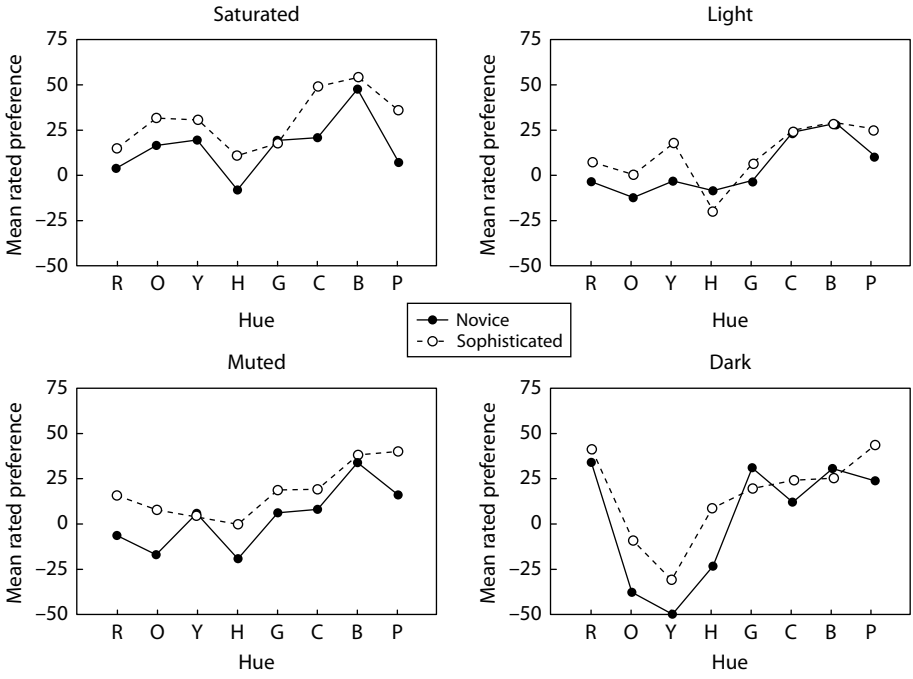

Figure 5. Color sophistication differences in color preference ratings as a function of hue for saturated, light, dark, and muted colors

5. Experiment 2: Weighted Affective Valence Estimates (WAVEs) of color

5.1 Estimating the WAVE

Experiment 2 was undertaken to test the central prediction of the EVT outlined in the introduction: color preferences should largely be determined by the average valences of people's affective reactions to objects having high 'color diagnosticity' (cf. Tanaka et al. 2001), including ineffable 'things' such as sky, water and clouds. We estimated average affective associations to colors by the following procedure. First, we showed 74 observers each BCP color and asked them to write descriptions of as many things of that color as they could in 20 sec. The 3874 resulting object descriptions were then filtered to eliminate items that (a) could be any color (e.g. crayons, paint, cars), (b) were abstract concepts instead of objects (e.g. peace, winter, Christmas), (c) were color names instead of objects (e.g. 'Cal Blue', 'teal'), (d) were very dissimilar to the presented color (e.g. 'grass at noon' for dark purple), or (e) were provided by only a single participant for all colors it described.

The remaining descriptions were then categorized to reduce the number of descriptions to be rated in the valence-rating phase of the experiment. Descriptions that

were judged to be essentially the same were combined into a single category (e.g. *algae* included the descriptions 'algae,' 'algae water,' 'algal bloom,' 'algae filled fish bowl,' and 'algae floating on top of water'). The resulting 222 descriptive categories were then shown in black text on a white background to 98 different participants, who were asked to rate the affective value of the referent object from positive to negative using the same line-mark rating scale as in Experiment 1.

We presented an additional set of 16 participants with each of the 222 object descriptions paired with each of the 32 colors for which it had previously been given as a description, one pair at a time. Participants were asked to rate how well the color of the described object category matched the color on the screen using a line-mark rating task analogous to those described for the other tasks.

These color-object matching ratings were used to weight the average affective valence rating for each object-color pair such that the valences of the descriptions that better matched the color on the screen were weighted more heavily. We call this measure the 'weighted affective valence estimate' (WAVE) of the color.

5.2 Fitting the models

The WAVE results are plotted in Figure 6. Their striking similarity to the corresponding chromatic preference functions (Figure 3) is supported by the high positive correlation between the two data sets (r = +0.894), accounting for 80% of the variance with a single operationally-defined predictor. This performance is especially impressive considering that no free parameters were estimated in calculating the WAVE. Even the weighting factor is relatively unimportant; unweighted average valence ratings are almost as highly correlated (r = 0.84). For comparison, we fit the same chromatic preference data to three other models.

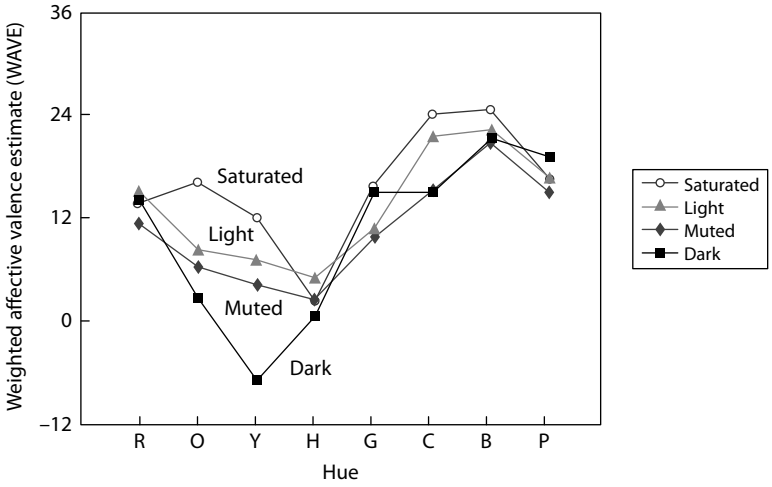

Figure 6. WAVE data for the 32 chromatic colors of the BCP

We fit Ling and Hurlbert's (2009) cone-contrast model using multiple linear regression with four predictor variables: the cone contrasts of the test colors against the gray background for the **L–M**, **S-(L+M)**, and **(S+L+M)** systems, plus CIELUV saturation. This model accounted for 37% of the variance: 21% by **S-(L+M)** output (colors that were more violet preferred), 4% by **S+L+M** output (lighter preferred), 8% by CIELUV saturation (more saturated colors preferred), and 4% by **L–M** output (colors that were more blue-green preferred). The model's markedly poorer performance on our data than on Ling and Hurlbert's data is very likely due to the wider gamut of colors in the present sample. When their original cone-contrast model (Hurlbert & Ling 2007) was applied just to the set of eight colors in the present study that are analogous to Hurlbert and Ling's color set in having the same saturation and similar luminance (MO, MY, MH, MG, SC, LR, LG and LP), it was able to explain 64.4% of the variance, comparable to its performance on Hurlbert and Ling's own data.[6] When the additional 24 colors in the present sample were included in the analysis, however, the cone-contrast model's performance decreased precipitously.

We fit an NCS-like color appearance model using multiple linear regression with the four color-appearance ratings our own observers made as predictors: *red-green*, *blue-yellow*, *light-dark* and *high-low saturation*. This model accounted for 60% of the variance (multiple-r = +0.77, $p < .01$): 34% by *blue-yellow* ratings (blue preferred), an additional 19% by saturation ratings (high-saturation preferred), and a further 7% by *light-dark* ratings (light preferred). This color appearance model explains more variance than the cone-contrast model primarily because the hue preferences conform more closely to rated blueness-yellowness than to **S-(L+M)**, which is more accurately described as varying from violet to yellow-green; i.e., the higher-level color-appearance space gives a better fit to the rated preferences than does the lower-level cone-contrast space. Nevertheless, even the color-appearance ratings fail to predict the salient interaction between hue preferences in the D cut relative to the S, L and M cuts. It also fails to explain *why* people prefer the colors they do; it merely provides a better description of the preference pattern.

Finally, we fit Ou et al.'s (2004a, 2004b) three-factor color-emotion theory using multiple linear regression based on our participants' direct ratings of *active-passive*, *heavy-light* and *warm-cool*, including their non-linear transformation of the *active-passive* factor. This model accounted for 55% of the variance: 22% by *active-passive* (active preferred), an additional 26% by *warm-cool* (cool preferred), and a final 7% by *heavy-light* (light preferred). One oddity of this theory, at least when it is used as a causal hypothesis about why people like the colors they do, is that, although cool colors are preferred to warm colors (akin to the blueness-yellowness differences

6. Yazhu Ling produced this model on our preference data.

described in the previous paragraph), coolness is not preferred to warmness as general 'feelings.'[7]

Despite the seemingly different semantics of these three models – cone-contrasts, color appearances, and color emotions – they are closely related because of the high correlations among their dimensions. Table 1 shows that the three most important dimensions in the cone-contrast and color-emotion models both have average correlations of 0.85 with the three most important dimensions of the color appearance model.

In accounting for 80% of the variance in the average preference ratings, the WAVE predictor substantially outperforms all three other models tested – the cone contrast model (37%), the color appearance model (60%), and the color-emotion model (55%) – and it does so with fewer free parameters. It is also better at capturing the primary qualitative features of the color preference functions: the pronounced peak at blue, the trough at chartreuse, higher preference for saturated colors, and the global minimum around dark yellow. Its main deficiencies lie in under-predicting the aversion to dark-orange (largely because chocolate is rated as very appealing) and under-predicting the positive preference for dark-red (largely because blood is rated as unappealing).

Equally important is the fact that the EVT, on which the WAVE is based, answers the *why* question: it claims that color preferences are *caused* by average affective

Table 1. Correlations between color appearance and cone-contrasts (top) and color-emotions (bottom)

Color Appearance	S-(L+M)	Sat (CIELUV)	L+M+S	L–M
Yellow-Blue	****–0.88**	0.12	**0.50	**0.56
Saturation	–0.15	****0.77**	–0.11	0.27
Light-Dark	–0.30	**–0.48	****0.90**	–0.07
Red-Green	0.12	**0.59	–0.16	****0.67**

Color Appearance	Warm-Cool	Active-Passive	Light-Heavy
Yellow-Blue	****0.73**	0.12	0.15
Saturation	0.35	****0.85**	*–0.41
Light-Dark	–0.11	0.29	****0.97**
Red-Green	**0.62	0.22	–0.21

* $p < .01$
** $p < .001$

7. We asked our participants to rate each of these six words in terms of how 'appealing' the feelings they described were for them. 'Warmness' was rated as +127 and 'coolness' as +69 on our –200 (least appealing) to +200 (most appealing) line-mark rating scale. The ratings of the other terms were consistent with the expected outcomes, with light (+25) being rated as more positive than heavy (-66) and active (+111) as more positive than passive (–52).

responses to correspondingly colored objects. Although the present evidence is correlational, we find it unlikely that causation runs in the opposite direction (i.e. that object preferences are caused by color preferences) because there are such clear counterexamples. Chocolate and feces, for instance, are similar in color but opposite in valence. Some third mediating variable could conceivably be at work, but it is unclear what that might be.

Further critical tests of the ecological valence theory will come from cross-cultural studies of color preferences and their relation to corresponding WAVE data. The theory clearly implies that differences between color preference functions in different cultures should be predictable from corresponding cross-cultural differences in WAVE functions. We are currently collecting such data using the BCP colors in Japan, Mexico, India and Serbia. WAVE functions in different cultures are likely to be different not only because people in different cultures see different objects and may have different affective responses to the same objects, but because the ecological valence theory implies that socio-cultural variables can also affect color preferences.

The EVT also predicts that if people have highly positive (or negative) emotional investments in a social institution that has strong color associations – e.g. an athletic team, gang, religious order, university, or even holiday – they should come to like the associated colors correspondingly more (or less) than the rest of the population, depending on the polarity of their relation to the institution. Experimental results with university colors support this prediction: among students at the University of California, Berkeley, the amount of school spirit correlates positively with preference for Berkeley's blue and gold colors but negatively with preference for the cardinal red color of Stanford University, a strong rival institution (Schloss, Poggesi & Palmer 2011). This finding not only supports the prediction that socio-cultural influences affect color preferences, but also provides further evidence of the direction of causality, because it is wildly improbable that students' attitudes toward universities are caused by their color preferences. Students who like Berkeley do not do so because they like blue and gold; they like blue and gold because they like Berkeley.

We do not claim that color preferences have *no* influence on object preferences; clearly they do, especially for functionally identical artifacts that come in many colors, such as cars, clothes, appliances, and personal electronics (i.e. objects with low color diagnosticity as discussed by Tanaka et al. 2001). Widespread (and presumably effective) market research on color preferences for specific products presupposes that such effects exist. Notice, however, that these effects too are compatible with the EVT: to the extent that people like something that they bought, made, or chose because they like its color, their preference for that color will be reinforced via positive feedback, provided that they continue to enjoy it. Color preferences will thus tend to be self-perpetuating until other factors, such as boredom, new physical or social circumstances, and/or fashion trends, change the dynamics of aesthetic response, as indeed they inevitably do.

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Look and learn

Links between colour preference and colour cognition

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As soon as infants start to perceive the world in colour they express clear preferences for some colours over others. We consider what the purpose of these early colour preferences is by reviewing recent studies that have explored the role of colour preference in colour term acquisition. We show that preference for basic colours mirrors the dichotomous developmental order by which young children acquire basic colour terms. In addition, experimental measures of new colour term learning with non-basic colour terms (e.g. 'vermillion') or nonsense words (e.g. 'cotram') shows this association is mediated largely by differences in saturation, as both young children and adults prefer highly saturated colours to desaturated colours and they learn to associate novel colour terms to the colours they prefer. Together, these studies provide mounting evidence to suggest that colour preference and colour term acquisition are linked, although the mechanism underpinning this association remains to be determined.

1. Introduction

From as young as three months of age, human infants start to see the world in colour and at the same age they express clear preferences for particular colours over others (see Teller, Pereverzeva & Zemach 2006 for an overview). At this early age, infants show a preference for blue and red over yellow and green, and between four and twelve months of age a clear preference against brown is shown (Franklin, Pitchford, Mahony, Davies, Clausse & Jennings 2008). The different perceptual dimensions of colour, namely hue, saturation, and brightness, which interact to create colour appearance, form the basis of infant colour preferences. Whilst infants prefer chromatic stimuli to white, differences in brightness do not appear to drive their colour preferences. Instead, saturation and hue (chromatic purity) determine which colours infants prefer to look

at, and they express a clear preference for blue even when differences in saturation are controlled for (see Teller et al. 2006).

The preference for blue observed in infancy appears to remain stable across childhood and into adulthood, as adults have consistently been shown to prefer blue hues to yellow hues (e.g. Camgoz, Yener & Guvenc 2002). The preference for blue in adulthood appears to traverse cultures (Saito, 1996) whereas adults' preference for other colours seems to be more culturally and gender bound (Ling, Hurlbert & Robinson 2006) and may be associated with the emotional connotation of colours (e.g. Ou, Luo, Woodcock & Wright 2004). Furthermore, studies have shown that, compared to infants, saturation is less important than hue in determining adult colour preferences (e.g. Ou et al. 2004).

In this paper we consider the purpose of colour preferences in early childhood and adults. In particular, we explore whether or not colour preferences serve to direct attention towards particular colours that might be important in the environment because of their biological meaningfulness, as suggested by Bornstein (1975). It stands to reason that preferences may support the necessary and effective communication about these colours, so colour preferences may be linked to colour naming. Childhood colour preferences might therefore have a mechanistic role in colour term acquisition by directing attention towards particular colours, making them more memorable than others, thus facilitating their ease of lexicalization (Zentner 2001). Accordingly, the order of colour preference in childhood should mirror the order by which young children acquire basic colour terms. The first objective of the current review is therefore to examine the empirical support for a role of preference in colour term acquisition. Secondly, as differences in saturation and hue have been shown to influence infant and adult colour preferences, these perceptual dimensions of colour may also influence lexical acquisition. If colour preferences and colour naming are shown to be mediated by differences in saturation and hue, this would suggest that the cognitive processing of colour may be driven, to some extent at least, by low-level perceptual mechanisms. Thus, saturation and hue may link colour preference and colour naming in adults as well as young children. Thirdly, this relationship may be mediated by the increased attentional salience or memorability of preferred colours, as suggested originally by Zentner (2001). The following sections review experimental evidence that directly addresses these hypotheses.

2. Links between preference for and acquisition of basic colours in early childhood

Zentner (2001) first noticed a potential link between colour preference and the naming of basic colours in early childhood when studying colour preference in relation to the emotional meaning of seven of the eleven basic colours in a group of Swiss preschool children aged two and half to five years of age. As a group, the children preferred red the most, followed by pink, blue, yellow, green, brown and black, thus showing a

preference for chromatic over achromatic colours and, within the set of six chromatic colours tested, a preference against brown, consistent with the infant studies reported above. Zentner noticed that the order of colour preference expressed by this group of Swiss preschoolers overlapped partially with the order of colour term acquisition proposed by Berlin and Kay (1969), leading him to suggest that colour preference and colour term acquisition may be developmentally linked.

To test this hypothesis more directly, Pitchford and Mullen (2005) conducted a study (Experiment six) with a group of preschool children (N = 52), aged two to five years, living in Canada. They presented children with each of the eleven basic colours identified by Berlin and Kay (1969), these being 'black', 'white', 'red', 'green', 'yellow', 'blue', 'pink', 'orange', 'purple', 'brown' and 'grey', and asked them to name each colour. They also measured children's colour preference by asking them to indicate which colour they most preferred from an array of the eleven basic colours, and then removing that colour from the array and repeating the procedure until all of the colours had been removed. This generated a rank order of colour preference for each child, which was averaged across the group, and the group preference order was then compared to the group order for accurately naming colours. Results showed that children preferred the colours 'brown' and 'grey' significantly less than the other nine basic colours and that these two basic colour terms were named significantly less accurately. Furthermore, across the eleven basic colours, preference and naming were significantly correlated ($r = -.765$, $N = 11$, $p = .004$, 2-tailed), indicating that children were more likely to name correctly the colours they most preferred.

These results show that during the period when young children acquire basic colour nomenclature an association exists between the colours they prefer and the colours they can name. The dichotomous order by which young children typically acquire basic colour terms, which is characterized by the later acquisition of 'brown' and 'grey' relative to the other nine basic colour terms (Pitchford & Mullen 2002), appears to be mirrored by their preferences for basic colours, which are established in early infancy prior to the acquisition of colour terms. This raises the possibility that the factors that underpin colour preferences in infancy, namely saturation and hue, may exert a similar influence on the learning of new colour terms. The next section presents empirical evidence that supports this link.

3. Links between preference for and naming of non-basic colours varying in saturation and hue

The studies reported above show that infant colour preferences are determined by differences in chromatic purity, brought about by the combination of saturation and hue. Whilst hue clearly varies across the eleven basic colours, saturation levels also vary, with 'brown' and 'grey' being relatively desaturated compared to the other nine basic

colours[1]. This provides the first indication that saturation may be an important perceptual colour characteristic in determining both colour preferences and colour term acquisition in early childhood (Pitchford & Mullen 2005).

To explore the role of hue and saturation in linking colour preference and colour naming, Pitchford (unpublished) conducted a study with a group of four-to-five-year-old children (N = 27, mean age 4:9 years), all of whom could name the eleven basic colours accurately, living in the U.K. She used tasks of colour preference and colour naming in which saturation and hue were systematically manipulated across a set of fourteen chips drawn from the *Munsell Book of Color*. The set of fourteen colour chips comprised of seven hue pairs that were drawn from the boundaries between eight chromatic colour categories. Within each hue pair, the two Munsell chips were matched for luminance but varied in saturation, as one chip was of the maximum saturation level for a particular hue and luminance and the other chip was relatively desaturated. (N.B. Although luminance was kept constant within each hue pair it varied slightly across the seven different pairs of Munsell chips.) A non-basic colour term was assigned to each of the fourteen Munsell chips by two professional artists (see Table 1 for stimulus details).

Table 1. Munsell chip co-ordinates and corresponding non-basic colour terms for the seven hue pairs (S = saturated, D = desaturated) used by Pitchford (unpublished) in tasks of colour preference, comprehension, and naming with 5-year-old children and adults living in the U.K. Colour stimuli were drawn from category boundaries derived from adult colour naming tasks (Davidoff, Davies & Roberson, 1999)

Category Boundary Hue Pair		Munsell Chip Reference	Non-Basic Colour Term
Red-Orange	S	7.5 R 5/16	vermillion
	D	7.5 R 5/6	umber
Orange-Yellow	S	7.5 YR 6/14	ochre
	D	7.5 YR 6/4	tawny
Yellow-Green	S	7.5 Y 7/12	chartreuse
	D	7.5 Y 7/4	khaki
Green-Blue	S	7.5 BG 6/8	aquamarine
	D	7.5 BG 6/2	teal
Blue-Purple	S	7.5 PB 5/10	cobolt
	D	7.5 PB 5/4	woad
Purple-Pink	S	2.5 RP 5/12	magenta
	D	2.5 RP 5/4	mauve
Pink-Red	S	2.5 R 5/14	crimson
	D	2.5 R 5/4	madder

1. 'Black' and 'white' are totally desaturated but are 100% pure achromatic colours. Thus, within the three achromatic colours, 'grey' is relatively less pure than 'black' and 'white'.

