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# The nature of infant color categorization: Evidence from eye movements on a target detection task

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**Abstract**

Infants respond categorically to color. However, the nature of infants' categorical responding to color is unclear. The current study investigated two issues. First, is infants' categorical responding more absolute than adults' categorical responding? That is, can infants discriminate two stimuli from the same color category? Second, is color categorization in infants truly perceptual? Color categorization was tested by recording adults' and infants' eye movements on a target detection task. In Experiment 1, adults were faster at fixating a colored target when it was presented on a colored background from a different color category (between-category) than when it was presented on a colored background from the same color category (within-category), even when within- and between-category chromatic differences were equated in CIE (Committee International d'Éclairage) color space. This category effect was found for two chromatic separation sizes. In Experiment 2, 4-month-olds also responded categorically on the task. Infants were able to fixate the target when the background color was from the same category. However, as with adults, infants were faster at fixating the target when the target background chromatic difference was between-category than when it was within-category. This implies that infant color categorization, like adult color categorization, is truly perceptual.


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## Introduction

Adults respond categorically to color. For instance, they respond faster or more accurately when discriminating two stimuli that cross a category boundary (between-category stimuli) than when discriminating two stimuli from the same category (within-category), despite between- and within-category stimuli being equated in color space (Bornstein & Korda, 1984). Similar effects, where between-category discrimination is facilitated compared with within-category discrimination, have been found in adults using two-alternative forced-choice (2-AFC) tasks (e.g., Pilling, Wiggett, Özgen, & Davies, 2003; Uchikawa & Shinoda, 1996), similarity judgment "odd one out" tasks (e.g., Kay & Kempton, 1984; Laws, Davies, & Andrews, 1995), and visual search tasks (e.g., Daoutis, Pilling, & Davies, 2005; Franklin, Pilling, & Davies, 2004; Kawai, Uchikawa, & Ujike, 1995). Categorical responding to color has also been found in toddlers using a 2-AFC task (Franklin, Clifford, Williamson, & Davies, 2005) and in children using a visual search task (Daoutis, Franklin, Riddett, Clifford, & Davies, in press).

The origin of color categorization is under debate. Some argue that categorical responding to color is an artifact of verbal labeling or that our color categories are linguistically constructed (e.g., Roberson, 2005). This argument is based in part on cross-cultural research showing that categorical responding is closely tied to the way in which a speaker's language segments the color space. For example, if a speaker's language does not mark the boundary between blue and green, categorical responding across this boundary is not seen on a 2-AFC task (e.g., Roberson, Davies, & Davidoff, 2000). However, others argue that color categorization is hard-wired. This argument is supported by evidence that infants respond categorically to color (Bornstein, Kessen, & Weiskopf, 1976; Catherwood, Crassini, & Freiberg, 1987; Franklin & Davies, 2004).

The findings from cross-cultural studies of color categorization and those from infant studies of color categorization seem to contradict each other. The cross-cultural studies suggest that color categorization is language dependent, whereas the infant studies suggest that color categorization can be shown in the absence of language. One reason for the apparent contradiction could be that category effects in adult studies are not equivalent to those in infant studies. For example, linguistic relativists have argued that the category effect in infants could be an artifact of the methods (habituation/novelty preference) (Özgen, 2004). The current investigation explored the nature of infant color categorization in an attempt to clarify the apparent contradiction in the debate about the origin of color categorization.

### *Infant color categories*

In a classic study, Bornstein and colleagues (1976) tested for color categorization in 4-month-olds. Infants were habituated to a colored stimulus and were then shown

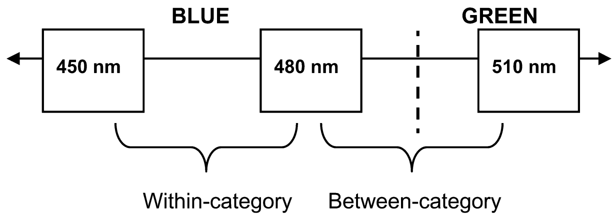


Fig. 1. Example of within- and between-category stimulus pairs in Bornstein and colleagues' (1976) investigation of infant color categorization. Stimulus pairs are separated by 30 nm of wavelength. The dashed line indicates the blue–green category boundary.

a stimulus of a novel color. The novel stimulus was either from the same color category (within-category) or from a different color category (between-category) compared with the original. The difference in wavelength between the novel and original stimuli was equated for within- and between-category stimulus pairs (Fig. 1).