Familiarity with these terms was first assessed in a comprehension task given before the colour preference and naming tasks. Rank order of preference across the fourteen chips was established using the same procedure adopted by Pitchford & Mullen (2005), as described above. Naming of these non-basic colours was assessed through two phases, a learning phase followed by a test phase. During the learning phase the experimenter presented one colour chip at a time with the corresponding non-basic colour term. For example, children were shown the desaturated 'pink-red' chip (2.5 R 5/4) and were told, "See this colour? This is called madder. Madder. Can you say that name?" Children were required to repeat the name given by the experimenter to ensure that they were attending to the task. This procedure was repeated until the experimenter had named each of the fourteen colour chips. During the test phase the experimenter presented the colour chips in a different randomized order for oral naming by asking children, "Now I'm going to see how many names you can remember. What's the name of this colour? What did we call this colour?" This procedure was followed until all of the fourteen chips had been presented once for oral naming. The entire learning phase followed by test phase procedure was repeated ten times, with the order of chip presentation being randomized across learning and test phases both within and across children, so as to control against order effects.

Results are reported in Table 2. To determine if the children exhibited a clear preference for either the set of saturated or desaturated chips, or particular hue pairs, prior to the learning of their colour names, a series of chi square tests was conducted using sum preference ranks for the group. For the set of saturated and desaturated chips the minimum rank possible was 28 (referring to the seven most preferred chips; sum of ranks 1 + 2 + 3 + 4 + 5+ 6 + 7) and the maximum rank possible was 77 (referring to the seven least preferred chips; sum of ranks 8 + 9 + 10 + 11 + 12 + 13 + 14). For each of the seven hue pairs the minimum rank possible was 3 (referring to the two most preferred chips; sum of ranks 1 + 2) and the maximum rank possible was 27 (referring to the two least preferred chips; sum of ranks 13 + 14). A one-group chi square test was then used to determine whether the children's preference for saturated colours (observed sum frequency = 1037, expected sum frequency = 1418) differed significantly from their preference for desaturated colours (observed sum frequency = 1798, expected sum frequency = 1418). Results revealed a significant effect of saturation on children's colour preference ($\chi^2 = 204.2$, $p < .0001$, 2-tailed) as children preferred the set of saturated chips significantly more than the set of desaturated chips.

In addition, a series of one-group chi square tests was conducted to establish whether children's preference for a particular hue pair (observed sum frequency for each hue pair) differed from chance (expected sum frequency = 405 for each hue pair). Results revealed that children preferred two hue pairs significantly more than would be expected on the basis of chance, these being blue-purple (observed sum frequency = 363, $\chi^2 = 5.08$, $p = .024$, 2-tailed)) and purple-pink (observed sum frequency = 352, $\chi^2 = 8.09$, $p = .004$, 2-tailed), and they preferred one hue pair, orange-yellow, significantly less than would be expected on the basis of chance (observed sum frequency =

447, $\chi^2 = 5.09$, p = .024, 2-tailed). This illustrates that differences in chromatic purity (as determined by saturation and hue) that have been shown to determine infant colour preferences (see Teller et al. 2006) continue to influence colour preferences over the preschool years and into early childhood.

Furthermore, as expected, the group of four-to-five-year-old children comprehended very few of the non-basic colour terms, all of which occur infrequently in adult spoken and written language, illustrating that they possessed little prior knowledge of these non-basic colour terms. Although minimal, to control for prior knowledge influencing performance on the non-basic colour naming task, performance on the comprehension task (e.g. 6/14) was subtracted from performance on the naming task (e.g. 10/14) so as to generate a measure of new colour term learning (e.g. 4/14) for each participant. Group mean performance was then calculated for the set of saturated and desaturated chips, and the seven different hue pairs and mean differences across these different sets of chips were explored. Results showed that, as a group, children named significantly more of the saturated than desaturated colour chips with the non-basic colour terms they had been taught (see Table 2), and this difference remained significant even when controlling for prior knowledge (Wilcoxon Signed Rank Test, Z = –2.01, p = .04, 2-tailed). This corroborates the findings by Pitchford and Mullen (2002, 2005) and shows that saturation appears to influence young children's lexical acquisition of both basic and non-basic colour terms. In contrast, naming differences in hue

Table 2. Mean percent performance by the group of five-year-old children on the colour preference, comprehension, and naming tasks, and new colour term learning (naming – comprehension) for the set of saturated and desaturated chips (collapsed across hue) and the seven different hue pairs (collapsed across saturation). For the preference task, the lower the mean percentage the more preferred the chip set as indicated by group rank order of preference given in adjacent column (where a rank of 1 = most preferred). For all other tasks, the higher the mean percentage the more accurate is performance

	Mean %				
Chip Set	**Preference (chance %)**	**Rank**	**Comprehension**	**Naming**	**Learning**
Saturated	21.2 (50)	1	6.8	15.0	8.2
Desaturated	78.8 (50)	2	3.7	6.6	2.9
Red-Orange	13.1 (14.3)	3	3.5	11.0	7.5
Orange-Yellow	15.8 (14.3)	7	2.0	10.6	8.6
Yellow-Green	15.1 (14.3)	4	5.5	16.9	11.4
Green-Blue	15.5 (14.3)	6	7.0	12.8	5.8
Blue-Purple	12.8 (14.3)	2	5.5	7.4	1.9
Purple-Pink	12.4 (14.3)	1	9.5	12.6	3.1
Pink-Red	15.3 (14.3)	5	3.5	4.7	1.2

did not remain significant after controlling for prior knowledge of the non-basic colour terms (Friedman Test, χ^2= 6.44, p = .38, 2-tailed), suggesting that for four-to-five-year-old children, hue is less influential than saturation in the learning of new colour vocabulary.

Importantly, the results of this study confirm the developmental association between colour preference and colour naming in young children reported previously (Pitchford & Mullen 2005) as the children learned the non-basic colour terms for colours they most preferred. Furthermore, saturation appeared to influence this relationship to a greater extent than hue, as the children preferred all of the saturated chips to the desaturated chips and, with one exception, they learned to name all of the saturated chips better than the desaturated chips, irrespective of hue. The exception to this relationship was the desaturated chip that fell on the yellow-green boundary (7.5 Y 7/4) to which the non-basic colour term 'khaki' had been assigned. As a group, the children expressed a particular preference against this colour chip, ranking it as their least preferred colour in the entire set of chips, yet they learnt to name this chip better than all of the other chips. As a consequence, the correlation between colour preference and colour naming for this group of four-to-five-year-old children only became significant when this particular chip was removed from the analysis (rho = –.75, N = 13, p = .009, 2-tailed). It is possible that children learned to assign the term 'khaki' to their least preferred chip because it was highly salient in eliciting feelings of unpleasantness (see Simmons (2011), and also Palmer and Schloss (2011), for further details). As such, the increased saliency of this particular chip could have drawn attention towards it, thus facilitating new colour term learning, even though this colour was least preferred. Alternatively it could be that the non-basic colour term 'khaki' was particularly salient to this group of four-to-five-year-olds as it was observed that they segmented this term into "car-key", a familiar term for children of this age, which in turn could have made this particular non-basic colour term relatively more salient linguistically and thus easier to learn than the other unfamiliar non-basic colour terms. To avoid this confound, Pitchford, Davis & Scerif (2009) conducted a further study using nonsense words.

4. Links between preference for, attention to, memory and naming of, within-category colours varying in saturation, luminance, and hue

The studies described above suggest that there may be an intrinsic bias towards to the processing of highly saturated colours by infants and young children that facilitates their conceptualization. Accordingly, a bias towards saturated colours may well be expected later in development, in adulthood, when learning novel colour terms, if saturation underpins a general learning principle linking colour preference and colour naming. Although previous studies have not investigated directly the relationship between colour preference and colour naming in adults, studies have shown that adults

prefer and name blue and green hues more consistently than yellow and red hues (Guest & van Laar 2000), suggesting that an association between colour preference and colour naming may extend into adulthood.

To explore if and how an association between colour preference and colour naming extends into adulthood, and also to address the issues with linguistic saliency discussed above, Pitchford et al. (2009) conducted a further study in which they taught nonsense word-colour associations (new colour term learning) to a group of preschool children (N = 20, mean age 3:11 years), primary school children (N = 32, mean age 7:11 years), and adults (N = 24). In addition, they explored the underlying mechanism by which colour preference may be associated with colour naming, by administering computerized tasks of selective attention and memory, as well as preference, for a set of colour stimuli varying in colour space. Each task employed a set of four computer-simulated colours (target colours) matched perceptually to four chips drawn from the *Munsell Book of Color*. The four colour targets were all from the 'purple' category. One chip was chosen as an anchor colour (10PB 4/8) from which the other three colours varied systematically by two Munsell steps in only saturation (10PB 4/4), luminance (10PB 6/8), or hue (5P 4/8).

Each participant was given five tasks. First, a colour memory task was administered in which participants were shown one of the four target colours briefly (for one second), followed by the presentation of one of three distracter colours (each of which varied by one Munsell step in only saturation 10PB 5/8, luminance 10PB 4/6, or hue 2.5P 4/8) for five or ten seconds, followed by a random horizontal array comprising the four target colours and three distracter colours. Participants were required to select the target colour initially shown from the array of seven different colours. Second, a colour attention task was given in which participants were shown one of the four target colours and were then asked to find all of the targets of this colour presented in an eight by eight colour grid (comprising 64 colours in total; sixteen of each of the four target colours). The grid was presented for five seconds during which participants were required to search, by touching the screen, for as many of the cued target colours (i.e. the colour that was presented before the grid appeared) as they could. Third, a colour preference task was given in which participants were presented with two different colour targets and were asked to indicate which they liked the most. Each of the four target colours was paired with each of the other colour targets so as to obtain a relative measure of colour preference for each of the four target colours. Fourth, a colour discrimination task was given to ensure that participants could tell the difference between the four colour chips. Participants were shown two target colours simultaneously, half of which were the same colour, and half of which were different colours, and were asked to say whether they were the same or different. Fifth, a nonsense word-colour association task was given to assess new colour term learning. This task followed the same procedure as that adopted by Pitchford (unpublished) described above, but used four nonsense words ('soppel', 'fillub', 'molcid', and 'cotram') randomly assigned to the four colour targets. For all tasks, the trial order was fully randomized within and across participants

so as to avoid order effects. Simplified versions of the tasks, using only two of the target colours, were used with the preschool children so as to avoid floor effects.

Results (reported in Table 3) showed a significant effect of saturation for both colour preference and colour cognition for primary school children and adults. However, the group of preschool children did not elicit significant preferences across the four target colours, which is surprising given that previous studies have shown preschool children to elicit strong preferences across basic colours. Unlike previous studies, this study used colours from within the same colour category and the four colour stimuli were very similar, differing only in two Munsell steps from the anchor either in saturation, hue, or luminance. Thus, in this study, the differences across colour stimuli would be much less than in previous studies where colour preference was investigated across a range of basic colours.

In contrast, both the primary school children and adults showed significant colour preferences, as they preferred the desaturated colour significantly less than chance and significantly less than the other three colour targets. Saturation also influenced

Table 3. Mean percent of each colour target chosen (preference) or identified accurately (cognitive tasks) for the group of preschool children, primary school children and adults in the study conducted by Pitchford et al. (2009). For all tasks the higher the percentage the greater was selection (preference) or performance accuracy (attention, memory and learning)

	Percentage Chosen/Correct			
Group/Task	**Anchor**	**Luminance increase**	**Saturation decrease**	**Hue shift**
	10PB 4/8	**10PB 6/8**	**10PB 4/4**	**5P 4/8**
Preschool children (n=20)				
Preference (chance %)	21.3 (25)	27.1 (25)	26.3 (25)	25.4 (25)
Attention	___	10.7	9.9	___
Memory	___	41.3	41.3	___
Learning	___	46.3	45.0	___
Primary school children (n=32)				
Preference (chance %)	29.4 (25)	28.4 (25)	15.9 (25)	26.3 (25)
Attention	29.7	56.4	56.4	61.8
Memory	41.7	59.3	47.0	56.3
Learning	31.3	39.0	22.8	22.8
Adults (n=24)				
Preference (chance %)	24.3 (25)	31.9 (25)	12.2 (25)	31.6 (25)
Attention	66.9	82.6	79.4	79.9
Memory	48.7	83.3	62.7	83.3
Learning	38.5	55.3	35.5	41.8

performance on some of the cognitive tasks for primary school children and adults (but not preschool children). Both groups learnt to associate significantly fewer nonsense words to the desaturated colour target compared to the colour target that differed in luminance (effect size: primary school children = .61; adults = .59). In addition, the group of adults memorized the desaturated colour significantly less than the colour targets that differed from the anchor in luminance (effect size = .68) and hue (effect size = .68). Thus, these results are consistent with previous studies that have shown similar effects of saturation operate across colour preference and colour naming (e.g., Pitchford & Mullen 2005; Pitchford unpublished).

However, the group of primary school children and adults differed in their preference for and cognitive processing of the other three target colours, which to some extent could be accounted for by differences in hue/luminance across the four target colours. At the group level there was little consistency linking colour preference to colour cognition, except for the lower preference for and naming of the desaturated colour. These discrepancies may have depended on consistent differences across participants in their individual preferences. As a result, individual analyses were conducted with participants who expressed significant preferences for and against particular target colours. Across age groups, twenty-three participants (eight primary school children and fifteen adults) were identified that expressed a significant preference for and against a particular target colour. Performance on the cognitive colour tasks was then compared for the colours they preferred significantly more and less than chance. Results showed no difference in participants' ability to attend to or memorize colours they preferred significantly more and less than chance. In contrast, participants learned to name significantly more accurately the colours they preferred significantly more than chance compared to the colours they preferred significantly less than chance (effect size = .44), illustrating a direct link between colour preference and new colour term learning.

These results provide little support for the mechanistic role, originally proposed by Zentner (2001), linking colour preference to colour term acquisition by directing attention to preferred colours, making them easier to memorize, and thus easier to conceptualize than less preferred colours. Rather, our results suggest a direct link between colour preference and colour naming that is mediated by perceptual characteristics of colour, especially saturation.

5. Conclusions

In this paper we have reviewed studies that have investigated the link between colour preference and colour term acquisition in young children and adults and have considered reasons why this association may exist. The summative evidence reviewed here suggests there may be an intrinsic bias towards the processing of saturated colours that influences the cognitive processing of colour. In general, young children and adults

prefer saturated colours to desaturated colours, and they learn to associate more easily new colour terms to colours they most prefer compared to colours they least prefer. The origin of this bias may well be cultural, reflecting an increased exposure to highly saturated colours, especially in the environment of young children. Alternatively, it may have biological underpinnings, reflecting an evolutionary advantage for animals and foods that are marked with highly saturated colours to stand out from the background, thus making them more salient and increasing their chance of transmitting their genetic code via mating or consumption (e.g. Mollon 1989). It is likely that highly saturated colours will be more salient perceptually than desaturated colours, making them stand out from the background, and thus drawing attention towards them. Preference for saturated colours may well be linked to perceptual saliency, so saliency could be an underlying factor linking colour preference and colour term acquisition (see Pitchford et al. 2009 for further discussion).

Research in other domains, such as face recognition, has also shown a link between infant preference and emerging cognition (e.g. Morton & Johnson 1991). This raises the possibility that the association between colour preference and colour term acquisition found in the studies reviewed in this paper reflects a more general role for preference in cognitive processing. There seem to be various features in the visual environment that infants like to look at. The purpose of these features appears to be related to later learning, as the same features appear, to some extent at least, to determine both preference and naming. Seemingly, critical dimensions of infants' perceptual input drive them to prefer and develop a lexicon for crucial aspects of their visual world, be they colours, faces, or other stimuli. However, the challenge that remains ahead is to understand the precise mechanisms through which infants 'look and learn'.

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Effects of lightness and saturation on color associations in the Mexican population

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Fehrman and Ferhman (2001), mention that blue is associated with tranquility, security, comfort, depression, melancholy, relaxation, isolation, infinitude and cold. However, these data do not indicate specifications for saturation and lightness of the hue in question. Is it a dark blue of low saturation or a very saturated light blue? Which type of blue actually evokes the stated meanings? Basing itself on such questions, a cross-sectional paper and pencil survey (of nine colors in three different intensities and lightnesses) was conducted with 622 subjects. The results showed different meanings associated with the same hue when there were variations in lightness and saturation. All of the foregoing results indicate the importance of continued research into the attributes that cause a color's associated meanings to vary. Knowing how (and perhaps why) these meanings vary with saturation and lightness should enable color to be used more effectively in all kinds of design applications.

1. Introduction

Among the most important psychological properties of colors for their application in design contexts are their capacities to evoke determinate emotional and conceptual values. Previous studies of such color associations, for example, show that blue is associated with *tranquillity*, *safety*, *comfort*, *depression*, *melancholy*, *relaxation*, *isolation*, *infinitude* and *cold* (Mahnke 1996; Ferhman & Ferhman 2001). However, this result does not indicate the saturation and lightness of the basic color category (BCC) in question. Is it a dark blue of low saturation or a highly saturated light blue? Which shade of blue actually evokes these particular meanings?

There are a few studies reported in the literature about how the meaning of the same BCC varies with differences in saturation and lightness. Eiseman (2000) reported different meanings for the same BCC with different degrees of saturation and lightness, finding that *happy*, *exciting* and *warm* are associated with ***intense*** (very saturated) ***pink***, for example, and that *romantic*, *soft*, *sweet*, *tenderness* are associated

with very ***light pink***. Similarly, *quiet* and *cleanliness* are associates of ***light blue*** whereas *dramatic*, *energetic* and *happy* are associates of ***intense blue***. Acking and Kuller (1972) found that *chroma* (the saturation or vividness) of a color has much more effect on the meanings people report than its hue. In other words, we perceive a highly saturated red and a highly saturated green as *exciting*, whereas we perceive less saturated (or muted) colors of any hue as *calming* (see Simmons 2011, who also cites other related literature, especially the contribution of Valdez and Mehrabian (1994)).

Other studies about variations in lightness and saturation have focused on preferences. For example, Camgöz, Yener and Guvenc (2002) found that the saturation and lightness of a color influences preferences regardless of the color hue. Palmer and Schloss (2011) also report large shifts in preference due to differences in lightness and saturation. They find that saturated colors are generally preferred to light, muted (low saturation) and dark colors, but that some effects are highly specific to warm hues. In particular, they report that dark orange and yellow are liked much less than all the lighter and more saturated shades of those hues, whereas dark red is liked much more than all its lighter and more saturated shades.

In the present chapter we examine whether there are variations in the meaning of a color that depend on saturation and lightness variations, using a cross-sectional paper and pencil survey that was conducted at the University of Guadalajara.

2. Method

2.1 Subjects

Participating subjects were 622 students, male (70%) and female (30%), with an average age of 20 years. These students were enrolled in two University Centres: the Sciences and Engineering Centre and the Biological and Agricultural Sciences Centre.

2.2 Materials

We provided each participant with the following materials:

A response sheet.

Three rectangular half-letter-size sheets, each containing eight 2 x 4 cm colored rectangles. There were seven basic colors (***blue, green, brown, red, pink, orange and yellow***) at three different saturations and lightnesses, plus two saturation/lightness variations for ***dark red*** (burgundy) and one for ***grey***. In total, there were 24 color stimuli, which were coded according to the Munsell Book of Color. These colors were selected because they are all BCCs. Purple was not included because in an earlier investigation (Prado-Leon, Avila-Chaurand & Rosales-Cinco 2006) it produced large variability in meanings.

An association sheet listing sixty-six possible meanings that could be given to any color. This sheet was in three versions, each of which varied the order in which the words were presented. It was obtained from the results of a pilot test in a previous study (Prado-León et al. 2006).

2.3 Procedure

Ishihara Pseudo-Isochromatic plates for testing color perception were used to screen participants for color deficiencies. The remaining participants were asked to give three meanings on the response sheet for each color, either by selecting from the list of 66 provided on the association sheet or by writing other meanings that were not listed.

3. Results

Table 1 shows the percentages of participants who selected the three highest frequency associates for each color. The results showed that different meanings were associated with the same BCC when there were variations in lightness and saturation. BCCs with the largest variation in meaning were:

Blue. A light and saturated blue (Munsell code 10B 7/6) is associated with *passivity* (13.5%), *balance* (8.5%) and *cold* (7.1%); an equally saturated blue that is blended with purple and with lower luminosity (5PB 3/6) was associated with *safety* (12.5%), *masculinity* (9.6%) and *stylishness* (7.6%); a less saturated and darker blue with *stylishness* (10.4%), *cold* (7.8%) and *seriousness* (6.6%).

Orange. A moderately saturated and light orange (10R 8/6) was associated with *tenderness* (14.0%), *comfortability* (9.3%) and *femininity* (7.9%); a saturated and light orange (7.5YR 7/12) was associated with *energy* (13.4%), *brightness* (11.9%) and *happiness* (10.1%), while a less saturated and darker one (Munsell code 2.5YR 6/10) was associated with *happiness* (8.5%), *caution* (4.2%) and *energy* (4.0%).

Yellow. A moderately saturated and moderately light yellow (10Y 9/6) was clearly associated with *brightness* (19.8%), *happiness* (16.9%) and *energy* (11.6%); a half-saturated and light yellow (5Y 9/4) was associated with *weakness* (9.8%), *passivity* (9.6%) and *tenderness* (7.8%); an intense and less light yellow (7.5YR 8/8) was associated with *brightness* (8.6%), *happiness* (6.3%) and *weakness* (5.9%).