Dishabituation rates for the within- and between-category novel stimuli were monitored, and blue–green, yellow–green, and yellow–red boundaries were tested. The results were striking. The 4-month-olds dishabituated to the novel stimulus only if it was from a different category. Even when the novel and original stimuli were very different in wavelength, there was no dishabituation to the within-category novel stimulus. This categorical effect was found across all three boundaries.

There is some criticism (e.g., Werner & Wooten, 1985) of the technical control of color in Bornstein and colleagues' (1976) study stemming from their use of highly saturated monochromatic lights and from their use of a wavelength-based color system to equate within-category and between-category original–novel stimulus separation sizes (for further discussion, see Franklin & Davies, 2004). Therefore, Franklin and Davies (2004) replicated and extended Bornstein and colleagues' (1976) investigation, controlling for these technical issues. The Munsell color order system[1] was used to equate within- and between-category stimulus separations; stimuli were at natural saturation levels and were reflective rather than radiant. Using a novelty preference technique, categorical responding was tested across primary[2] hue boundaries (blue–green) and secondary hue boundaries (blue–purple). A secondary boundary defined by differences in lightness and saturation (red–pink) was also tested. Following familiarization with the original color, preference for the novel stimulus was shown only if the original and novel stimuli were between-category rather than within-category. Novelty preference was approximately 70% for all between-category pairs tested, and there was no significant novelty preference for any within-category stimulus pair. Even when within-category stimulus separation sizes were

[1] The Munsell color order system is three-dimensional: hue, value (lightness), and chroma (colorfulness, e.g., saturation). The system is standardized, and each dimension is intended to be perceptually uniform. Stimuli are reflective.

[2] Primary colors (red, green, yellow, and blue) correspond with Hering's (1878/1964) unique hues and to the cardinal directions in color space (e.g., Krauskopf, Williams, & Heeley, 1982). Secondary colors (pink, purple, orange, and gray) appear to be blends of these primaries.

maximized by introducing a lightness difference between stimuli, significant within-category novelty preference was not found.

Similar categorical effects were found by Catherwood and colleagues (1987), although no attempt was made to equate within- and between-category separation sizes. Therefore, it seems that infants respond categorically not only to faces (Kotsoni, de Haan, & Johnson, 2001), speech (Eimas, Siqueland, Jusczyk, & Vigorito, 1971), and orientation (Bomba, 1984) but also to color.

Here we explore the nature of infants' categorical responding to color. Is the category effect that we find in infants the same as the category effect that we find in adults? There are two issues. First, does the lack of within-category novelty preference or dishabituation indicate that infants cannot discriminate within-category stimuli and consequently indicate that categorical responding is more absolute in infants than in adults? Second, is the category effect in infants truly perceptual? Both of these issues are discussed below.

## *Is categorical responding by infants more absolute than categorical responding by adults?*

Infants show significant novelty preference for novel between-category stimuli and therefore show evidence of being able to discriminate stimuli from different color categories. However, even for large separation sizes, no significant novelty preference is shown for novel within-category stimuli. Does this mean that infants at 4 months of age cannot discriminate two stimuli from the same color category? One of the problems with the novelty preference and habituation technique is that interpretation of no significant novelty preference is not clear-cut. If novelty preference is found, infants must be able to discriminate. However, a lack of novelty preference implies nothing about discriminability. For example, Snyder, Blank, Cheek, Kuefner, and Marsolek (2004) revealed that infants who showed novelty preference and infants who did not show novelty preference for a novel visual stimulus both showed evidence of discriminating the novel stimulus in their pattern of event-related potentials (ERPs) on an oddball task. Even though infants were discriminating the novel stimulus, no novelty preference was shown for some infants. Therefore, it is possible that infants are actually capable of discriminating two stimuli from the same color category but that the novelty preference and habituation measures are not sensitive enough to detect this. Adults can discriminate within-category stimuli; they are merely slower or less accurate at doing so than at discriminating between-category stimuli. If infants cannot discriminate two colors from the same color category, this would suggest that the categorical effect in infants is more absolute than the categorical effect in adults. Therefore, it is important to establish whether infants are capable of discriminating within-category stimuli using tasks that are sensitive to infant discrimination.