Dark red (burgundy). A half-saturated and low lightness burgundy (2.5R 3/4) was associated with *stylishness* (14.3%), *seriousness* (6.4%) and *fear* (4.8%), whereas a half-saturated and light burgundy (5R 4/4) was associated with *darkness* (8.2%), *seriousness* (5.5%) and *malaise* (4.5%).

Table 1. Percentages for the three principal meanings

Color /Munsell code	Concept	Percentages
Orange	Tenderness	14.0%
10R 8/6	comfortability	9.3%
	Femininity	7.9%
Orange	Energy	13.4%
7.5YR 7/12	Brightness	11.9%
	Happiness	10.1%
Orange	Happiness	8.5%
2.5YR 6/10	Caution	4.2%
	Energy	4.0%
Red	Love	37.2%
5R 5/4	Sexuality	32.8%
	Heat	12.1%
Red	Love	20.7%
5R 5/12	Heat	15.6%
	Sexuality	13.1%
Red	Sexuality	14.1%
5R 4/10	Love	13.2%
	Stylishness	6.3%
Yellow	Brightness	19.8%
10Y 9/6	Happiness	16.9%
	Energy	11.6%
Yellow	Weakness	9.8%
5Y 9/4	Passivity	9.6%
	Tenderness	7.8%
Yellow	Brightness	8.6%
7.5YR 8/8	Happiness	6.3%
	Weakness	5.9%
Grey	Cold	19.8%
N8.25	Sadness	13.2%
	Emptiness	7.1%
Burgundy	Stylishness	14.3%
2.5R 3/4	Seriousness	6.4%
	Fear	4.8%
Burgundy	Darkness	8.2%
5R 4/4	Seriousness	5.5%
	Malaise	4.5%
Green	Nature	28.5%
2.5G 8/4	Life	15.5%
	Weakness	5.3%
Green	Nature	26.6%
7.5GY 8/10	Life	18.8%
	Happiness	17.8%
Green	Seriousness	8.3%
5G 4/2	Nature	5.5%
	Death	4.3%

A chi-square test was applied to all the meanings that recurred with variations of lightness and saturation for the same BCC, using percentages in the color variations. In the cases of *cold* and *stylish* for ***blue***, *hot* for ***red***, *life* for ***green***, *dryness* for ***brown***, *happiness* for ***orange*** and *seriousness* for ***burgundy***, no significant difference was found ($p \geq 0.05$). By contrast, for the meanings of *love* and *sexuality* for ***red***, *nature* for ***green***, *femininity*, *tenderness* and *innocence* for ***pink***, *seriousness* and *dirtiness* for ***brown***, *energy* for ***orange***, *brightness*, *happiness* and *weakness* for ***yellow***, and *sadness* and *cold* for ***grey***, the difference was significant ($p < 0.05$).

4. Discussion

The present results suggest that there are indeed substantial variations in meaning for the same BCC at different levels of saturation and lightness. Colors presenting the greatest variation in their meanings were ***blue, orange, yellow*** and ***dark red*** (burgundy). However there are also BCCs that maintain some meanings across variations in lightness and saturation: ***red*** with *love* and *sexuality*; ***green*** with *nature*; ***pink*** with *femininity* and *tenderness*; ***brown*** with *dryness* and *dirtiness*. All of them present a significant difference ($p < 0.05$), except *dryness* for ***brown***. This suggests that, although these meanings are present in three variations, there is a greater or lesser association depending on the saturation or lightness.

Favre (1989), Ortiz (1992), Mahnke (1996) and Fehrman and Fehrman (2001) have attributed the meaning of *love* to ***red***, reporting it to be highly significant. In the present research as well, that meaning was maintained despite variations in saturation and lightness of the ***reds***: strong and light (5R 5/14), weak and light (5R 5/12) and weak and dark (5R 4/10). Regarding ***green***, Ferrer (2007) mentions that it means *happiness*, and especially *life*. Our results indicate that the meaning of *nature* in ***green*** seems stronger when it is light, even when it is mixed with the ***yellow*** (for 2.5G 8/4 *nature* was associated at 28.5% and for 7.5GY 8/10 it was associated at 26.6%), compared with a darker and less saturated ***green*** (5G 4/2 where it was associated at only 5.5%). When the saturation and lightness of ***green*** was reduced, it lost its meaning of *life* and *happiness*, acquiring its opposites, *seriousness* (8.3%) and *death* (4.3%).

For three variations of ***pink*** – weak and light (10RP 8/6), strong and less light (5RP 7/10), and weak and dark (10RP 6/6) – the attribution of *femininity* as a meaning was predominant, coinciding with results reported by Ortiz (1992). Interestingly, our findings also suggest that, if a color tends towards another BCC, as in the case of light ***orange***, with pinkish shades moving towards what is commonly called "***salmon***" (10R 8/6), then it acquires the meanings of ***pink*** (*tenderness*, *comfortability*, *femininity*). This finding coincides with the analysis of Arnheim (1989), who confirmed that the relevant factor in the correlation between color and affect is not the main color, but the one towards which it converges. In this case, the main color is ***orange*** tending toward ***pink***, and its principal meanings derive from those we already know as pertaining to ***pink*** (Prado-León et al. 2006). The results of the present study also indicate that

lighter colors are associated with *cold* by comparing the ***lighter grey*** (N 8.25) used in this study with the ***darker grey*** (6BG 3/4) of Prado-León et al. (2006). In comparing the meanings of three types of ***blue*** with meanings attributed to blue in a previous study of a similar population (Prado-León et al. 2006), we confirm that some meanings persisted, whereas other new meanings were added. This fact suggests that they were due to changes in saturation and lightness. For example, the meanings of *passivity* and *masculinity* for ***blue*** are constant in both studies, with the light shade (10B 7/6) eliciting meanings of *balance* and *cold*, and the dark shade (5PB 3/6) those of *safety*, *stylishness* and *masculinity*. The latter meaning was also given in research reported by Ortiz (1992). Some words associated with colors, such as *energy*, *weakness*, *hot* and *cold*, might be related to personality traits, physical aspects of people or objects and even color contents. However, it is not possible to establish what connotations the participants had in mind when they chose that meaning.

All of the foregoing results indicate the importance of continued research into the attributes that cause a color's associated meanings to vary, taking into account Valence, Arousal and Dominance (Bradley & Lang 1999). Knowing how (and perhaps why) these meanings vary with saturation and lightness should enable color to be used more effectively in all kinds of design applications.

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Colour and emotion

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Whilst there are many anecdotal links between particular colours and particular emotions, there is relatively little in the way of systematic research. In this chapter a protocol is proposed for establishing these links empirically which is then tested on the emotional terms "pleasant", "unpleasant", "mood-enhancing" and "calming". It was found that it is possible to establish reliable colour-emotion associations, at least with culturally homogeneous participants. A framework for understanding these associations is proposed.

1. Introduction

When asked about the associations they make between certain colours and certain emotions, most people will happily express a strong opinion. For example, we conventionally associate red with anger, green with envy and blue with sadness (e.g. the "blue" period of Picasso), to name but a few. These associations are well established and can be surprisingly old, some dating back as far as the Middle Ages (see the *Oxford English Dictionary*).

There are also numerous theories purporting to map the relationships between colours and emotions. These range from the sublime (Goethe 1810) to the mundane (Brook 1999). A number of commercial organizations have their own ideas about colour-emotion relationships too (e.g. the 2008 television advertising campaign in Britain by DULUX paints "We know the colours that go"). However, there is surprisingly little in the way of systematic research in the public domain, and what there is tends to be methodologically flawed.

Two quotes from Davidoff (1991) capture this situation:

> ...one ought to be cautious about the widely held belief that different parts of the color space are necessarily associated with particular emotions. (1991: 113)
> ...most of the studies that purport to show effects of color on mood and behavior are not well controlled. (1991: 114)

One of the key studies which tried to address this issue systematically was that of Valdez and Mehrabian (1994). They employed a set of 76 Munsell colour samples and

asked 250 participants to rate each sample using a semantic differential. So, for example, a participant would be presented with a colour and asked where on the dimension joining "happy" to "cruel" it made them feel, where between "frustrated" and "sad", where between "masterful" and "fascinated", etc. Established techniques (Mehrabian 1978) were then used to map each colour onto a position in the "Pleasure-Arousal-Dominance" (PAD) space (Russell & Mehrabian 1977). Valdez and Mehrabian's rather surprising conclusion was that saturation and brightness dominated emotional responses to colour. Hue, the dimension that is normally considered to be predominant, accounted for less than 30% of the variance.

Whilst Valdez and Mehrabian (1994) was an impressive study, there were some problems with it. Due to the sheer number of colour samples involved, not all participants saw the same set of colours, so the authors were forced to collate data across participants, thereby losing information on individual differences. There is also concern that any effects of hue may have been diluted by presenting each hue at multiple saturation levels. This would result, for example, in shades of brown being bracketed with the shades of yellow with which they shared Munsell hue coordinates.

More recent studies include Terwogt and Hoeksma (1995); Zentner (2001); Ou, Luo, Woodcock and Wright (2004); Clarke and Costall (2008) and Palmer and Schloss (2009; 2011). With the exception of the latter, which was carried out simultaneously with the current research and will be dealt with in Sections 10.2 and 11, these studies have not proved conclusive in establishing reliable colour-emotion links. Both Terwogt and Hoeksma (1995) and Zentner (2001) employed only a limited range of colours, and the former obtained their colour-emotion links by the indirect means of simultaneous preference ranking. Whilst Ou et al. (2004) used an extensive range of colours that were assessed using semantic differential scales, they curiously avoided what are usually termed emotions and were really looking at less "loaded" associations (e.g. clean/dirty, masculine/feminine, heavy/light). Clarke and Costall's (2008) study was qualitative, so does not allow for quantitative predictions. The results of Palmer and Schloss (2011) are, to a certain extent, complementary to those presented here. They employed a broad colour range, suitable emotion descriptors and quantitative techniques, but ranked individual colours in isolation, unlike the closed set approach that is employed here.

2. Pilot experiments

Initial pilot experiments were designed to investigate colour-emotion relationships further, using techniques similar to those of Valdez and Mehrabian (1994) in an effort to replicate their results, at least in part. In two separate experiments two different presentation modes were used: high-quality inkjet printer output, illuminated by daylight fluorescent lamps, and data projector output, giving a large field of a single colour. Each printed sample and coloured light was measured using a CS-100 chromameter (Konica Minolta Inc.) to establish accurate CIE (1931) colour coordinates. Responses were made

using rating scales for different emotions. Within the participant group of university undergraduates we found significant and apparently systematic variations in the reported emotional responses to different colours. It was striking that the relative importance of lightness/brightness, saturation and hue seemed to vary between emotional categories, and it was decided that a more systematic and focused paradigm was required.

3. A systematic approach to measuring associations between colours and emotions

The systematic approach that was developed consisted of the following steps:

1. Decide on the emotion to be assessed.
2. Sample a limited set of widely spaced colours (e.g. the eleven basic colours of English (Rosch Heider 1972)) in groups of three and presented in all possible combinations.
3. For each presentation of three colours, ask participants to report which of the three most evokes the emotion under test (see Figure 1).
4. Average these data across participants to arrive at an "emotional" order for the colour set.
5. By concentrating on the most evocative colours the set can be narrowed down further to test specific hypotheses.

Note that whilst it is more conventional to use the paired comparisons technique for comparative colour judgements (e.g. Terwogt & Hoeksma 1995; Hurlbert & Ling 2007), this three-colour presentation technique has the advantage that colours are embedded in a richer and more varied context which increases the ecological validity of the judgement.

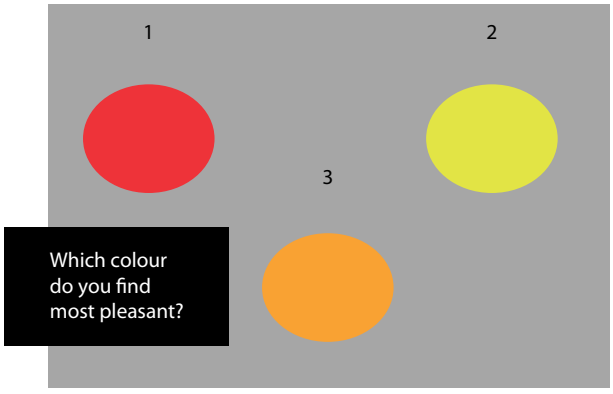

Figure 1. Illustration of a typical stimulus from the "pleasant" experiment (Experiment 1)

4. Experiment 1: Pleasant colours

The first emotion we focused on was "pleasantness". The adjective *pleasant* can be associated with the +P or positive pleasure axis of the PAD emotion space (Valdez & Mehrabian 1994), or alternatively higher valence in the Valence/Arousal model of emotion space (Barrett & Russell 1999), linking it with approachability. Pilot studies, and the data of Valdez and Mehrabian (1994), suggested that there would be a strong effect of saturation, with the most saturated colour samples being favoured. Therefore, a set of saturated colours was chosen for the main experiment, sampling the hue circle at maximal saturation: purple, blue-purple, blue, cyan, green, yellow-green, yellow, red and pink. CIE colour data of these colours are given in Table 1. It was decided to allow luminance of the colours to vary in order to permit maximum achievable saturation for each hue. Note that, even so, this saturation differs substantially from hue to hue, due to the characteristic "lumpiness" of colour space and the limitations of the presentation equipment and software.

4.1 Methods

The colour samples were presented on the cathode-ray-tube (CRT) monitor at a viewing distance of 60cm in a dark room (no illumination other than the light coming from the monitor). Each circular colour patch subtended 7.6 degree of visual angle, and was presented on a neutral grey background. Figure 1 shows a typical presentation slide. Each slide was embedded into a Powerpoint® presentation which was under the control of the experimental participant. At the beginning of the experiment, participants

Table 1. Colour names, CIE (1931) coordinates (Luminance, x-coordinate, y-coordinate) and CIELUV Lightness, Hue and Saturation values of the colours used in the "Pleasant" experiment (Experiment 1)

	CIEY	CIEx	CIEy	Lightness	Hue	Saturation
Purple	32.2	0.238	0.14	72.5	5.01	1.95
Blue-Purple	24.6	0.198	0.117	64.9	4.79	2.35
Blue	11.0	0.145	0.062	45.9	4.66	3.67
Cyan	90.4	0.224	0.313	108.9	3.06	0.53
Green	82.8	0.325	0.562	105.3	1.91	1.56
Yellow/green	95.2	0.373	0.527	111.1	1.65	1.43
Yellow	97.4	0.377	0.471	112.1	1.49	1.22
Orange	60.9	0.417	0.425	93.5	1.06	1.24
Red	22.3	0.604	0.348	62.3	0.353	3.07
Pink	36.4	0.286	0.168	76.2	5.34	1.65
Background Grey	72.4	0.274	0.295	100	–	0.00

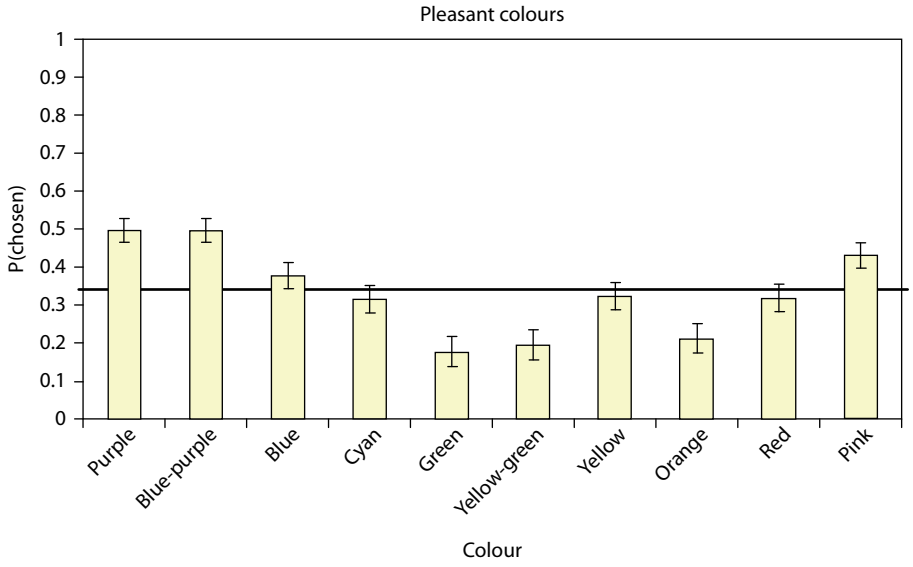

Figure 2. Data from the "pleasant" experiment (Experiment 1). Probability of being chosen (p(chosen)) is plotted for each colour used. Error bars are 95% confidence limits assuming the normal approximation to the binomial distribution. The solid horizontal line depicts chance performance (0.33)

were asked to report, for each slide, the number of the colour which most evoked a pleasant sensation (i.e. which they would associate most with the adjective *pleasant*). This number was recorded by the experimenter for subsequent analysis. There were 120 slides in each experiment, therefore allowing all combinations of three colours to be presented. Blank screens of neutral grey between stimulus slides assisted in the dissipation of colour after-effects. The presentation duration for each slide was under the control of the participant (self-paced). The total duration of the experiment was typically 15 minutes.

A total of 60 participants was tested (52 female, 8 male), all psychology undergraduate students at the University of Glasgow, largely in the age range 18–22 years. No payment, other than a sweet or chocolate bar, was given for participation. All participants were verified as having normal colour vision using the Ishihara colour test (Ishihara 1978) before being allowed to participate.

4.2 Results

The results are shown in Figure 2. Each colour was presented 36 times to each participant, giving a total of 2160 presentations of each colour across the 60 participants. The ordinate represents the proportion of times that the colour was picked as the most pleasant of the set of three. The horizontal line indicates chance performance (1/3).

The error bars are 95% confidence limits on the proportion-chosen data and calculated assuming the normal approximation to the binomial distribution (Hoel 1984). Consequently, if the error bars do not overlap with the chance line, it can be argued that the colour was chosen at a rate significantly above or below chance.[1] It is clear that purple, blue-purple and pink were chosen at rates significantly above chance, and that green, yellow-green and orange were chosen at rates significantly below chance. Blue, cyan, yellow and red were chosen at chance, and thus approximately randomly. Whilst there is very little to choose between them, purple and blue-purple were ranked as the most evocative of pleasant emotions in the sample, and green and yellow-green the least.

4.3 Discussion

This set of data is remarkably consistent with the dependence of "pleasure" on wavelength as reported by Valdez and Mehrabian (1994). In their study (see Figure 3) the

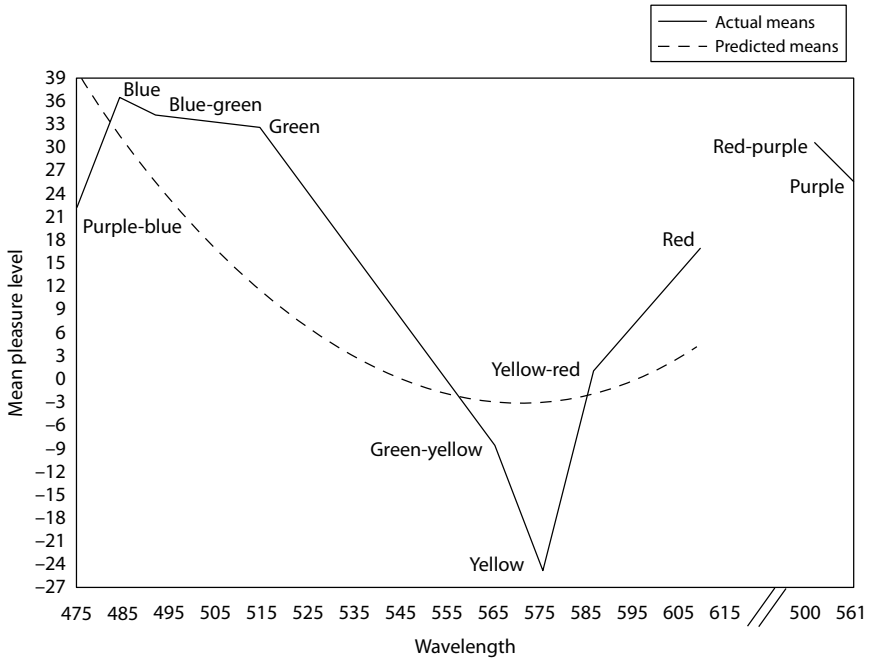

Figure 3. Data from Valdez and Mehrabian (1994) showing mean ratings on the "Pleasure" axis as a function of stimulus central wavelength. Reproduced with permission of the American Psychological Association (APA)

1. There is a statistical argument that a multiple-comparisons correction should be imposed here because there was no specific hypothesis about which colours would be above or below chance before the experiment. In this case, 99.5 confidence limits would be more appropriate (about 1.5 the size of the current error bars).

highest pleasure ratings were given to short-wavelength-dominant colours, especially in red-purple through to blue-green. Although the lowest pleasure rankings were given to yellow, rather than green to yellow-green, it should be noted that, as Valdez and Mehrabian (1994) collapsed across saturation and brightness, their yellows would have included browns as well. It is difficult to compare the magnitude of the hue effect shown here with that of Valdez and Mehrabian, but there is clearly a significant effect of hue on "pleasantness" when saturation is maximized. Similar data have also been obtained in experiments on preference judgements which are probably closely linked (see Ling & Hurlbert 2011; Palmer & Schloss 2011).