## *Is the category effect in infants truly perceptual?*

Categorical responding has been shown in adults using a range of tasks. It is commonplace to describe these categorical effects as "categorical perception" (Harnad, 1987). However, some of these tasks have a memory component. For example, on a 2-AFC task, the participant is shown a target stimulus, the target stimulus is removed, and after a delay the participant must identify the target when it is presented alongside another stimulus (the foil). This task requires the participant to memorize the original target stimulus. Therefore, a categorical effect on a 2-AFC task— more accurate identification of the target when paired with a between-category foil than when paired with a within-category foil—could be based on a memory process rather than on a perceptual one. Huttenlocher, Hedges, and Vevea (2000) argued that categorical perception is actually due to a shift in the visual representation of the target stimulus to the prototype when the participant memorizes the target stimulus. Because within-category stimuli have the same prototype, this makes within-category target identification harder, and because between-category stimuli have different prototypes, this makes between-category target identification easier. Therefore, Huttenlocher and colleagues argued that the categorical perception in adults is not perceptual at all but rather is based on a memory process.

However, category effects have been found in adults on 2-AFC tasks that are not consistent with this argument (Pilling et al., 2003). In addition, category effects in adults have been found on tasks that have no memory component. For example, Daoutis et al. (2005) showed that search for a colored target among colored distractors is both faster and more efficient when the target and distractor are between-category than when they are within-category. This study and similar studies using visual search tasks (Franklin et al., 2005; Kawai et al., 1995) showed that a perceptual form of color categorization can be found in adults.

However, is the category effect in infants perceptual? The novelty preference and habituation techniques, like 2-AFC tasks, also have a memory component. An infant is familiarized or habituated to an original stimulus, and then novelty preference or dishabituation to a novel stimulus is tested. The amount of dishabituation or novelty preference is partially dependent on the infant's ability to memorize the original stimulus. It is possible that the category effect in infants is due to a "shift toward prototype" rather than being a perceptual effect. It is important to establish whether infants respond categorically on a task that has no memory component.

Therefore, to establish whether infants can discriminate within-category stimuli, we need a task that is sensitive to infant discrimination, and to eliminate memory as a candidate explanation for categorical responding, we need a task that has no memory component. To compare the nature of the category effect in adults and infants, it would also be ideal to have a task that could be used with both adults and infants using the same measure of discrimination.

## *The current investigation*

In the current investigation, we tested for categorical responding in both adults and infants using a target detection task. During a target detection trial, participants were shown a colored background. Somewhere on this colored background was a colored target. The chromatic difference of the background and the target was either within-category or between-category. Participants' eye movements were recorded to see whether they fixated the target and to record the time taken to fixate the target. If categorical responding is shown on this task, the target should be fixated more frequently and more quickly when the chromatic difference of the target and the background is between-category than when it is within-category.

There are various advantages to this task. First, the task has no memory component; the target does not have to be memorized because the target and background are presented simultaneously and the target merely has to be detected. Therefore, if infants respond categorically on this task, we can be more certain that the category effect is not due to a memory process and is perceptual. Second, there are various benefits to recording eye movements and using eye movements as a measure of perceptual similarity. As eye movements are recorded, we can see exactly which targets the infants can discriminate. If infants are capable of fixating a target when the chromatic difference of the background and the target is within category, we can infer that infants are able to discriminate stimuli from the same color category. By recording eye movements in both infants and adults, we are also using the same measure to assess the category effect in infants and adults. This should mean that comparisons of infant and adult categorical responding are easier to make. Therefore, by recording infants' and adults' eye movements on a target detection task for between- and within-category target–background chromatic separations, we can further our understanding of the nature of infant color categorization. Accordingly, Experiment 1 tested for categorical responding in adults across the blue–green boundary for two chromatic separation sizes. Experiment 2 tested for categorical responding in 4-month-olds using the stimuli from Experiment 1 with the larger chromatic separation.

## Experiment 1: Categorical responding to color by adults on a target detection task

Experiment 1 tested categorical responding across the blue–green boundary in adults by recording eye movements on a target detection task. Category effects were tested in adults for two reasons: (a) to investigate whether the target detection task and eye movement measure can be reliably used to show categorical responding and (b) so that adults' performance on the task could be compared with infants' performance in Experiment 2.

The usual measure of perceptual similarity in adult studies of categorical perception is reaction time. Faster reaction times for between-category target identification, rather than within-category target identification, is taken as evidence of categorical perception. Here we do not use reaction time as a measure because this measure could not be obtained from infants. What evidence exists that eye movements can be used as a reliable measure of perceptual similarity? Studies that have recorded both reaction time and eye movements when adults are completing a visual search task have highlighted the correspondence between reaction time and eye movement measures such as the number of fixations and eye movement latencies (Maioli, Bengalio, Siri, Sosta, & Cappa, 2001; Shen, Reingold, & Pomplun, 2000; Zelinsky

& Sheinberg, 1997). By recording eye movements on a visual search task, Beutter, Eckstein, and Stone (2003) showed that "saccades and perception share a similar visual processing mechanism" (p. 1532). If measures of perceptual similarity such as reaction time reveal categorical responding, time to fixate the target should show corresponding category effects.

The target detection task was designed to assess target fixation accuracy and target fixation time when the chromatic difference of the color of the target and the background was between- or within-category. The color of the target was kept the same for all trials, and the color of the background was changed so that the background was either within- or between-category. The chromatic difference between the target and the background was equated in CIE (Committee International d'Éclairage) color space (L*u*v*),[3] and stimuli differed only in hue. For both within- and between-category pairs, the background was either 23ΔE (near) or 40ΔE (far) units from the target. The chromatic separation size of the target and background (near/far), as well as the categorical status (within/between), was manipulated for three reasons: (a) to check whether any category effect found was not particular to the stimuli chosen and could be found with other stimulus pairings, (b) to assess the effect of chromatic separation size on target detection accuracy and time and see whether there was an interaction of separation size with the size of the category effect, and (c) to include a large chromatic separation size (40ΔE) because infants have higher chromatic thresholds than do adults (Knoblauch, Vital-Durand, & Barbur, 2001).

## *Method*

### Participants

A total of 30 students (18 women and 12 men) from the University of Surrey with a mean age of 20.2 years ($SD = 2.6$) took part in the study. Participants were tested for deficiencies in color vision using the City University Color Vision Test (Fletcher, 1981), and no participants were color deficient.

### Apparatus and experimental setup

Participants were seated 70 cm away from a 21-in. Sony Trinitron monitor (model GDM-F520) so that the center of the monitor was at eye level. Eye movements were recorded using an ASL 504 pan/tilt eye-tracking camera recording at 50 Hz. The pan/tilt eye-tracking camera was placed centrally, directly in front of the monitor. A PC controlled the eye-tracker using Eyenal software. One monitor (monitor A) displayed the image of the participant's eye with pupil and corneal crosshairs shown.

[3] The CIE (Committee International d'Éclairage) has various systems for describing color. For the L*u*v* space, L*u*v* are the axes of the color space, where L* is lightness, u* is a red–green axis, and v* is a blue–green axis. Equal distances (ΔE) are intended to correspond with equal perceptual distances. For further information, see Hunt (1987).

A second monitor (monitor B) displayed the output of the pan/tilt's scene camera (the participant's face and upper body) in one mode and displayed what the participant was being shown, with the participant's crosshairs indicating point of gaze (POG) superimposed, in another mode. The two outputs of monitor B were fed into a visual mixer (Panasonic, model WJ-MX12) along with the output from a time code generator. The mixer's output was fed into a third monitor (monitor C), and a video recorder (Panasonic, model MD830) recorded this output during the experiment. The result was a video of the participant's face, what the participant saw, and the participant's crosshairs superimposed on top of each other, with a time code running at the bottom of the image.

## Stimuli and design

A colored target (colored circle, diameter = 2 cm, visual angle = 3.22°) was shown on a colored background (40 × 30 cm). The target appeared in one of eight locations, and the target location was randomized across trials. These eight target locations were positioned in a ring around the center of the display so that the distance from the center of the display to each target was the same. Studies that have used eye tracking to assess visual search have also standardized target location using this "ring design" (e.g., Adler & Orprecio, 2005). The color of the target was green,[4] and this was kept constant across all trials. The background color was either green (from the same color category, i.e., within-category) or blue (from a different color category, i.e., between-category) to the target. The chromatic separation size of the target and the background was either 23ΔE or 40ΔE. Fig. 2 shows the resulting four stimulus pairs.

The target and background colors varied only in hue, with saturation and lightness kept constant (for the $Y, x, y$ chromaticity coordinates of the stimuli and the white point, see Table 1). Each participant saw arrays from all four conditions, and for each of the four conditions there were three trials, each lasting 4 s. Before each trial, a flashing black and white bull's-eye image was presented in the center of the screen to ensure that fixation was centered. This was followed by a gray screen (for the $Y, x, y$ chromaticity coordinates, see Table 1) that was shown for 250 ms.