5. Experiment 2: Unpleasant colours

The adjective *unpleasant* can be associated with the -P direction in PAD emotion space and decreased valence (i.e. avoidance behaviour). Pilot studies suggested that the most-chosen colours were yellows, greens, browns and oranges with lower saturations. The ten colours chosen for the main study were therefore: purple-grey, grey-brown, olive green, yellow-brown, green brown, beige, chocolate, orange brown, pink-brown, red brown (see Table 2 for CIE colour data).

5.1 Methods

Identical with the "Pleasant Colours" experiment except that the adjective was *unpleasant* instead of *pleasant*. The same group of 60 undergraduate psychology students was used.

Table 2. Colour names and CIE (1931) coordinates (Luminance, x-coordinate, y-coordinate) and CIELUV Lightness, Hue and Saturation values of the colours used in the "Unpleasant" experiment (Experiment 2)

	CIEY	CIEx	CIEy	Lightness	Hue	Saturation
Purple Grey	12.2	0.302	0.283	46.6	6.13	0.34
Grey Brown	31.1	0.312	0.355	69.5	1.43	0.50
Yellow Brown	50.8	0.404	0.500	84.7	1.43	1.39
Olive Green	13.55	0.330	0.382	48.8	1.42	0.69
Green Brown	29.4	0.406	0.474	67.9	1.33	1.31
Beige	66.1	0.305	0.334	94.0	1.27	0.36
Chocolate Brown	9.93	0.355	0.355	42.5	0.91	0.73
Pink Brown	30.95	0.361	0.359	69.4	0.91	0.77
Orange Brown	19.03	0.448	0.409	56.6	0.84	1.42
Red Brown	8.46	0.414	0.341	39.4	0.51	1.22
Background Grey	77.6	0.274	0.296	100	–	0.00

5.2 Results

The results are presented in Figure 4. Graphical conventions are the same as with Figure 2. This time only two colours were chosen at rates significantly above chance: green-brown and yellow-brown. Purple-grey, beige, pink-brown and red-brown were chosen significantly below chance, with grey-brown, olive-green, chocolate and orange-brown being close to chance. The most unpleasant colour of the sample was green-brown, and the least unpleasant beige.

5.3 Discussion

As mentioned above, Valdez and Mehrabian's (1994) "yellow" will have included colours close to some of the browns used in this experiment, and this could well have contributed to the low pleasure rating for yellow hues in their data. The results in this experiment are highly significant and much more clear-cut than in Experiment 1. It is also clear that this group of participants was quite discerning about particular shades of brown, most obvious from the proximity of the hue values for each colour. Human observers with typical colour vision have their best wavelength acuity in this region of colour space, due to its lying in the 'sweet spot' between the wavelength sensitivities of the Medium- and Long-Wavelength-Sensitive cone photoreceptors (Goldstein 2002), but there are also sound ecological reasons for having high discrimination abilities due to the environmental ubiquity of brown (Parraga, Troscianko & Tolhurst 2002). These ideas are discussed further below.

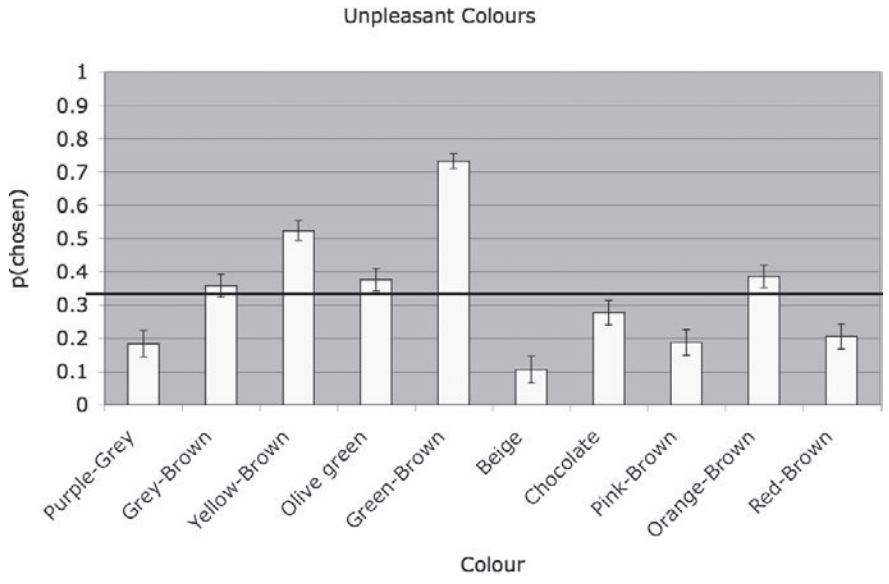

Figure 4. Data from the "unpleasant" experiment (Experiment 2). Figure conventions are the same as in Figure 2

6. Experiment 3: Mood-enhancing colours

The +A or "Arousal" dimension of the PAD or Valence-Arousal emotion space is arguably trickier to address than the P dimension. Some studies (e.g. in the IAPS; Lang, Bradley & Cuthbert 2008) simply ask participants to rank for arousal, but it was thought that this was a misleading question for our participants because of the term's overwhelming association with sexual arousal. Consequently we embedded the task in a scenario to get at a more general meaning of the term.

6.1 Methods

The scenario employed was the following: "You have been feeling a little down lately and have decided to paint one wall of your white bedroom in a colour that will make you feel positive". Note that the use of "white" bedroom was to set a neutral tone for this imaginative situation. Pilot data suggested that grey, whilst the background colour for the experiments, would have an inappropriate connotation of sadness which might encourage the participant to choose *any* colour rather than grey. Other procedural details are the same as with Experiments 1 and 2, except that the colour patches were rectangular (size: 5.6 x 8.9 deg visual angle) and there were now 56 participants with a more even gender split (31 Female, 25 Male). Again these participants were taken from the undergraduate psychology population at the University of Glasgow.

Following on from the pilot studies, it was clear that three close hues were most important: yellow, orange and red. These were presented at three brightness/saturation levels each, giving nine colour samples in total: Dark/Medium/Light Yellow/Orange/Red

Table 3. Colour names and CIE (1931) coordinates (Luminance, x-coordinate, y-coordinate) and CIELUV Lightness, Hue and Saturation values of the colours used in the "Mood enhancing" experiment (Experiment 3)

	CIEY	CIEx	CIEy	Lightness	Hue	Saturation
Dark Yellow	83	0.418	0.496	133.9	1.36	1.46
Medium Yellow	105.6	0.393	0.515	146.4	1.53	1.46
Light Yellow	109.6	0.322	0.382	148.4	1.52	0.72
Dark Orange	42.8	0.500	0.432	104.2	0.81	1.81
Medium Orange	55.7	0.441	0.419	115.2	0.94	1.41
Light Orange	65.7	0.372	0.362	122.6	0.90	0.89
Dark Red	18.2	0.627	0.346	74.4	0.35	3.35
Medium Red	20.7	0.609	0.346	78.3	0.36	3.16
Light Red	114.9	0.423	0.314	151.0	0.34	1.42
Background Grey	38.5	0.272	0.291	100.0	–	0.00

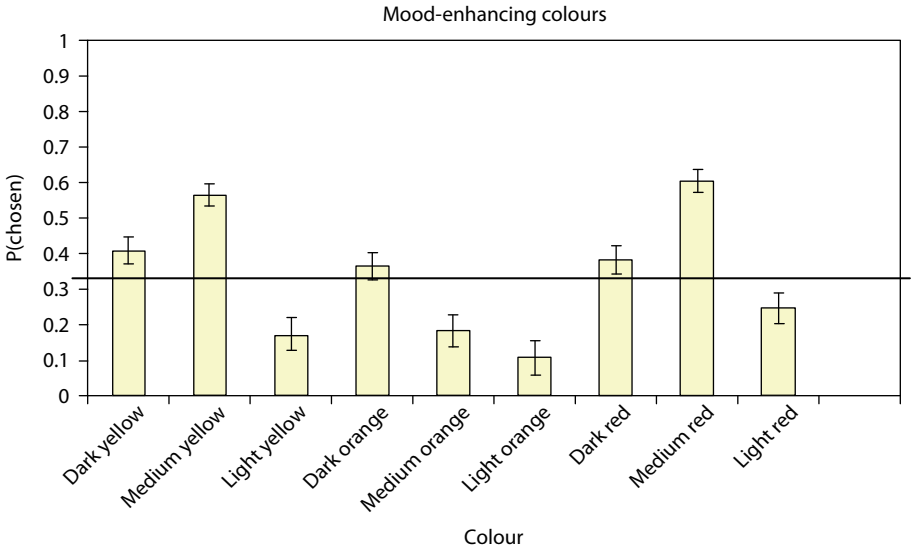

Figure 5. Data from the "mood-enhancing" experiment (Experiment 3). Figure conventions are the same as in Figure 2

(see Table 3 for CIE colour data). Consequently there were fewer trials in this experiment (84).

6.2 Results

The data from this experiment are presented in Figure 5. Whilst both the dark yellow and dark red were just above chance, the medium brightness/saturations won the day, being chosen many more times than any other colours. The lighter/pastel shades of yellow, orange and red were all chosen significantly less than chance, along with the medium orange. Dark orange was apparently picked only randomly.

6.3 Discussion

These data clearly demonstrate that the most arousing colours, at least in our scenario, were the medium red and yellow. These two colours both present something close to a focal red and yellow. Inspection of the Lightness, Hue and Saturation values for these colours suggests that the main factor influencing arousal choices was saturation, rather than lightness/brightness (Valdez & Mehrabian 1994). The pattern of data with the orange hues was different, suggesting a strong influence of hue. This was confirmed in the pilot experiments, where blues, greens and purples were not favoured despite being highly saturated.

The choice of bright, saturated reds and yellows as arousing colours does not seem particularly surprising. There are a number of companies that use colours close to these in their branding, where the aim is to target young people and attract attention.

7. Experiment 4: Calming colours

This experiment was the obverse of Experiment 3, looking in detail at the "-A" dimension of both PAD and Valence-Arousal emotional dimensions.

7.1 Methods

For similar reasons, it was thought wise to embed this task in a scenario: "You have been feeling rather stressed lately and have decided to paint a wall in your bedroom. You decide to choose a calming colour which will help you relax and wind down". The participant group was the same as for Experiment 3. Following on from pilot experiments, the colour set was shades of purple, blue and orange (dark/medium/light) plus white. As there were ten colours, 120 presentations were necessary. CIE colour data for the colours used are presented in Table 4.

7.2 Results

The results of Experiment 4 are shown in Figure 6. The light pastel shades of blue and purple (e.g. lilac) were favoured over all the other colours, although the light orange

Table 4. Colour names and CIE (1931) coordinates (Luminance, x-coordinate, y-coordinate) and CIELUV Lightness, Hue and Saturation values of the colours used in the "Calming" experiment (Experiment 4)

	CIEY	CIEx	CIEy	Lightness	Hue	Saturation
Dark Purple	45.3	0.247	0.182	106.5	5.01	1.24
Medium Purple	61.8	0.251	0.224	119.8	4.92	0.68
Light Purple	82.1	0.255	0.264	133.3	4.58	0.27
Dark Blue	19.1	0.167	0.100	75.8	4.66	2.70
Medium Blue	49.0	0.194	0.199	109.7	4.39	1.13
Light Blue	96.4	0.258	0.275	141.5	4.36	0.17
Dark Orange	41.0	0.499	0.429	102.5	0.80	1.80
Medium Orange	59.3	0.413	0.415	117.0	1.04	1.23
Light Orange	83.1	0.323	0.338	133.9	1.07	0.51
White	110.7	0.276	0.301	149.0	1.68	0.09
Background Grey	38.5	0.272	0.291	100.0	–	0.00

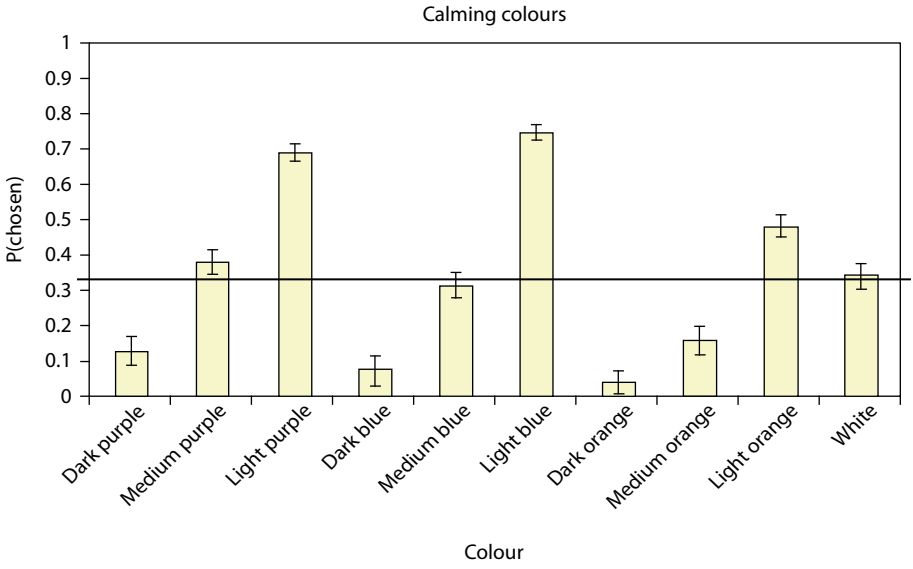

Figure 6. Data from the "calming" experiment (Experiment 4). Figure conventions are the same as in Figure 2

was also chosen above chance. All the darker and more saturated colours were chosen at sub-chance levels, whereas the medium colours were chosen around chance, except for the medium orange. Choice of white was essentially random.

7.3 Discussion

In this experiment there were clear effects of saturation on the choice of calming colours. This is not solely a brightness effect because the white had the highest brightness but was not favoured over the light desaturated colours. There are also clear differences between hues, with the short-wavelength-dominated colours being favoured over long-wavelength-dominated. Greens were used in the pilot studies but were found not to be favoured, although they were not tested at the same range of saturations. Again, the data echo Valdez and Mehrabian (1994) in that, with all hues tested, calmness seems to increase with decreasing saturation, but the effect disappears before reaching neutrality, suggesting a non-linear relationship.

8. Results summary

In summary, in this study the most "pleasant" colours were found to be deep purple, purple-blue and pink, the most "unpleasant" greenish and yellowish brown, the most "mood-enhancing" saturated reds and yellows, and the most "calming" pastel blue and lilac.

9. General discussion

What do these data tell us about the associations between colours and emotions? A first criticism of this approach might be that evoked emotional responses as such were not measured using this task, but merely word associations. Despite the emphatic instructions there was no guarantee that participants were responding according to their *feelings* on viewing the colour, and they may simply have been responding according to convention. It is possible to address this point somewhat using objective measurement techniques such as physiological responses (heart rate, skin conductance, pupil size), neuroimaging (ElectroEncephaloGraphy (EEG)) or functional Magnetic Resonance Imaging (fMRI)) to look for associated physiological or neural activity. However, it is unlikely that the emotional responses to colours are particularly strong; they are probably not as strong as those to emotive photographs such as those in the IAPS, and the neural and physiological signatures are likely to be subtle and variable (what might be called a *frisson*, rather than a full-blown emotional response). In that sense, whilst behavioural measurements are technically flawed, they are also highly informative and might be the best we can get with current technology, especially when we concentrate on those responses in which there is a lot of agreement between participants.

Note also that none of the colours tested was so universally dominant that it provoked close to 100% responses. The highest responses for a given colour were in the region of 70–80%. This is probably indicative of two things. First, there is no absolute universal agreement, even amongst such a culturally homogeneous group, over the emotional associations of given colours. Second, in all cases the colours in a set were chosen to be potential candidates for the most evocative, and therefore would be competing with the most favoured colour. If, for example, in the "pleasant" set we had tested our favoured blues and purples alongside yellowish and greenish browns from the "unpleasant" set, we would probably have seen higher choices of the blues and purples relative to the other colours in the set.

A second potential criticism is that the terms used were potentially ambiguous. This is particularly true of the "pleasant" term, which is likely to have been affected by mood. The pilot experiments found that saturated blues were ranked high in "contentment", unlike saturated reds and yellows. If your mood is relaxed already, then a stimulating red or yellow (see Experiment 3) might be perceived as pleasant, whereas if one is more stressed, the contenting blues might be more favoured. This might explain why the saturated reds and yellows were chosen only randomly in Experiment 1.

9.1 Results from other studies

In another study, not discussed in detail here (Simmons & Asher 2007) the same techniques were used to look at "happy" and "sad" colours. It was found that the most happy colour was a saturated yellow, similar to the most "mood-enhancing" colour from Experiment 3, closely followed by a saturated purple-pink. Sadness, on the other

hand, was most evoked by low saturation and specifically a neutral grey. Less formal experiments have also confirmed the conventional association of redness with anger and blackness with fear, although it is particularly unlikely with these stronger emotions that genuine fear or anger was evoked by viewing coloured patches. Taking these results together, it seems that Davidoff's (1991) statement that we cannot identify particular regions of colour space with particular emotions is incorrect, at least in a culturally homogeneous group. This leads us to try to think of reasons why these colour-emotion associations arise and how universal they might be.

10. The basis of colour-emotion associations

10.1 Stereotypical associations

As mentioned above, one of the most obvious routes towards an association between colour and emotion is the stereotype (e.g. redness = anger). The thought process for this type of association, which is sketched in Figure 7, involves a perception of the colour, some sort of cognitive appraisal (one of the colours is red, red is associated with anger, therefore...) and an appropriate response. In this case there would be no genuine emotional evocation, but there should be considerable agreement among informants, so long as the stereotype is a shared one. This would be expected to be different in, for example, Chinese cultures, where red is associated with good luck more than with anger.

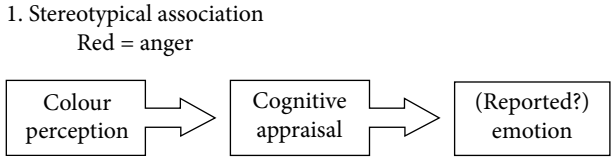

Figure 7. Diagram illustrating a potential route to colour-evoked emotions, in this case stereotypical associations

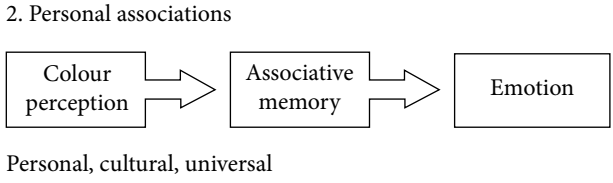

Figure 8. Diagram illustrating a second potential route to colour-evoked emotions, in this case personal associations

10.2 Personal associations

People will often say that a particular colour reminds them of a person, place or situation, and this is clearly another route towards a specific colour-emotion association, which is sketched in Figure 8. Here the route to emotion is via an associated memory. The colour evokes the memory, and the (genuine) emotional response is to the memory rather than the colour itself. The memory could be personal (e.g. the walls of the childhood bedroom, the colours of a favourite football team), cultural (e.g. corporate colours of a widely known product, associations suggested by popular media) or environmental. Linked with the environmental associations are common experiences which are highly likely to influence the colour-emotion associations of many people. The first is the association of brownish and greenish colours with mud, slime and faeces, generally regarded as unpleasant substances, which could explain the high scores for these colours in the "unpleasant" experiment. The second is the experience of distance. It is a well-known phenomenon in art that distant objects appear bluer and less saturated than close objects (aerial perspective: see Goldstein 2002; Troscianko, Montagnon, Leclerc, Melbert & Chanteau 1991). This may be a factor in the choice of "calming" colours, which possibly simulate the colours of a distant object. A third is the weather. On a sunny day colours appear more saturated and yellowish (Lovell, Tolhurst, Parraga, Baddeley, Leonards & Troscianko 2005) whereas on a cloudy day they are less saturated and more bluish. This could be a factor in the happy/sad responses as well as the mood-enhancing responses of Experiment 3. Finally, the time of day, especially the colour of the sky at dawn or sunset (Troscianko, Fennell, Benton & Baddeley 2009), could be a factor in the pleasant, mood-enhancing and calming responses.

Without asking specific questions on de-brief it is hard to estimate the relative strength of these different classes of association. One would expect that the personal associations would be relatively random in the associated colour, but all of the other associations, both cultural and environmental, are likely to be shared by the participant group used here and would result in agreement between them. Possibly the strongest associations would be established in childhood: that between mud/slime/faeces and unpleasantness would then be strongest whereas it is likely that the appreciation of sunsets might develop later. Note that this idea has been developed into a full-blown theory of colour preference choices by Palmer and Schloss (2011), called the "Ecological Valence Theory" (EVT).