## Procedure

Using the remote control, the pan/tilt was angled so that the participant's eye was captured by the camera, and the eye was put into focus. The correct threshold values for the detection of the corneal reflection and pupil were found, and the crosshairs for the corneal reflection and pupil appeared on the image of the eye on monitor A. The participant was instructed to look at a grid of nine numbers (calibration points) on a gray display shown on his or her monitor. The participant was in-

[4] The color names for the five experimental stimuli were verified using a naming task, where each stimulus was presented individually on a gray background, to a sample of 10 adults. Naming was unanimous.

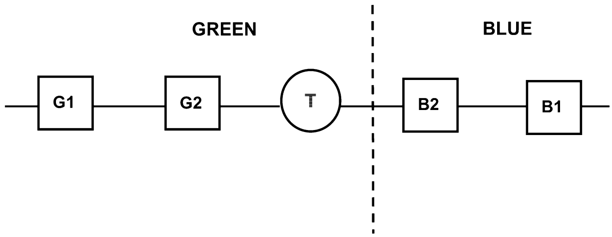


Fig. 2. Diagrammatic representation of the five stimuli in Experiment 1: the target (T) and the four background stimuli (G1/G2/B1/B2). The dashed line represents the category boundary. The four conditions are as follows: between/far (T-B1), between/near (T-B2), within/far (T-G1), and within/near (T-G2).

Table 1
$Y, x, y$ chromaticity coordinates of the stimuli and of the intertrial gray and white point of the monitor

| Stimulus | $Y$ | $x$ | $y$ |
|---|---|---|---|
| Target | 14.14 | 0.233 | 0.344 |
| B1 | 14.18 | 0.210 | 0.255 |
| B2 | 14.11 | 0.211 | 0.289 |
| G1 | 14.18 | 0.306 | 0.458 |
| G2 | 14.17 | 0.267 | 0.411 |
| Gray | 40.01 | 0.326 | 0.341 |
| White point | 71.90 | 0.327 | 0.339 |

structed to look at each number in turn, and the location of the corneal reflection and pupil signal at each point was recorded. After all nine points were completed, if the calibration was successful, crosshairs indicating the participant's POG could be seen on monitor B—superimposed on the image of what was being shown to him or her. The participant was then asked to look at five randomly selected points on the screen. Accuracy of calibration was assessed, and if the crosshairs did not hit the requested calibration point on any of the points or if no crosshairs appeared at all, the calibration procedure was repeated. Once accurate calibration was achieved, the time code generator and video recording were started.

Each participant was told to "fixate the flashing bull's-eye when it is shown, but other than that, just look at the screen." The participant was also instructed to keep his or her head as still as possible throughout the experiment.[5] The flashing bull's-eye was shown, and the experimenter looked at the crosshairs and image on monitor B to assess whether the participant was fixated on the bull's-eye. Once the experimenter was sure that the participant was centrally fixated and that both the corneal reflection and pupil signals were registering, the trial was started. This was repeated until all 12 trials were completed.

[5] The pan/tilt can track the eye only if head movements are small; the eye is lost by the pan/tilt if head movements are large, and in this case the eye must be manually reacquired using the remote control.

## *Results*

### Analysis of eye movements

Eye movement data were analyzed using the POG coordinates and the videotaped output. For each trial, the time taken for the participant to fixate the target was calculated (see formula below), with a target fixation being defined as when the POG rested on any part of the target:

$$\text{Time Taken to Find Target} = \text{Time of Target Fixation} - \text{Time of Trial Onset}$$

For each condition, there were three fixation times, and the average of these three times was calculated, giving a mean target fixation time for each condition. On fewer than 1% of the trials, the crosshairs were lost during the trial (due to unstable signals from the corneal reflection or pupil). These trials were excluded from the analysis, and the average fixation time for the condition was calculated using the remaining trials. Adults fixated the target on 100% of these remaining trials. Therefore, target fixation time, but not target fixation accuracy, was analyzed.

### Analysis of target fixation times

Fig. 3 gives the mean target fixation times for the four conditions: within/near, between/near, within/far, and between/far. It appears that target fixation was faster when the background was between-category than when it was within-category for both the far and near conditions.

This was supported by a two-way repeated measures analysis of variance (ANOVA) looking at the effects of target–background categorical status (within/between) and chromatic separation size (near/far). Target fixation time was faster for the between-category conditions ($M = 397$ ms, $SD = 53$) than for the within-category conditions ($M = 440$ ms, $SD = 92$), $F(1,29) = 8.26$, $MSE = 7$, $p < .01$. Target fixation time was not significantly faster for the far conditions ($M = 407$ ms, $SD = 85$) than for the near conditions ($M = 430$ ms, $SD = 70$), $F(1,29) = 1.86$, $MSE = 9$, $p = .18$.