10.3 Non-visual responses

A third, and possibly less well-known, route towards colour-emotion associations is illustrated in Figure 9, where a visual signal with a particular wavelength distribution evokes a response that is not strictly visual. The argument here is partly based on the James-Lange theory (see Gleitman et al. 1999) that emotions are essentially perceptual responses to internal bodily states (so fear does not *cause* butterflies in the tummy, fear

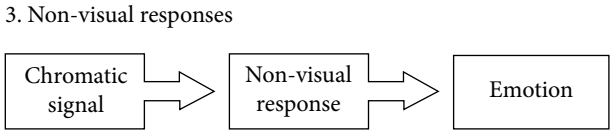

Figure 9. Diagram illustrating a third potential route to colour-evoked emotions, in this case non-visual responses

is butterflies in the tummy). Prinz (2004) has recently updated this description to talk of emotions as "valent embodied appraisals". In other words, if a particular stimulus evokes a particular bodily response, then this could in turn evoke an associated emotion. Two potential factors here involve the spectral content of the image. Recently a new set of light-sensitive cells has been found in the eye which contains the chemical *melanopsin*. The light sensitivity of these cells is different from conventional photoreceptors in that the light-sensitive pigment is contained in the body of the cell itself (Hankins, Peirson & Foster 2008). The neural pathways that emanate from this group of melanopsin-containing cells are thought to link with such mechanisms as the biological clock and the pupillary response system (in other words, neural mechanisms that care about the amount of overall light but not its spatial distribution). These mechanisms have in turn been linked to mood disorders such as Seasonal Affective Disorder (SAD, sometimes known as the "winter blues", Levitan 2007). Melanopsin also has a particular spectral sensitivity function, so that manipulating the spectral content of the illumination in a room could potentially have profound effects on the mood of the room's inhabitants. This is currently a topic of major interest amongst lighting designers (Tonello 2008).

Another potential non-visual factor is visual stress, in particular accommodative response (focusing). Some individuals benefit from using coloured lenses or filters during either reading or daily life (Wilkins 2003). Wilkins has suggested that restricting the spectral content of light entering the eye reduces unwanted brain activations which can result in headaches and migraines. However, another effect of restricting spectral input is to make the job of the accommodation system easier. Newton's well-known demonstration of the deviation of light of different wavelengths by a prism demonstrates that shorter and longer wavelengths of light are deviated by different angles, and the same is true in the optical system of the eye. The longer wavelengths (associated with red light) are focused towards the back of the eye and the shorter wavelengths (associated with blue light) more towards the front, a phenomenon known as *chromatic aberration*. One of the curious consequences of this is the phenomenon of *chromostereopsis* where the images of, say, a red and a blue object on the retina are in different relative positions in each eye, creating a retinal *disparity* which is interpreted as a difference in stereoscopic depth (similar to the illusion of depth obtained when

watching a 3D movie).[2] The upshot of this is that saturated blues (and purples) can actually appear further away than saturated reds and oranges. This distance effect potentially relaxes the eyes and gives rise to a feeling of relaxation/pleasantness. Humphrey (1976; 2006) offers some further ideas on how different colours, especially reds, can potentially affect us physiologically.

11. Some final thoughts

The results and arguments presented in this chapter bring forward a number of unanswered questions. A surprising result was that green tends not to be placed in the pleasant/relaxing/happy categories and in fact seems to evoke the opposite. Yet anecdotal experience would suggest that forest/pastoral environments are pleasant to be in (see, for example, Andrew Marvell's poem *The Garden*). Possibly this is relevant to another potential major factor in colour-emotion associations: the influence of context. The experiments presented here were performed in a dark, cool room in the depths of winter. As such, the pleasant associations would probably be those concerned with either warmth and heat (warm colours) or sunny weather. Maybe for green to have this association more than one shade has to be presented, or it needs to occupy a bigger portion of the visual field; in particular one could simulate the effect of sunlight on grass in a context where the less pleasant associations of yellow-green with pus and slime were downplayed. Clearly, in a context-free situation such as ours, these unpleasant associations of green must have predominated.

Another issue is the importance of the precise spectral content of the coloured sample. Our report of the chromaticity of the sample in CIE coordinates does not detail this (a given chromaticity is possible with an infinite variety of spectral distributions; these are called *metamers*), but chromatic-aberration effects like chromostereopsis will depend on it. At this stage it is not certain that the results found were due to the peculiarities of the particular spectral samples used (constructed from the phosphors of a CRT) or to the chromaticities used. It is hoped to address this issue in future experiments with more advanced display technology.

A final factor, particularly relevant to this chapter, is the relationship between emotional responses and colour preferences (see Palmer & Schloss 2011; Pitchford 2011). The potential confusion over the term *pleasant* suggests a similar problem with preference judgements: we might prefer a red to a blue if we require stimulation, but a blue to a red if we are feeling stressed. I would argue that emotion associations are

2. *Chromostereopsis* is easy to demonstrate on a computer. Create a slide with a red (255,0,0) and a blue (0,0,255) rectangle next to each other on a black background. Most people will see the red rectangle jumping out of the screen and the blue behind, although there are variations between observers which depend on the optical idiosyncrasies of the individual (see Winn, Bradley, Strang, McGraw & Thibos 1995; Faubert 1994).

more informative than preference judgements because they give more precise information about what is causing the judgement.

Some of the more far-reaching issues of this work have already been touched on. How well do these laboratory data map onto emotional responses to real-world stimuli? What do they tell us about the popular but controversial field of colour psychology? What can they tell us about the evolutionary importance of colour vision? It is hoped that these questions will be answered in future experimental studies.

Acknowledgements

This chapter is based on experimental work carried out by Lesley-Anne MacRae, Lindsay Shearer, Gemma Gallagher, Aisha Inam, Jacqueline Beattie, Natalie Bordon and Clare Moffat. The data and some of the ideas were previously presented at Vision Sciences Society meetings in Sarasota, Florida in 2006 and 2007 and published in abstract format (Simmons 2006; Simmons & Asher 2007). The author is supported in part by a grant from the ESRC/MRC ("Social Interactions: A Cognitive Neurosciences Approach": RES-060-25-0010).

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Colors and color adjectives in the cortex

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An important question in studies on color perception in humans concerns the extent to which lexical items related to colors affect color concepts. In the hope of shedding additional light on this longstanding debate, we propose a computational model of the convergence between visual and linguistic processing paths in the cortex, aimed at exploring the emergence of color concepts in pre-linguistic and linguistic phases of early human development. Three versions of the model, trained with color terms in three different languages, English, Berinmo and Himba, are compared.

1. Introduction

An important question concerning color perception in humans, the only possessors of language in the natural world, is whether lexical items related to colors affect color concepts (Davidoff 2001; Kowalski & Zimiles 2006). In the hope of shedding additional light on this vast and longstanding debate, we propose a computational model of the convergence between visual and linguistic processing paths in the cortex, which aims to explore the emergence of color concepts in pre-linguistic and linguistic phases of early human development.

This model is a system of artificial cortical maps, each built with the LISSOM (*Laterally Interconnected Synergetically Self-Organizing Map*) architecture (Miikkulainen, Bednar, Choe & Sirosh 2005). This approach is both simple, which allows the building of complex models of higher level cognitive functions, and adequately close to the biological reality of the cortex within limits that will be explained in Section 3.

A similar but simpler system was first introduced in Plebe and Domenella (2006) to model the emergence of object recognition. This approach has also been used to investigate color processing in the primary visual cortex (Bednar, De Paula & Miikkulainen 2005). It has recently been extended to simulate the acquisition of object names (Plebe, De La Cruz & Mazzone 2007). The architecture is almost entirely void of predefined functions, with all the functional organization in the cortical maps emerging through exposure to several sets of environmental stimuli. In a later stage of development, three different versions are specialized through exposure to color terms of

three different languages while looking at objects of the color named. One language is English, the other two are Berinmo, from New Guinea, and Himba, from Namibia. The reason behind this choice is the singular properties these languages possess, as has been reported by recent research. This will be discussed in the following section. Subsequently, the architecture of our model will be explained, followed by the details of the training procedures, and the presentation of the results.

2. Color terms and the brain

The domain of color terms has traditionally been a privileged terrain of debate in the universalism/relativism issue. Color is a conceptually well-circumscribed domain, without neat boundaries in it from a physical point of view. Some have therefore thought that the different ways in which colors are lexicalized in different languages can be easily understood as purely cultural and arbitrary options. Color terms have been taken as evidence in favor of the linguistic relativism thesis, whose best-known formulation is the Sapir-Whorf hypothesis, according to which language and culture have the power to determine the way we conceptually perceive the world. The reply of universalists has been to search for underlying regularities beneath the apparent lexical variation, where such regularities are mainly thought of as consequences of physiological constraints in the process of vision. Berlin and Kay (1969), in particular, proposed the well-known hypothesis that basic color terms follow a rigid evolutionary pattern, that is that there would be precise rules governing how color terminology expands from the minimal repertoire of two terms (all languages have at least words for black and white) to repertoires of eight or more terms. Moreover, each of the languages examined would select virtually identical focal hues for the same basic colors. In other words, putting aside minor variations, languages would differ from each other just in the number of colors they give a name to, while universal preferences would dictate the sequence of lexicalized color categories and the focal hue for each category. These conclusions have been rejected from the relativist side with the argument that Berlin and Kay's assumptions and methodology have the effect of discarding data which conflict with their over-regularized picture. According to Saunders and van Brakel (1997) and Lucy (1997), it is far from clear whether each language has a clear-cut color domain, with color terms behaving in the simple referential way portrayed by Berlin and Kay; in particular, Saunders and van Brakel argue, Berlin and Kay's use of the Munsell color system in order to assess how color terms are used is a rather abstract procedure and far from real linguistic practice.

More recently, additions to the debate have come from investigations of two languages with just five basic color terms: Berinmo, which is spoken in Papua New Guinea, and the Himba language, which is spoken in a completely different part of the world, Northern Namibia. In both of these cultures, speakers seem to be much better

at recognizing prototypical examples of their own linguistic color categories rather than poor examples, regardless of these items' status in English color categories, a result difficult to explain according to the idea of universals in color terms (Davidoff, Davies & Roberson 1999; Roberson, Davidoff & Davies 2000; Roberson, Davidoff, Davies & Shapiro 2004, 2005).

We believe that the current debate can benefit from the new data available on color processing, and on how vision and language interact in the brain. While a common view might associate universalism with the color processing functions performed by the human brain, and relativism with cultural influence, modern neuroscience does not support this view. Culture is indeed a brain product, thus typically human, precisely because our brain is so particularly plastic as to adapt its functions during development (Mareschal et al. 2007; Quartz 2003). Adopting a neurocomputational perspective, therefore, does not mean ruling out the influence of culture; on the contrary, our aim is to trace where in brain mechanisms the genetic endowment for color processing and the functional plasticity resulting from cultural exposure meet.

Vision is certainly the best known function in the brain, and the knowledge of how color is processed has advanced greatly; for recent reviews see Solomon & Lennie (2007); Conway (2009). However, simplifying greatly, we can say that the known details in the understanding of color processing gradually diminish as we move from the early processing stages in the visual pathway to that in higher cortical regions. Thus we have a good picture of chromatic properties of cells in the retina and the geniculostriate visual pathway (Lennie & Movshon 2005), and fairly good evidence concerning organization for color processing in areas V1 (Tootell, Switkes, Silverman & Hamilton 1988; Landisman & Ts'o 2002; Xiao, Casti, Xiao & Kaplan, 2007) and V2 (Xiao, Wang & Felleman 2003; Lim, Wang, Xiao, Hu & Felleman 2009). Color signals in higher areas have been extensively investigated in monkeys (Conway, Moeller & Tsao 2007). Results for humans are partial and controversial, with regions like V4 reported as being strongly involved in color processing (Zeki 1983; Lueck et al. 1989), with functions such as color constancy (Walsh, Carden, Butler & Kulikowski 1993) and color awareness (Morita et al. 2004), not directly comparable with homologous regions in primates (Zeki, McKeefry, Bartels & Frackowiak 1998), probably embedded in a wider area involved in color analysis (Wandell, Brewer & Dougher 2005; Brewer, Liu, Wade & Wandell 2005). It is clearly overly simplistic to expect that the perception of color be associated with the activity of single cells or even a single visual area; rather, the processing of color is likely to be spread over quite a large part of the brain's visual pathway, as well as in other areas behind it. It is very likely that aspects of color in humans would be strongly influenced by those upper areas (Brouwer & Heeger 2009), where, unfortunately, our understanding is still not clear. Higher regions of the visual pathway in humans are also those areas where feedback from language may play an important role.

3. The proposed model

The path we take to understanding the interaction of color perception and languages in the brain is through computational models of the visual and auditory paths in the cortex. In the structure of the model there is a minimum amount of mathematical design, specific to the functions to be acquired. Most of the efforts made have been in the inclusion of plasticity mechanisms, and in the reproduction of a coherent hierarchy of cortical maps.

For this purpose, we have chosen a mathematical abstraction of cortical maps which is faithful enough in reproducing a biological learning mechanism, through the combination of Hebb's principle and neural homeostasis, yet simple enough to allow the building of high level models. The LISSOM (*Laterally Interconnected Synergetically Self-Organizing Map*) architecture (Sirosh & Miikkulainen 1997; Bednar 2002) is a two-dimensional arrangement of neurons, with intracortical excitatory and inhibitory connections. An example of a LISSOM map is given in Figure 1. The model's basic architecture is made up of an array of two-dimensional computational units that correspond to the vertical columns found in the biological cortex. These columns act as functional units that respond to similar types of inputs. Each unit receives input from a neighboring receptive field in the model's simulated thalamic input, or from a lower cortical map. The cortical units connect laterally with cells of the same cortical map, that can contribute in the activation of the receiving cell, with excitatory or inhibitory effects. This aspect is one of the key characteristics of the LISSOM architecture in that similar connections have been found in neural anatomy, and because lateral interactions are known to play an important role in building representations of the input patterns in the mature organization of biological cortical maps. The model is trained in a series of phases in which it is exposed to different types of stimuli. During each training phase, the synaptic weights of all connections are changed according to Hebbian plasticity, combined with homeostasis, to keep the average firing rate constant. This procedure, once again, mimics the plasticity of cortical circuits in a basically realistic way (Turrigiano & Nelson 2004).

As training proceeds, individual neurons develop an initial response in the form of a weighted sum of the activations in its afferent input connections. These initial patterns of activation are subsequently focused by the cortical neurons into a localized response on the map (see Figure 1). Once the stabilization of the pattern has taken place, the connection weights of the cortical neurons are changed. As the progression of the process of self-organization occurs, these neurons become more non-linear and weak connections are eliminated. The result is the emergence of a self-organized structure that is in dynamic equilibrium with the input.

While in principle it is possible to model fine details of cortical signal processing with the LISSOM architecture, as has already been done in several studies (Miikkulainen et al. 2005), the level of realism of this model has precise limitations, primarily for three main reasons. The first is the necessity to keep the computation manageable

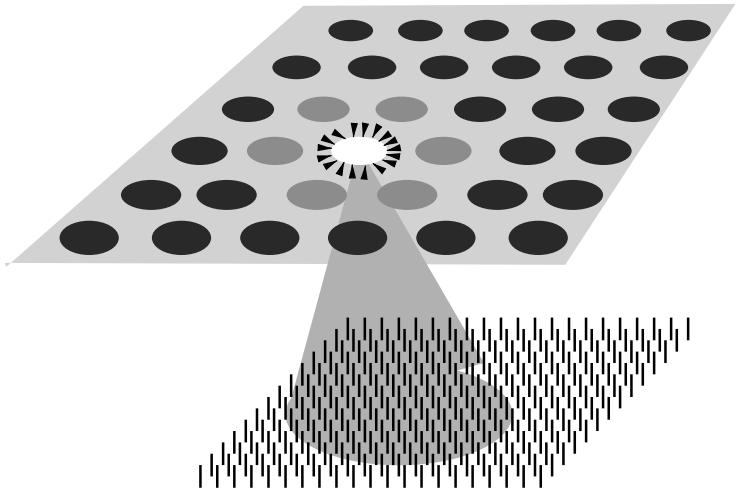

Figure 1. The LISSOM neural concept, with details of afferent connections as receptive fields, and lateral excitatory and inhibitory connections for a single neuron (in white)

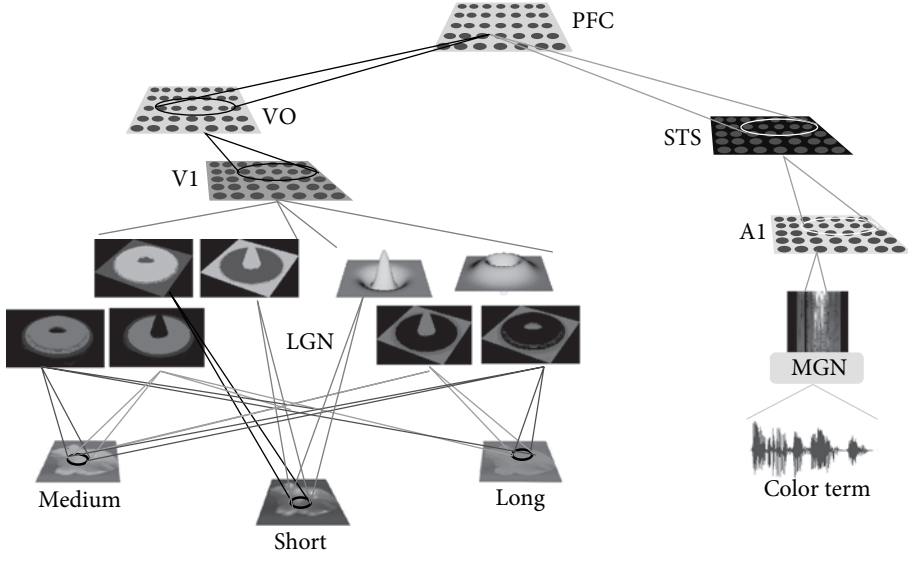

Figure 2. Overall scheme of the model, composed by LGN (*Lateral Geniculated Nucleus*), MGN (*Medial Geniculated Nucleus*), V1 (*Primary Visual*), A1 (*Primary Auditory*), VO (*Ventral Occipital*), STS (*Superior Temporal Sulcus*), PFC (*PreFrontal Cortex*)

in a complex model involving important cognitive functions. The second is due to the general lack of knowledge that researchers in the field still have of aspects of the cortical

hierarchy, which prevents us from coming up with a detailed reproduction, especially in the auditory path. The third is the overall economy of the experiment, in which several processes, although being involved, do not significantly affect the main goal of the investigation, which is the influence of language on color perception, and as such might be simplified in their essence.

An outline of the modules that make up the model is shown in Figure 2. There are two main paths, one for the visual process and another for the auditory channel.

In the visual path the external incoming signals are converted from their standard color representation into long, medium and short wavelength components, using filters with frequency responses corresponding to those of retinal receptors (Stockman, Sharpe & Fach 1999; Stockman & Sharpe 2000). The LGN block in the model actually simulates the responses of both the ganglion cells of the retina and the cells in LGN. There are two main types of receptive fields: center surround, where two concentric areas have excitatory/inhibitory effects, connected to different combinations of chromatic signals, and coextensive, without a suppression area, but with one chromatic channel acting as inhibitory with respect to an opposite channel. The cortical process proceeds to the primary visual map V1 and the color center, here called VO (Brewer et al. 2005). Even though the processing of contours and forms is not essential in this experiment, for the sake of realism the model is constructed to allow the combination of color processing and the geometric local feature processing characteristic of V1.

The hardwired extracortical MGN component is just a placeholder for the spectrogram representation of the sound pressure waves, which is extracted using tools of the *Festival* software (Black & Taylor 1997). It is justified by evidence of the spectro-temporal processes performed by the cochlear-thalamic circuits (Escabi & Read 2003). The thalamic afferents are collected by a LISSOM module, acting as the auditory primary cortex. The next map in the auditory path of the model is STS, because the superior temporal sulcus is believed to be the main brain area responsive to vocal sounds (Belin, Zatorre & Ahad 2002). The auditory path in the model is an oversimplification of what in the cortex is involved in the recognition of utterances. It is clearly not essential in this work to reproduce full-blown linguistic capabilities, in that our focus is on the learning of a small class of words, the color terms of a language. However, we avoid treating the linguistic input in an abstract symbolic way, because including the gradual learning of language, starting from phonology, allows a fairly realistic simulation of what is experienced by learners of different languages.

The model map where the ventral visual path and the auditory path meet is PFC. As pointed out earlier, there are actually several areas where visual and auditory signals converge, and more than one area is involved in color perception and categorization. The reason for calling this model map PFC is that it is the upper map in this system hierarchy, where categorization is expected to express the best possible abstraction (Fuster 2001, 2002). Needless to say, biological PFC deals with larger sets of world information and behavioral functions than those used in this model.

4. Experiments and results

The model is exposed to a variety of stimuli, in different stages of its development, that to some extent parallel periods of human development from the pre-natal stage to the initial language acquisition stage. While the early developmental phase is common to all the models, in the linguistic phase three different models are developed, corresponding to English, Berinmo and Himba. Initially, only V1 and A1 maps are allowed to modify their synaptic weights. The stimuli presented to V1 are synthetic random blobs that mimic waves of spontaneous retinal activity that are known to play a fundamental role in the ontogenesis of the visual system (Mastronarde 1983; Katz & Shatz 1996; Thompson 1997; Gödecke & Bonhoeffer 1996; Chapman, Stryker & Bonhoeffer 1996).

In this first training period, the blobs presented as input to the model V1 are elongated along random directions to stimulate orientation selectivity, with random hues, size, position and intensity. The A1 model map is exposed to short trains of waves sweeping linearly around a central frequency. Time durations, central frequencies and sweeping intervals are changed randomly.

The next period of development involves higher model maps VO and STS. The visual stimuli are taken from the McGill Calibrated Colour Image Database (Olmos & Kingdom 2004), using random samples from the Flowers and Landscape collections, and simulate natural scenes captured by the eyes after birth. The auditory stimuli are synthesized waves of the 7200 most common English words[1], with a length of three to ten characters, or Spanish words for the Berinmo and Himba versions of the model. All words are converted from text to waves using Festival software (Black & Taylor 1997), with cepstral order 64 and a unified time window of 2.3 seconds. These patterns represent exposure to the native language, in the period where phoneme categorization begins to take place without grasping the meaning of utterances. Obviously Spanish is a very crude approximation for the Berinmo and Himba classes of sounds; however a higher degree of fidelity at the phonetic level is meaningless for the scope of this experiment.

The last stage of the experiment simulates events in which colored patches are viewed, and a word corresponding to its basic color category is heard simultaneously. Note that in the previous developmental stage, the model was stimulated in both its visual and auditory paths as well. However, it is clear, with reference to the structure of the model in Figure 2, that the two paths cannot interact with each other until maturation of the upper PFC map. In this stage, that roughly corresponds to the beginning of language learning in a child, the auditory process is already able to categorize phonemes of the mother tongue, and the visual system has developed the main capability of hue and form detection. It is now the turn of the abstract PFC map to organize itself by collecting afferents from the ends of the visual and auditory paths, in response to stimuli that replicate the naming of colors. Each color term is converted from text to waves using the standard male American and Spanish speakers in the Festival software,

1. The words are taken from http://www.bckelk.uklinux.net/menu.html

replicated at several speeds, using the Duration_Stretch parameter in Festival. During each exposure, three different shaped patches are presented in the field of view, each colored with a random variation inside the range of a single basic color, avoiding the boundaries. The position of the three shapes is varied inside the visual field of view. There are in total nine different exposures for each basic color, each exposure comprising three different patches in one view. The exact positions and range of the samples in color space are given in Figure 3.

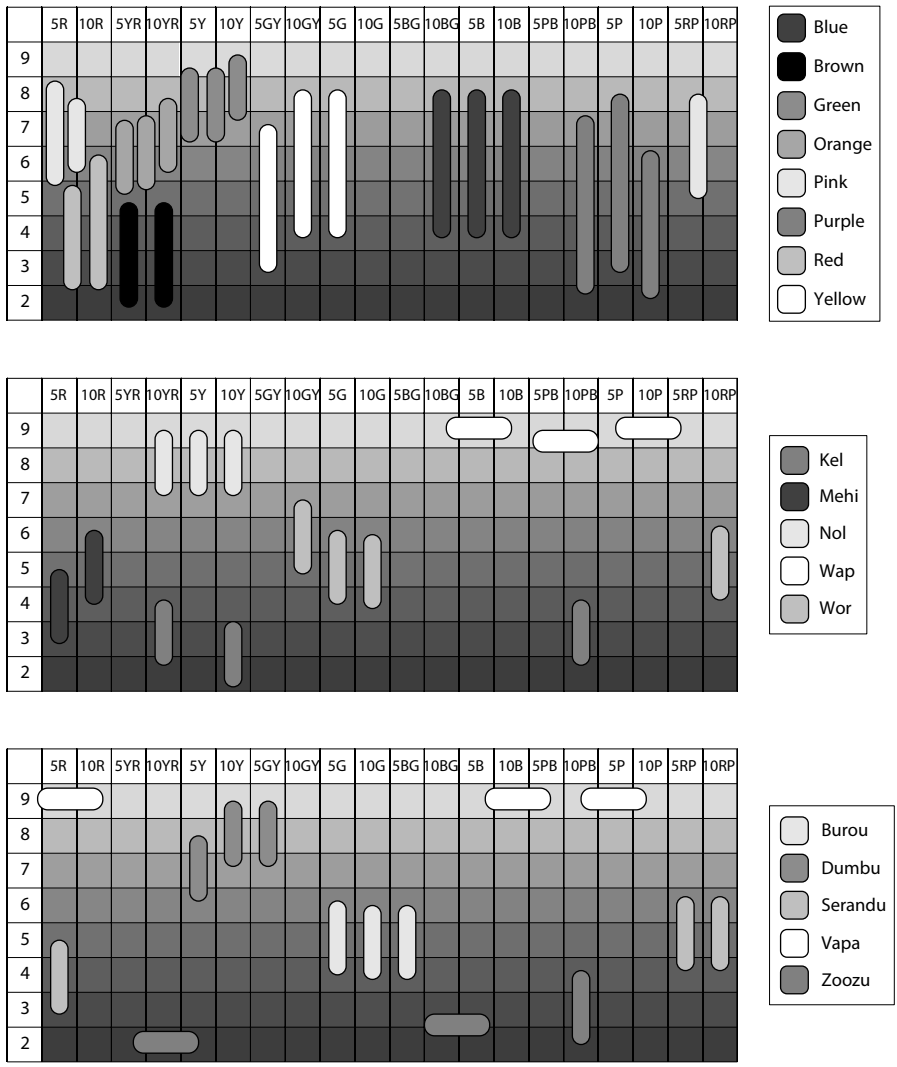

Figure 3. Locations in the standard Munsell chart of the colors used as stimuli. From top to bottom: English, Berinmo and Himba. For each basic color there are in general three separate areas of colors for the samples; the extension of each area signifies the range of variability allowed for each sample patch

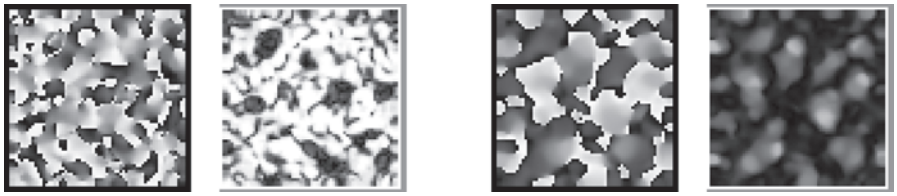

Figure 4. Selectivity domains developed in the model's V1 map. The two maps on the left depict orientation domains, the two on the right the hue domains. In each pair of pictures, in the left map the intensity of the gray level codes for the kind of stimulus to which the neuron in that position is sensitive; in the right map the gray level is the indication of the amount of selectivity. Orientation is visualized in gray with black as horizontal orientation to white as vertical orientation. Hue is coded as black corresponding to the longest wavelength, and white to the shortest. In the maps of amount of selectivity, black signifies no selectivity at all, white peak selectivity for a single cue

At the end of development, different organizations are found in the lower maps that enable the performance of processes that are essential to vision, and that are similar to those found in corresponding brain areas. The model's V1 map organized orientation selectivity, with responsiveness of neurons to oriented segments. Overlapped with orientation, we find an organization with respect to color, with cells sensitive to specific hues, results already obtained in Bednar et al. (2005).

It is possible to visualize this neural organization by stimulating the maps with patterns that change continuously along the dimensions of interest (orientation, hue), recording for each neuron the kind of stimuli for which it is most selective, and displaying this stimulus, coded in gray level, at the position of the corresponding neuron in the map. The resulting domains of selectivity, made visible with this technique, are shown in Figure 4. It can be seen how the domains of orientation are arranged over repeated patterns of gradually changing orientations, broken by a few discontinuities, resembling the ordering known to be found in the biological primary cortex (Blasdel 1992; Vanduffel, Tootell, Schoups & Orban 2002). As has been said before, this property is not essential to the experiment, but it is important to obtain in that it demonstrates one of the realistic aspects of the model, since it is the chief organization in biological V1. In Figure 4 it can be seen that the organization of hue preferences is also on a smooth and regular map; however the patches of selective units are much more scattered inside the map, and often overlap with units that display poor orientation responsiveness. Moreover, patches of hue sensitive units tend to encompass the whole range of hues by close peak neurons. This feature resembles the distribution of hue cells found in primate V1 (Xiao et al. 2007).

Having proven in V1 the possibility of overlapping features necessary for full-blown vision, like orientation selectivity, with just color processing, in the next map, named VO, no functions other than color have been addressed. It is therefore much

smaller than V1, 16 x 16 versus 64 x 64, with larger receptive fields, covering a wide portion of the visual field. At the end of the training most neurons in VO respond to specific hues, regardless of intensity. This is one of the basic features of color processing. Color constancy is crucial in object recognition and is known to develop somewhere between two and four months of age (Dannemiller 1989). The kind of mapping found in A1 is typically tonotopic, and encodes the dimensions of frequency and time sequences in a sound pattern. This is known to be the main ordering of neurons in biological A1 (Verkindt, Bertrand, Echallier & Pernier 1995).

In this model, V1 and VO represent the contribution to color perception that is independent of language. Since their development is strongly related to the external stimuli, there might be differences even at this level, due to chromatic differences in the environments, especially in societies where the dominant background scenes are natural; however this has not been tested in this experiment.

Our aim has been to compare the effect of language in the higher cortical maps involved in vision, here included in what we named PFC, which is slightly larger than VO and STS, to allow a finer distribution of color responses combined with linguistic inputs. The patterns of hue selectivity of each language model are compared with VO hue responses in Figure 5, using the same method as for V1 and VO.

The overall distribution of hues in PFC is not much different from that in VO, and the main hue domains are the same for the three languages; the cultural effect appears mainly at the boundaries in between, which differ in the three models.

This map could be further analyzed using the concept of population coding, where assemblies of neurons in one map co-operate to code overlapped concepts. We searched for populations coding the color categories of the language-specific basic color terms. The analysis is performed using all the stimuli with three patches, described in the last training stage. A neuron is found to co-operate in the population coding a specific color if its firing is consistently higher in the sample set of that color, with respect to the set of all other samples. The results of the population coding analysis are shown in Figure 6.

For each language, the basic colors span the entire PFC map evenly, crossing the multiple hue domains in which the color is represented. All neurons that are not shown in any color coding are clearly activated by more than one basic color, in its possible

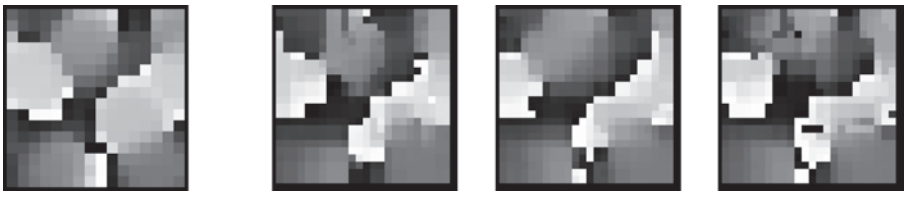

Figure 5. Hue selectivity domains in the PFC map for the different language exposure of the models, and the model VO map (leftmost picture). From the second left to right: English, Berinmo, Himba

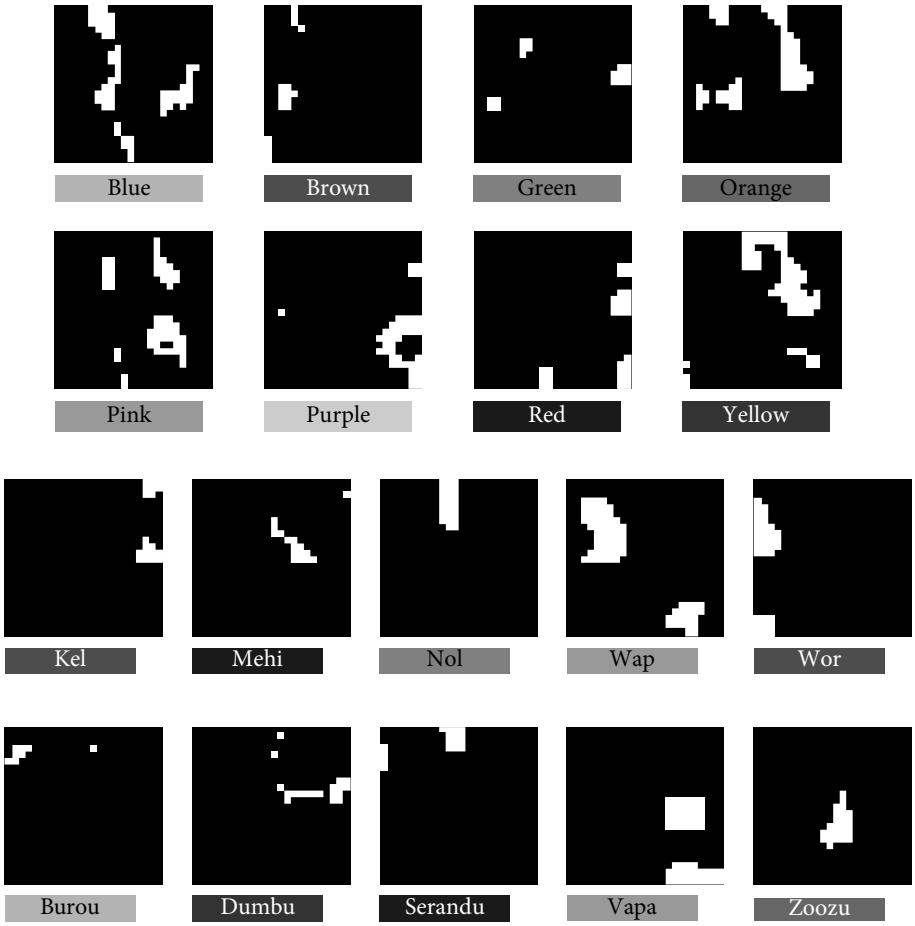

Figure 6. Population coding of basic colors in the PFC map of the three language models, from top to bottom: English, Berinmo, Himba

appearance, and therefore contribute to percepts at a finer level than basic categories. The distribution between neurons recruited for coding basic colors only, or shared by multiple colors, is considerably different between languages. Even for colors that share most of the color space, like Berinmo *wor* and Himba *dumbu*, the population coding is quite different. This is possible, despite the similarity of the PFC hue domains, thanks to the redundancy of the domain itself. Moreover, also to be taken into account is how the model's PFC keeps its association with the phonological form of the words as well.

5. Conclusions

We have developed a neural model of part of the visual cortical and auditory paths, merged in a higher area, that can be used to simulate the effect of language on the perception of colors. The model is quite accurate in including aspects critical to color perception, like the combinations of color-opponent cells, connected to the *L–M–S* cones. It is much less faithful in reproducing components not essential here, like the phonological processing of words. The main result observed is the development of color discrimination abilities, including color constancy, purely by exposure to the environment, and the modulation of the higher coding of colors by language. The model demonstrates that it is possible to achieve close similarity in the distribution of selectivity to hues in the higher map, in different language models, despite large differences in the population coding of categories bound to the basic color terms. Work in progress with the model includes the investigation of the effect of different landscapes in the development of color processing in the lower areas, as well as testing with large populations of models in each language, rather than with individuals, in order to compare variability inside and between languages.

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SECTION 7

Colour vision science

Preface to Section 7

The chapters in this section give a flavour of current topics within contemporary colour vision science. The first partially returns to the topic of categorical colour perception dealt with in Section 4. Sowden and colleagues look at perceptual learning: a very specific form of learning where improvement is shown with practice in very simple tasks such as judgements of the orientation of a line. Sowden et al. find that this type of learning is specific to both the retinal location and the chromatic hue of the practice stimulus, rather than being generalized across the visual field and to stimuli of different hue. They argue that this type of perceptual learning could be the basis for colour categorical perception. Wuerger and Parkes, on the other hand, deal with another contentious issue in vision science: the concept of unique hues. These are hues which are, in theory, 'pure' colours. For example, unique red is a red that is neither yellowish nor bluish (a red, of course, can never be greenish according to opponent-process colour theory: that would be a grey!). Wuerger and Parkes explore which combinations of cone photoreceptor excitations (precisely measured with their calibration techniques) give rise to these unique hues and proceed to look at the brain activations which support them, using the technique of functional Magnetic Resonance Imaging (fMRI). This chapter gives us a glimpse of the future of colour vision science: with her technique, Wuerger claimed (in response to a question put to her at the PICS08 conference) that she was able to "read the minds" of people viewing colours. In other words, by looking at the pattern of brain activations, the colour being perceived by the observer, lying prone in the MRI scanner, could, in theory, be ascertained by the scanner operator. What new directions in colour studies, we wonder, will be followed by the time of the next PICS conference in 2012?

Finally, as a coda to the book, Ronchi gives us a brief introduction to the concept of visual balance and how this might be useful in measurements of the colour appearance of complex objects.

Chromatic perceptual learning

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Perceptual learning has been shown on a wide variety of achromatic visual tasks. However, very little work has explored the possibility of improvements on chromatically based tasks. Here, we used a transfer of learning paradigm to assess the specificity of improvements at discriminating the orientation of a chromatically defined edge presented in luminance noise. Chromatic thresholds were estimated for two different hues and retinal locations, before and after a ten day training period. During training observers discriminated the orientation of a chromatic edge at just one location and hue. Whilst performance improved following training, these improvements failed to transfer across either retinal location or hue. Our findings suggest that improvements in chromatically-mediated discrimination may involve plasticity at early, retinotopically mapped, stages of visual analysis. Further, they suggest that categorical perception of colour might in part arise from chromatic perceptual learning at colour category boundaries.

1. Introduction

Perceptual learning involves an improvement in some perceptual judgement with practice. During the last twenty years there have been numerous demonstrations that the detection or discrimination of a range of visual attributes improves as a result of training (cf. Fahle & Poggio 2002). For instance, the ability to judge simple attributes such as line orientation (Shiu & Pashler 1992), vernier separation (Fahle & Edelman 1993) and luminance contrast (Sowden, Rose & Davies 2002) have all been shown to improve. These improvements are frequently found to be specific to dimensions of early visual analysis such as retinal position and stimulus orientation. Consequently, the inference is often made that the learning results from neural plasticity at the early stages of visual analysis that are selective for these dimensions of visual analysis.

However, this inference has been challenged and it has been suggested that permanent changes to early visual analysis to enhance performance on a particular task would interfere with performance on other tasks that are reliant on the same early analysis. Instead, it has been argued that later stages learn to attend those outputs from early analyses that provide the optimal information for solving the task at hand (cf. Mollon & Danilova 1996; Petrov, Dosher & Lu 2005). Despite this argument, a variety of neuroimaging studies provide convergent evidence for an early locus of perceptual learning (e.g. Furmanski, Schluppeck & Engel 2004; Pourtois, Rauss, Vuilleumier & Schwartz 2008; Schwartz, Maquet & Frith 2002).

A third view extends previous ideas by suggesting that later stages of analysis dynamically modify those earlier stages that optimize task performance whilst that task is being carried out (see Sowden & Schyns 2006 for a review). In this way, changes are made only to as early a level of analysis as necessary to perform a given task and only on a temporary basis, thereby avoiding interference with the performance of other tasks reliant on those same stages of analysis.

Despite the wealth of studies showing perceptual learning, and the advances made in understanding its mechanisms, to our knowledge there has been almost no work conducted to explore the possibility that the chromatic perceptual system can exhibit learning in the same way as seen for many tasks performed using the achromatic system.

Consistent with the possibility of chromatic perceptual learning, evidence from categorical perception (CP) research suggests that our colour perception may change as a result of experience. Categorical perception refers to an enhanced ability to discriminate stimuli that fall either side of a category boundary compared to equally different stimuli that fall within a category. For instance, speakers of languages that differ in their colour vocabulary show differences in their performance on a variety of colour tasks that probe colour CP, and these differences are predicted by their respective colour vocabulary (Roberson, Davies & Davidoff 2000). Further, category training results in the development of categorical perception effects at newly learned category boundaries, again consistent with the possibility that chromatic perception may change with experience (Özgen & Davies 2002). Interestingly, recent work that explores whether CP is equivalent in the left and right visual fields finds that colour CP is most marked in the right visual field. As initial visual processing of the right visual field is carried out by the left hemisphere of the brain, where language centres typically reside, it has been suggested that colour CP results from an online dynamic influence of language on the visual analysis of colour (Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies 2007; Siok, Kay, Wang, Chan, Chen, Luke & Tan 2009). Consistent with this is evidence showing that as children acquire their colour vocabulary so colour CP effects change from the left to the right visual field (Franklin, Drivonikou, Clifford, Kay, Regier & Davies 2008). This suggestion, of an online influence of higher level language processing on earlier perceptual processing, is consistent with current ideas about the locus of perceptual learning effects.

Consequently, in our experiments we sought to test directly whether chromatic perception can change as a result of training and to explore the likely neural locus of these changes. Specifically, we tested the specificity of chromatic perceptual learning to retinal position and hue.

2. Method

2.1 Participants

Fifteen observers (mean age 24; range: 19–31) were paid to participate. All had normal colour vision as assessed by the City University Colour Vision Test (Fletcher 1980).

2.2 Apparatus and stimuli

Participants sat 57 cm away from and at eye-level to a 21-inch Eizo Flexscan F980 CRT monitor (CIE, 1931, x,y phosphor co-ordinates: $x_{red} = 0.614$ $y_{red} = 0.335$; $x_{green} = 0.277$ $y_{green} = 0.599$; $x_{blue} = 0.155$ $y_{blue} = 0.072$). Stimuli were generated by a Cambridge Research Systems (CRS; Rochester, UK) Visual Stimulus Generator (VSG) 2/3 graphics card. This uses a 12-bit per gun resolution palette-based graphics system to generate colour stimuli. The monitor and VSG system were calibrated using proprietary CRS software in combination with a CRS ColorCal colorimeter. Calibration involved measuring (in CIE 1931 Yxy co-ordinates) the response of the red, green and blue monitor guns in isolation and combination throughout their response range, thereby providing information on the monitor phosphor co-ordinates (in CIE 1931 xy co-ordinates as listed above), the dark point for each gun, and allowing calculation of the gamma function for each gun in isolation and their combination. This calibration information was used to define the monitor gamut (the region of colour space that the monitor can reproduce) and to ensure accurate and high resolution reproduction of the desired colours. The chromaticity and luminance co-ordinates (CIE, 1931, Y,x,y) of the resultant stimuli were then verified using the ColorCal colorimeter. Participants' responses were made with a game pad and they received auditory feedback.

Stimuli consisted of two semi-circles of colour abutted to make a circle of 10° diameter displayed against a luminance matched background (mean luminance 30.5 cd/m^2). The two halves of the circle were designed to be isoluminant. Nevertheless, due to display non-uniformity over space and time, and variation in the isoluminant point with retinal location (Schiller, Logothetis & Charles 1991), it is possible that there may be very small residual luminance differences that could be used by observers to detect the chromatic boundary. To prevent this, on each trial, the stimuli were embedded in Gaussian luminance noise, which serves to swamp any residual luminance signal that could be used to detect the boundary (Snowden 2002). A fixation spot was always present in the centre of the screen.

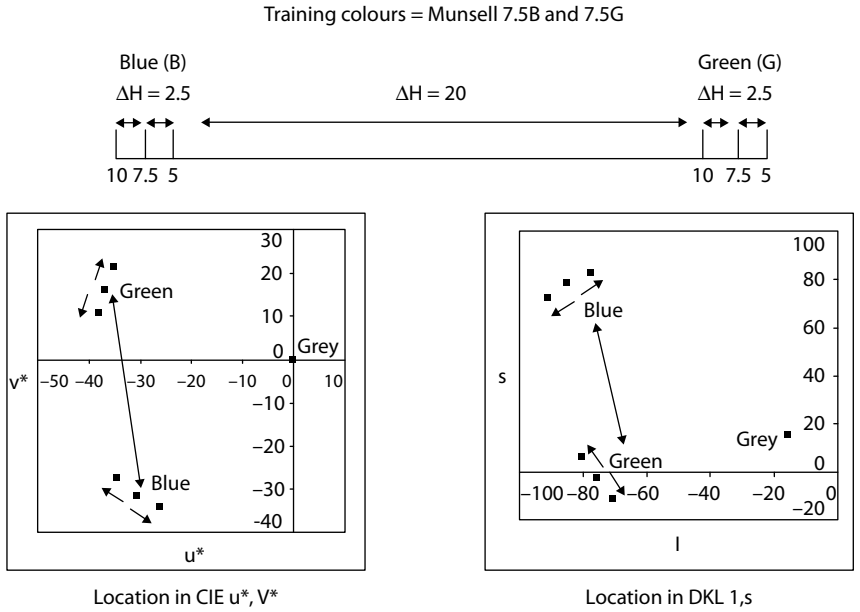

Figure 1. Positions of training and test stimuli in colour space. The training colours were Munsell 7.5G and 7.5B (value/chroma 6/6). The top panel is a linear representation of a portion of Munsell hue space showing the 2.5 hue unit separation between the 'near' hues and the 15 hue unit separation between the closest green and blue hues experienced during testing. The left and right lower panels show these same colours represented in CIE and DKL colour spaces

In separate trials, stimuli were presented at two locations. These locations were centred 7° from fixation in the upper right and lower right quadrants of the visual field. The centre-to-centre separation of the two locations was 9.9°.

Stimuli were drawn from two sets of three Munsell colours – blues (5B, 7.5B, 10B), and greens (5G, 7.5G, 10G), at constant Chroma and Value of 6/6. See Figure 1 for the locations of the stimuli in CIE and DKL colour spaces.

2.3 Design

Observers were randomly allocated into one of four training conditions that varied the training stimulus location (top or bottom right display quadrant) and the training hue (7.5G 'Green' or 7.5B 'Blue'). Thus, the four training groups were designated top green, top blue, bottom green or bottom blue.

On day 1 and day 10, observers' discrimination thresholds for both sets of colour stimuli (green and blue) were measured at both locations (top and bottom) in order to assess their pre- and post-training thresholds. Between these measurements, on days 2

to 9, observers were trained just at their training location with their training hue. Thus, we were able to measure the effect of training on chromatic thresholds at the training hue/location and the extent of generalization of learning to another location, to other hues in the same colour category ('near' ± 2.5 Munsell hue units relative to the training hue) and to hues in a different category ('far' 17.5, 20 or 22.5 Munsell hue unit difference from the training hue).

2.4 Procedure

The task was to discriminate whether the boundary between the two colours sloped to the left or right (see Figure 2).

To focus on 'low-level' perceptual analysis we selected a large orientation difference (90°), which produces threshold measures that are similar to those for detection (Thomas & Gille 1979). The discrimination thresholds were measured using the ZEST algorithm (King-Smith, Grigsby, Vingrys, Benes & Supowit 1994)[1], which was set to

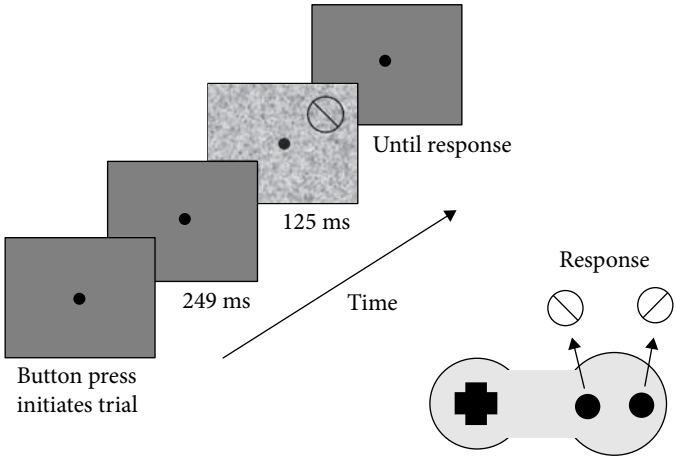

Figure 2. Schematic representation of the trial structure. The observer initiated each trial by pressing a button. After 249 msec the stimulus was briefly presented (125 msec) such that the observer would not have time to move their eyes from fixation to the stimulus. The observer used the buttons on the gamepad to indicate whether the colour defined boundary was tilted left or right

1. The ZEST algorithm is a Bayesian adaptive threshold estimation procedure that continuously modifies an assumed *a-priori* probability density (pdf) function, which represents the probability that threshold is at each of a range of levels of stimulus intensity (or chromatic difference as used here), on the basis of the preceding response, and sets the difficulty of the next trial to be the mean of the current pdf function. In this way all of an observer's previous responses are taken into account in setting the difficulty of the next trial.

converge on threshold at 82% correct discrimination. Three ZEST runs were randomly interleaved lasting 32 trials each and threshold was estimated as the average of the three runs. In this case the algorithm varied the size of the hue difference between the two halves of the circle around the current threshold measurement point along a linear line through colour space that also passed through the other 'near' points for that hue category.

The order of measuring the different thresholds for the various hue/location combinations on Day 1 was randomized for each participant and then held constant when the measurements were repeated on Day 10.

On days 2–9 participants completed six blocks of training (96 trials per block comprising three randomly interleaved ZEST runs of 32 trials each) on their training colour at their training location.

3. Results

Statistical analysis was conducted using Analysis of Variance (ANOVA) with Bonferroni corrected post-hoc tests. The results of the ANOVA analyses are reported in Tables 1 and 2, with p-values for the post-hoc tests shown in the text. Below we describe the statistically significant findings.

3.1 Transfer across location

We explored the effects of training on thresholds for the trained and untrained locations and on hues in the same region of colour-space (see Figure 3).

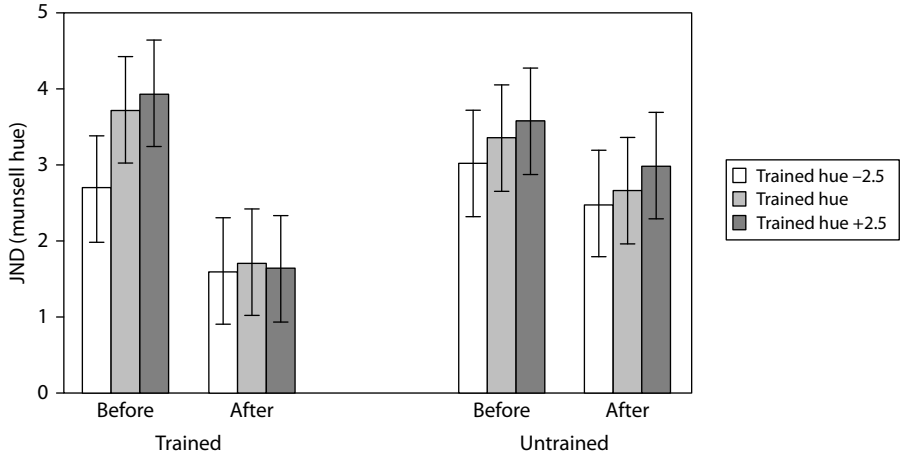

Figure 3. Graph to show threshold (in Munsell hue units) for discriminating the orientation of a chromatically defined edge before and after training. Separate bar charts are shown for trained and untrained retinal locations and separate bars are shown for the training hue and adjacent 'near' hues

Table 1. Statistically significant results of three-way ANOVA to explore the effects of training on thresholds for the trained and untrained locations and on hues in the same region of colour-space (time (2) – pre-training, post-training; location (2) – trained location, untrained location; near hue (3) – –2.5, 0 and +2.5 Munsell hue steps relative to the training hue). The Greenhouse-Geisser correction to the degrees of freedom is made when the assumption of sphericity is violated (assessed by Mauchley's w)

Effect	*F*	*df*	*p*	Partial Eta2	Observed power
Time	7.62	1,14	<0.05	0.35	0.73
Near Hue	5.72	1.24, 17.43	<0.05	0.29	0.83
Time x Location	7.72	1,14	<0.05	0.36	0.73
Time x Location x Near Hue	3.35	2,28	<0.05	0.19	0.56

In general, thresholds decreased following training (main effect of time; see Table 1). In other words, participants become better at the task with practice.

Overall performance also differed between the 'near' hues (main effect of near hue; Table 1), with better performance on the –2.5 hue than the +2.5 hue ($p < 0.05$). Of particular interest, thresholds decreased significantly at the trained location ($p < 0.0005$) but not at the untrained location ($p = 0.39$) (interaction between time and location; Table 1).

Finally, for the trained but not untrained location, before training thresholds for the –2.5 'near' hue were significantly lower than for the 0 or +2.5 hues (*p's* < 0.05), which did not differ ($p = 1.0$). After training none of the thresholds differed significantly across the near hues (*p's* = 1.0) (interaction between time, location and near hue; Table 1).

3.2 Transfer across colour

We explored the effects of training on thresholds for the trained and untrained colours (blue or green) and on hues in the same region of colour-space (see Figure 4).

In general, thresholds decreased following training (main effect of time; Table 2). In other words participants become better at the task with practice.

Overall performance also differed between the 'near' hues (main effect of near hue; Table 2), with better performance on the –2.5 hue than the 0 hue ($p < 0.05$). Of particular interest, thresholds decreased significantly for the trained colour ($p < 0.0005$) but not for the untrained colour ($p = 0.12$) (interaction between time and colour; Table 2).

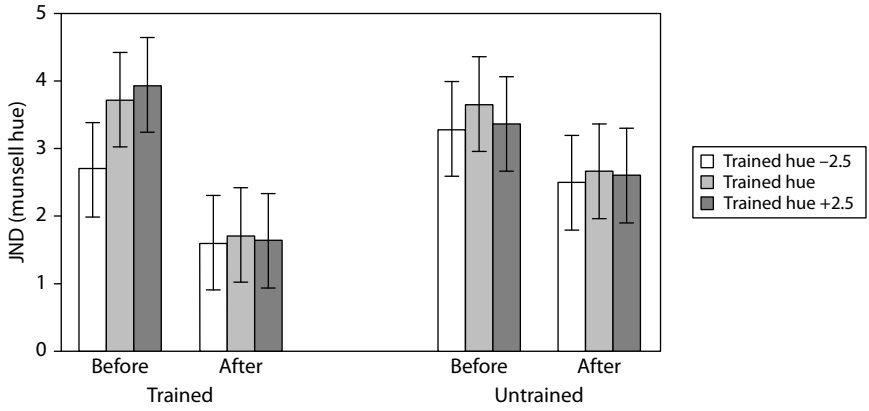

Figure 4. Graph to show threshold (in Munsell hue units) for discriminating the orientation of a chromatically defined edge before and after training. Separate bar charts are shown for trained and untrained hues and separate bars are shown for the trained/untrained hue and adjacent 'near' hues

Table 2. Statistically significant results of three-way ANOVA to explore the effects of training on thresholds for the trained and untrained colours and on hues in the same region of colour-space (time (2) – pre-training, post-training; colour (2) – trained colour, untrained colour; near hue (3) – –2.5, 0 and +2.5 Munsell hue steps relative to the training hue). The Greenhouse-Geisser correction to the degrees of freedom is made when the assumption of sphericity is violated (assessed by Mauchley's w)

Effect	F	df	p	Partial Eta2	Observed power
Time	10.58	1,14	<0.01	0.43	0.86
Near Hue	4.57	2,28	<0.05	0.25	0.73
Time x Colour	4.51	1,14	=0.052	0.24	0.51

4. Discussion

Previous research has indicated that performance on a wide variety of visual tasks can improve with practice. In the present experiment we sought to explore whether similar performance improvements can be observed for chromatically based judgements and to probe the potential neural locus of these improvements.

We found that eight days of practice at making judgements about the orientation of a chromatically defined boundary improved discrimination performance. This performance improvement did not transfer to another retinal location that was

approximately 10° from the training location. At early stages of visual processing, such as V1, cell receptive fields at our stimulus eccentricity tend to be small (0.5°), whilst as we progress through the various stages of the visual processing hierarchy receptive field sizes tend to increase up to around 5.5° in area V4 and to 20° or more in anterior inferotemporal cortex (AIT) (Kastner, Weerd, Pinsk, Elizondo, Desimone, & Ungerleider 2001; Smith, Singh, Williams & Greenlee 2001). Thus, our finding of positional specificity to within at least 10° is consistent with learning localized to relatively early stages of visual analysis that deal with the processing of chromatic stimulus properties. Future work could probe the limits of this specificity to retinal position to provide a finer-grained estimate of the likely neural locus of the learning.

Our observation that improvements in chromatic discrimination based judgements transfer within a hue category, but not to a different hue category, bears an intriguing resemblance to colour CP. Recall that, in colour CP, discrimination of colours that fall within a category is less acute than discrimination of colours that are placed in different categories. Consequently, we might expect that in the present case learning would transfer to similar 'near' hues in the same category because these hues are relatively indistinct from the training hue. However, a true test of whether transfer patterns across hue reflect the categorical structure of colour space would compare transfer to near hues within a category to equally different hues from a neighbouring category. This test must remain the subject of future experiments.

Initial processing of the visual scene is conducted, in part, by two separate but interacting streams concerned with achromatic and chromatic stimulus properties (Schiller & Logothetis 1990). Previous perceptual learning research has largely focused on tasks that can be accomplished by attending to achromatic stimulus properties. Consequently, the extent to which judgements that require processing of chromatic stimulus properties can improve with training has remained substantially unknown. Here, the observation that adults' performance of a chromatically based discrimination can improve with practice extends the perceptual learning literature to the chromatic processing stream. This observation supports the expectation that plasticity and learning are a generic capacity of adult visual processing and are not restricted to specific aspects or streams of visual analysis.

Further, the observation of chromatic perceptual learning lends support to the possibility that colour categorical perception effects may arise as a result of learning during everyday experience. Specifically, the act of attending to a colour category boundary may drive a learning process that enhances discrimination of colours that straddle that boundary. Consequently, where a particular colour boundary occurs in one language but not another then we would expect speakers of the language that marks a given boundary to show relatively enhanced perception at that boundary, just as has been observed (e.g. Roberson et al. 2000). These language-driven effects need not involve permanent modifications to the early neural circuits processing colour. Instead they may be implemented dynamically as a chromatic task is performed, consistent with recent neuroimaging evidence (Siok et al. 2009).

5. Conclusions

Chromatic discrimination judgements improve with practice and this improvement may reflect changes at early stages of visual analysis. This type of chromatic perceptual learning may partially underpin colour categorical perception and the differences in colour CP observed between the speakers of languages with differing colour vocabulary.

Acknowledgements

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Unique hues

Perception and brain imaging

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What computation does the human brain perform when we experience 'red', 'green', 'yellow', or 'blue'? Where in the visual pathway does the human visual system combine the retinal cone signals (L, M, S) to yield these fundamental colour sensations? Behavioural data show that the four unique hues (red, green, yellow, blue) do not map onto the cone-opponent mechanisms (i.e. L–M; S-(L+M)) found in the Lateral Geniculate Nucleus, a subcortical structure involved in early visual processing. The brain imaging experiment supports the behavioural result: using pattern classification algorithms applied to fMRI brain activation patterns we show that unique hues cannot be classified in the LGN, but we achieve above chance classification in primary visual cortex (V1). Our imaging data provide strong evidence that the unique hues do not originate in subcortical areas, but in the visual cortex, possibly as early as primary visual cortex.

1. Introduction

When human observers are asked to adjust a coloured light such that it appears neither red nor green, or such that it appears neither yellow nor blue, most colour-normal observers have no difficulty in making these adjustments (Valberg 1971) and these colour appearance judgements are fairly robust across different cultures (Saunders & van Brakel 1997; but see also Webster, Webster, Bharadwaj, Verma, Jaikumar, Madan & Vaithilingham 2002). This suggests that there is something very fundamental about these four attributes: redness, greenness, yellowness and blueness. However, no clear rationale for the organization of human colour vision into these four unique hues and their neural origin has emerged (Mollon 1991; 2009).

Human colour vision depends on several stages of processing. First the light is absorbed by the long-, medium- and short-wavelength-sensitive (L-, M-, or S-) cone receptors (Helmholtz 2000). The cone outputs are recombined in cone-opponent channels in retinal ganglion cells (Dacey 2000), and this cone-opponency is inherited by the Lateral Geniculate Nucleus (Derrington, Krauskopf & Lennie 1984;

DeValois, Cottaris, Elfar, Mahon & Wilson 2000; DeValois & DeValois 1993; however see Tailby Solomon & Lennie 2008). One class of cells takes the difference between the L and the M cones ('L–M mechanism'), the other takes the difference between the summed L and M cones and the S cones ('S-(L+M)' mechanism), named 'cardinal' directions (Krauskopf, Williams & Heeley 1982). The cardinal cone-opponent colour directions are often loosely referred to as red-green and yellow-blue colour directions, which is a misnomer since the appearance of the 'red-green' axis is more along an axis ranging from cyan to reddish-pink; the 'yellow-blue' axis ranges from lime to violet. Numerous behavioural experiments employing adaptation (e.g. Wuerger 1996) and habituation (e.g. Krauskopf et al. 1982; Zaidi, Yoshimi, Flanigan & Canova 1992) paradigms or similarity measures (Wuerger, Maloney & Krauskopf 1995) confirm that these cardinal directions are important and salient colour mechanisms, but they do not map readily onto the perceptual 'unique hue' sensations (DeValois, DeValois, Switkes &. Mahon 1997; Mollon & Jordan 1997; Valberg 1971).

The cone-opponent signals from the LGN feed into the primary visual cortex (Lennie, Krauskopf & Sclar 1990). The distribution of peak tuning in V1 is much flatter than in the LGN, implying that a substantial number of cortical neurons are tuned to intermediate and non-opponent colour directions (Hanazawa, Komatsu & Murakami 2000; Wachtler, Sejnowski & Albright 2003) or even tuned to directions more aligned with the perceptual unique hues (Horwitz, Chichilnisky & Albright 2007). Also, whereas neurons with similar colour preferences are spatially clustered and arranged in distinct layers in LGN, less is known about the spatial organization of colour-tuned neurons in V1.

The first aim of the experiments reported here was to identify how these post-receptoral cone-opponent channels are combined in the brain to yield the unique hues (Experiment 1: Behavioural unique hue settings). The second aim was to determine at what neuranatomical level of processing the unique hues may be derived. We therefore measured brain activations while observers viewed unique hues and cardinal colour modulations (Experiment 2: Brain activations in response to colour stimuli).

2. Experiment 1: Behavioural unique hue settings

To determine the loci of the unique hues we used a hue selection task (Wuerger, Atkinson & Cropper 2005) to obtain settings for a wide range of luminances and saturations. We found that the hue selection task was faster and easier for the observers than obtaining the unique hues via cancelling the opponent colours by method of adjustment. On each trial an annulus of coloured disks (12 disks) was presented and the subject was asked to choose the coloured disk that appeared to best satisfy the criteria of a specified unique hue. Thus for unique red, the observer was instructed to select the

coloured disk that appeared 'neither yellow nor blue'. Unique green was established by showing a range of greenish coloured disks and the observer was asked to pick the disk that looked 'neither yellow nor blue'. Unique yellow and unique blue were determined by asking observers to choose the disk that contained 'neither red nor green'. All observers found the task easy and did not need any further instructions or any explanations of what 'neither red nor green' (or 'neither yellow nor blue') meant. All coloured patches were presented on a steady grey background.

2.1 Apparatus and procedure

Stimuli were presented on a CRT screen of a DELL monitor (DELL P790). Linearized look-up tables were produced by measuring the CRT light outputs with a spectradiometer (SpectraScan PR650; PhotoResearch). The background was always grey with a mean luminance of 43 cd/m^2 and with chromaticity co-ordinates x = 0.282 and y = 0.307. The observers were seated in a darkened room 1m away from the monitor and adapted to the grey background for at least 5 minutes. The stimuli were presented continuously until the observer responded. There was no time limit for the response and the observers were encouraged to move their eyes freely. All 18 observers were colour-normal as assessed with the Cambridge Colour Vision Test (Regan, Reffin & Mollon 1994). For each observer, all four unique hues were determined at different luminance and saturation levels; each observer made at least 80 settings for each unique hue. Altogether, for each unique hue we obtained 1616 settings.

2.2 Results

To test how the unique hues are related to the cardinal cone-opponent mechanisms (which reflects the tuning of LGN neurones) we plot each individual unique hue setting as a point in a 2-dimensional chromaticity diagram whose axes correspond to the two cone-opponent mechanisms ('$\triangle L - \triangle M$' and '$\triangle S - (\triangle L + \triangle M)$'; Brainard 1996; Wuerger, Watson & Ahumada 2002). In Figure 1 (0,0) indicates the grey background and all colours are expressed as increments or decrements with respect to the grey background; the luminance component is not shown in this diagram.

Red symbols (circles) refer to the settings for 'unique red' and green symbols (squares) to 'unique green'; yellow symbols (upward pointing triangles) denote the settings for 'unique yellow', and blue symbols (downward pointing triangles) indicate the loci of 'unique blue'. Unique hues do not coincide with the cardinal cone-opponent axes, confirming previous results (e.g. Webster, Miyahara, Malkoc & Raker 2000). Unique red is at the positive end of the 'L–M' axis and requires a small negative S cone input; unique green lies at the negative end of the 'L–M' axis (i.e. M–L > 0) and needs a significant negative S-cone contribution. This means that the green that constitutes the negative end of the 'L–M' axis is too bluish. Unique blue and yellow also lie in

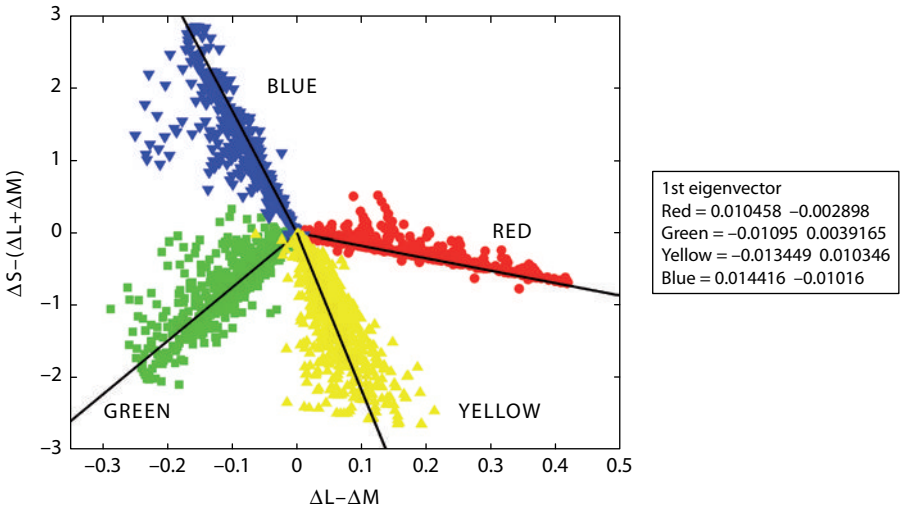

Figure 1. Unique hue settings in the cone-opponent diagram. Only unique red is close to the positive end of the 'L-M' axis; all other unique hues are in intermediate directions, hence requiring input from both cone-opponent mechanisms

intermediate directions; colours of a positive S cone and a negative L–M component are perceived as unique blue; the reverse is true for unique yellow, which requires a negative S cone input and a positive L–M component. Secondly, unique red and unique green do not lie on a line through the origin. This implies that it is not a single opponent yellow-blue mechanism, which is silenced when observers consider a light being neither yellow nor blue.

3. Experiment 2: Brain activations in response to colour stimuli

In the behavioural experiment (Experiment 1) we have confirmed that the mechanisms that mediate the unique hues are not aligned with the cone-opponent mechanisms found in the LGN, a subcortical visual processing area. This provides strong evidence that the origin of the unique hues is cortical. The purpose of Experiment 2 was to look for neural correlates of this behavioural finding. We therefore measured brain activation patterns in LGN and primary visual cortex (V1) while observers viewed either unique hues or cardinal colour modulations. From these brain activations subtraction images were derived (see fMRI analysis) and then the colour of the viewed stimulus was predicted based on these subtraction images. Our hypothesis was that we will be able to decode cardinal cone-opponent colour modulations based on the LGN activations, but not based on the V1 activations; we also expected the reverse

to occur in V1. To test our hypothesis, we use two different methods, a correlation analysis and a pattern classification analysis.

3.1 Participants

Five healthy subjects (two female, age 21–31 years) with normal or corrected-to-normal vision gave written informed consent to take part in this study. All participants had normal colour vision as assessed with the Cambridge Colour Test (Regan et al. 1994). The study was approved by the Sefton Liverpool Research Ethics Committee.

3.2 Experimental design and stimuli

We used high resolution fMRI (1.5mm in-plane resolution) to record the BOLD signals in LGN and V1 in response to two different sets of colour stimuli: modulations along the cardinal directions (condition 1) or unique hues (condition 2). Colour stimuli were presented for 12 sec followed by 12 sec of an isoluminant grey screen. Colour stimuli consisted of flickering radial sinusoidal gratings (0.8 cycles/deg; 1.5 Hz; 20 degrees of visual angle diameter) temporally modulated along one of the three cardinal directions in condition 1 (along the two axes shown in Figure 1 and an additional achromatic axis which is not shown in Figure 1; for details see Parkes, Marsman, Oxley, Goulermas & Wuerger 2009; Liu & Wandell 2005). Each cardinal colour modulation was presented three times in a random order per run (216 s). There were six runs giving 18 presentations for each of the three colours. In condition 2, we used unipolar modulations between the grey background and a particular perceptual hue (red, green, yellow, blue; shown in Figure 1). The average CIE coordinates of the four unique hues were similar to the settings obtained in Experiment 1. The contrast of the unique hues was then scaled such they were roughly equal in terms of detectability (Webster et al. 2000). The luminance level of the test patterns was always the same as the background at each point in space and time. Each hue was presented three times in a random order per run (288 s). There were five runs giving 15 presentations for each of the four hues. During the scan, subjects were asked to decide if the fixation shape was a circle or a square. In the first session a retinotopic mapping scan was included. Experiments were run on a standard DELL PC with a VSG2/5 graphics card (32-MB memory, Cambridge Research Systems, Ltd.). Stimulus presentation was controlled with Matlab 7 (Mathworks®) and stimuli were presented on a PANASONIC LCD PT-L785U projector, which was calibrated using a spectroradiometer (Photo Research PR650).

3.3 fMRI analysis

High-resolution fMRI scans were obtained on a 3 T Siemens system with an eight channel phased-array head coil for signal collection. The data were analysed using

BrainVoyager (Brain Innovations, Maastricht, Netherlands) on an individual basis. LGN and V1 were identified using standard procedures (Parkes et al. 2009). A subtraction image for each colour presentation was calculated in the following way. For each presentation, three scan images from 6 s to 15 s following colour stimulus onset were averaged (i.e. those containing the maximum BOLD response), as were two scan images from 3 s preceding colour onset to 3 s post onset (i.e. those containing the minimum BOLD response). The average minimum image was subtracted from the average maximum image to give a single subtraction image per colour presentation. To avoid the classification results being driven by any small difference in overall amplitude rather than the spatial pattern of the response, the subtraction images were normalized within the region of interest (Haxby, Gobbini, Furey, Ishai, Schouten & Pietrini 2001).

3.4 Pattern Classification Results

The set of subtraction images and the mask files were input into the Support Vector Machines (SVM) with a linear kernel (Joachims 1999). Pair-wise classification was performed between all colour pairs within each set, i.e. three pairings for the cardinal colours and six pairings for the perceptual hues. Testing involved Leave-One-Out (LOO) validation, which is a special case of the k-fold cross validation widely used for classification analysis and classifier evaluation (Duda, Hart & Stork 2002).

Figure 2 shows the classification performance in LGN (a) and V1 (b) for both unique hues and cardinal colour stimuli. It can be seen that there is significant classification in LGN for cardinal colour directions, but classification for unique hues is at chance performance (thick solid line). The dashed lines indicate 95% confidence intervals. In V1, we find significant classification of unique hues and chance classification for cardinal colours.

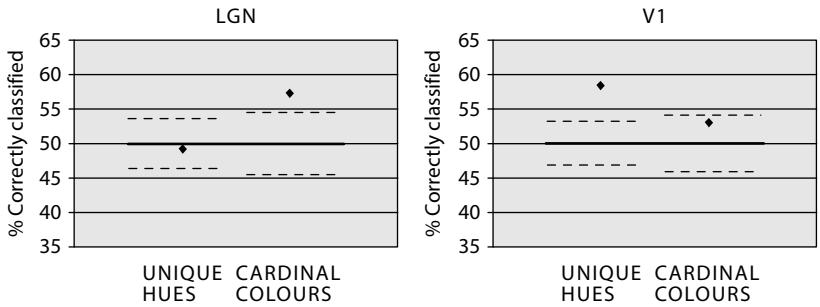

Figure 2. Classification performance. Cardinal colours can be classified in the LGN and unique hues can be classified above chance in V1. The other two classifications, i.e. unique hues in LGN and cardinal colours in V1, do not exceed chance performance

3.5 Correlation results in LGN and V1

To determine if there is a robust and unique pattern of fMRI activation for each colour presented we calculated correlations between the activation patterns within LGN and V1, following Haxby et al. (2001). For each subject and each colour category the subtraction images were split into two sets, namely even and odd sets, and averaged to create two mean subtraction images per colour category. Odd sets comprised the first, third, fifth, etc. subtraction image; even sets the second, fourth, etc. image. Correlation coefficients were computed between the (spatial) response patterns for odd sets compared to even sets for both same-colours (e.g. red odd sets and red even sets) and different-colours (e.g. red odd and blue even). For the different-colour case there were four possible combinations (red odd or red even + blue odd or blue even), the mean of which was found. If the spatial response pattern is unique for a particular colour, we expect higher correlations for the same-colour response pattern compared to the different-colour response pattern.

Figure 3 shows the correlation coefficients between pairs of response patterns over all 5 subjects. The upper left diagram shows the correlations between 'same' and 'different' cardinal colours for the LGN. The first three bars show the correlation between the BOLD signals in response to BW and, in the following order, BW, RG and YV. Similarly, the next three bars represent the correlations between the BOLD signal distribution in response to RG, and in that order, BW, RG, and YV; the right-most bars show the correlation between YV activation and BW, RG, and YV activation. The 'within colour' correlations are higher than the 'between-colour' correlations; this suggests that the brain activation pattern in response to each cardinal colour modulation (BW, RG, YV) is unique in the LGN, probably reflecting the spatial clustering of neurons with similar colour preferences in the magno-, parvo-, and koniocellular layers (Tailby et al. 2008).

The upper right panel shows the correlation coefficients based on V1 responses to cardinal colours. As before, 'within-colour' correlations (BW-BW; RG-RG; YV-YV) and 'between-colour' correlations are calculated based on the spatial activation patterns in V1. In contrast to the correlation patterns in LGN, 'within-colour' correlations are about the same as 'between-colour' correlations and no clear pattern emerges. Correlation coefficients are in general higher in V1 compared to LGN, which is probably due to the weaker BOLD signal in LGN in comparison to the strong V1 signals (Parkes et al. 2009). Interestingly, the increase in the correlation coefficients, comparing V1 to LGN, is much higher for YV (about a factor of 10) than for RG and BW (about a factor of 2), which is consistent with a boosting of the S cone signal between LGN and V1 (Mullen, Dumoulin, McMahon, de Zubicaray & Hess 2007). These generally high correlation coefficients without a clear difference between 'within-colour' and 'between-colour' correlations suggest that these activation patterns are not uniquely associated with a particular cardinal colour modulation. The most parsimonious explanation for this result is that neurons in V1 respond strongly to cardinal colours (Gegenfurtner 2001; Lennie et al. 1990) but that these neurons are not spatially clustered, as is the case in the LGN.

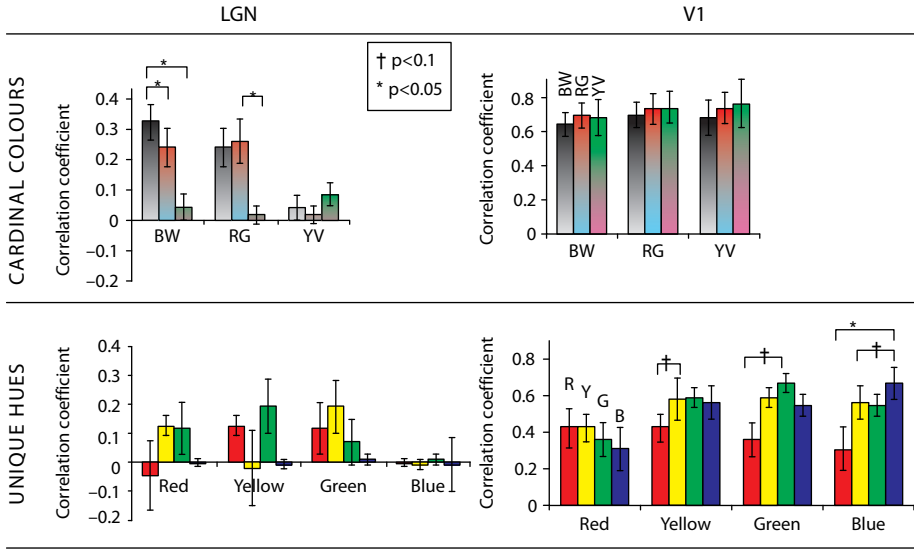

Figure 3. Correlation analysis. Within-colour correlations are significantly larger than between-colour correlations only for cardinal colours in LGN (upper left quadrant) and for unique hues in V1 (lower right quadrant). Note that the correlation coefficients are duplicated for clarity, e.g. the correlation between BW and RG (in the leftmost set of bars) is the same as the correlation between RG and BW (2nd set of correlations)

Figure 3, lower row, shows the correlation analysis when the observers viewed unique hues. When the correlation coefficients are computed based on LGN activations, no clear pattern emerges that could differentiate 'within-colour' from 'between-colour' correlations. The leftmost group of bars indicates the correlation of the red hue with, in that order, red, yellow, green, blue. The next group of bars denotes correlations of yellow with red, green, yellow and blue, and so on. Correlation coefficients are small and non-systematic; this suggests that no unique activation pattern is associated with LGN activations in response to unique hues. In V1, on the other hand (rightmost panel), 'within-colour' correlations are on average larger than 'between-colour' correlations, which is consistent with unique activation patterns in response to these particular hues. Not all pairs of correlation coefficients exhibit significant differences; significant differences are denoted with a star ($p < 0.05$) or with a cross ($p < 0.1$). The correlation patterns in V1 for unique hues are not as clear as the LGN correlations for the cardinal colours, but, together with the classification performance (Figure 2), we believe that they provide convincing evidence for unique spatial activation patterns in response to unique hues in V1.

4. Discussion

In the behavioural experiment (Experiment 1) we confirmed that the four perceptually simple colours – unique red, green, yellow and blue – do not align with the chromatic preferences of neurones at early stages of visual processing (Mollon & Jordan 1997). In Experiment 2, we recorded brain activations (in LGN and V1) while observers viewed these two sets of colour stimuli, cardinal colour modulations reflecting chromatic preferences at the early stages of visual processing (LGN) and unique hues reflecting behaviourally special mechanisms. Based on the spatial activation patterns we then tried to predict the viewed stimulus using multi-voxel pattern analysis techniques. Both the classification and correlation analysis demonstrate that cardinal colour modulations *cannot* be decoded in V1 despite reliable BOLD signals (Figure 2: right panel; Figure 3: upper right panel). Decoding performance depends both on the chromatic properties (chromatic preference and selectivity) of the neural population underlying the activity of a particular voxel and on the spatial clustering of the neurones with similar chromatic preferences; neurones with similar chromatic preferences must be sufficiently clustered to induce a detectable bias in a single voxel. Since a significant number of neurones in primary visual cortex are tuned to cardinal colour modulations with a similar selectivity as LGN neurones (Lennie et al. 1990) the most parsimonious account for the failure to decode cardinal colours in V1 is that these neurones are not spatially clustered in the same way as they are in LGN.

Unipolar colour modulations between the grey background and the four unique hues can be decoded in primary visual cortex (Figure 2, right panel) and 'within-colour' correlations are higher than 'between-colour' correlations (Figure 3: lower right panel), hence suggesting that each hue is associated with a unique BOLD activation pattern in V1. It does *not* follow that the four hues are *special* colours; we may have obtained the same classification performance using intermediate unipolar hues, such as modulations from grey to orange, turquoise, etc. The success in decoding the four hues is consistent with a hue map in primary visual cortex as shown using optical imaging (Xiao, Casti, Xiao & Kaplan 2007): neurones with similar colour preferences are also spatially contingent, in analogy to orientation encoding (Kamitani & Tong 2005). From a functional point of view a hue map is an effective way to achieve fast and simple discrimination between visual stimuli based on small hue differences.

Despite the compelling behavioural evidence for the special status of the four unique hues, it has proven difficult to underpin the behavioural data with neurophysiological evidence (Conway 2009; Stoughton & Conway 2008; Mollon 2009). Nevertheless, convincing explanations have been put forward as to why these early cone-opponent signals in LGN are recombined into higher-order colour mechanisms that yield the four unique hues: the weights of the cone-opponent signals are adjusted to yield higher-order colour mechanisms that reflect the statistical properties of the natural environment, such as the blue sky and the sun (Mollon 2006; Webster 2009). The existence of such compensatory mechanisms is consistent with the remarkable constancy

of human colour perception with ageing; despite significant age-related changes in the optical and neural properties of the eye, our colour vision remains constant throughout the life span.

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A short note on visual balance judgements as a tool for colour appearance matching

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The experimental methods traditionally available for assessing the colour appearance of complex objects include (1) matching with samples from an atlas, (2) analyzing colour names, or (3) hue and saturation scaling (Billmeyer 1987; see also Giesel & Gegenfurtner 2010). However, these methods lead to dependencies of the response on experimental factors, such as object size. We suggest here a new approach using the visual 'balance' response. The sensation of balance is the extension of that of geometrical bilateral symmetry for two juxtaposed samples differing in their information content. Balance is basic and familiar in architecture, photography, and visual arts, and may be experienced by everybody, after appropriate training (Morriss & Dunlap 1988; Ronchi 2002; Locher, Overbeeke & Stappers 2005).

The idea of visual balance in colour matching was first put forward by Munsell (Munsell 1905). His rule states that balance is given by the formula: $A_1V_1C_1 = A_2V_2C_2$ where A_n is the area of sample n, V_n its value (i.e. brightness) and C_n its chroma (i.e. saturation), as measured using the Munsell colour system. This pioneering example of the conjunction of spatial and colour characteristics holds for spatially uniform samples. It states, in short, that small areas of high chroma will balance large areas with low chroma (assuming constant value).

In our experiments we use a display in which a Test (10° x 10°) and a Reference (10° by a variable width, wR) are juxtaposed. The intra-display match of visual weights, related to their appearances, is recorded by the use of the constant stimulus method, by assigning a number of values to wR. The response categories, leading to the related psychometric function, are 'Balanced', 'Not Balanced', and 'Unsure'. Visual balance is self-evidently a 'second order' visual perception (Landy & Oruc 2002; Wong & Levi 2005), which is dependent on the global characteristics of the stimulus. The appearance of the conjoined feature 'colour' is, we argue, subsumed by this global percept and consequently loses its identity, entangling itself with the luminance. In our experiment we used spatially uniform samples (made of cardboard) and textured samples (wool knits, rendered rough by garter stitch). We plotted the balance data represented by wR, the width of the Reference, versus the intra-display luminance contrast, a robust factor

of colour appearance (Billmeyer 1987). Satisfactory balance matches were made using both stimulus classes.

The experiment may be extended to use stimuli which do not match in their texture characteristics, such as bi-chromatic contrast gratings, and a range of other stimuli, which we obtained by generating knitted patterns using a variety of wool colour and stitch combinations. The key novelty here, in the context of colour vision research, is that the observer is not requested to observe a characteristic of the colour appearance *per se*, but simply to assess the balance of the pairs. This makes the judgement, to a certain extent, unconscious and less influenced by preconceptions.

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