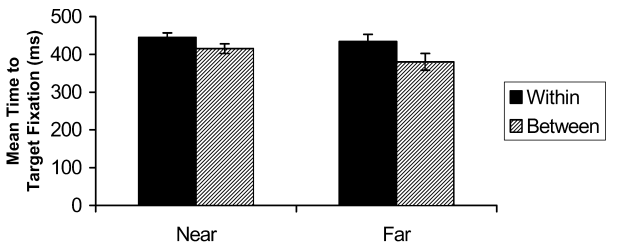


Fig. 3. Mean target fixation times (±1 *SE*) for the four conditions in Experiment 1: within/near, between/near, within/far, and between/far.

There was no significant interaction between categorical similarity and chromatic similarity, $F(1,29) = 1.46$, $MSE = 3$, $p = .24$.

### *Discussion*

Adults were faster at fixating the target when the target–background chromatic difference was between-category than when it was within-category. The between-category advantage was found, and the size of this advantage did not differ significantly across both chromatic separation sizes. Therefore, we found a category effect on target fixation time in adults for two chromatic separation sizes. Target fixations were not faster when the target–background chromatic difference was 40ΔE than when the chromatic difference was 23ΔE. Therefore, we did not find an effect of target–background chromatic separation size on target detection in adults. One explanation for the lack of an effect of chromatic separation size could be that the difference in the two chromatic separation sizes (17ΔE) is not large enough to produce a difference in target fixation time. An alternative explanation is that only a qualitative categorical code, and not a quantitative physical code, affects target detection time on the task (see Bornstein & Korda, 1984). Further research is needed to investigate this.

Are these category effects necessarily perceptual? We believe so. It is highly unlikely that the category effect is based on a memory process. The participants were not asked to memorize the target color and then detect it, so effects such as the shift toward prototype are unlikely to occur on this task. Adults were not asked to make any explicit judgment about the target; they were just told to look at the screen, and the targets were found rapidly (average target fixation time = 413 ms). Therefore, we claim to show that the origin of categorical responding to color in adults is in perceptual processes.[6] In Experiment 2, we investigated whether an equivalent effect can be found in 4-month-olds.

## Experiment 2: Categorical responding to color by infants on a target detection task

In Experiment 1, the categorical status of the target and background affected adults' target fixation times. Because the task was a target detection task, it was argued that this category effect is a perceptual effect. In Experiment 2, we tested for a perceptual category effect in 4-month-olds using the same task and some of the stimuli from Experiment 1. If infants identify the target more frequently and more quickly when the background is between-category than when it is within-category, this would

[6] One reviewer gave the interesting suggestion that the category effect may be due to chromatic induction effects. The primary effect of chromatic induction would be equivalent to simultaneous color contrast in which the color of the background shifts the perceived color of the target, effectively increasing separation between target and background. However, the size of this effect would be approximately the same for the within- and between-category conditions and is therefore unlikely to be the source of the category effect (Smith & Pokorny, 1996; Teufel & Wehrhahn, 2004; Wachtler, Sejinowski, & Albright, 2003).

suggest that infants' color categorization is perceptual. Infants' performance on the task would also allow us to assess whether infants at 4 months of age are capable of discriminating two colors if they are from the same color category. In addition, comparisons between adults' and infants' performances on the task can be made.

Eye tracking was first used to study infant perception during the 1960s (e.g., Salapatek & Kessen, 1968; for an outline of the development of the technique, see Aslin & McMurray, 2004). Since then, eye tracking has been used to investigate a variety of issues. For example, object perception (Gredebäck & von Hofsten, 2004; Johnson, Slemmer, & Amso, 2004; Lécuyer, Berthereau, Taíb, & Tardiff, 2004), face perception (Hunnius & Geuze, 2004), visual search (Adler & Orprecio, 2005), and categorization (Aslin & McMurray, 2004).

The benefits of using eye tracking to assess infant perception are obvious. Eye tracking allows us to record what the infant looks at, when the infant looks, the length of fixation, and the pattern of looking with great accuracy. The long familiarization and habituation phase of novelty preference and habituation techniques is not needed to be able to assess discrimination, and inferences are not based on assumptions about preference. However, with these benefits come disadvantages. As Hunnius and Geuze (2004) stated, the technique must "cope with a number of problems inherent to using a complex and highly sensitive technique with delicate and unpredictable subjects" (pp. 233–234). Calibration can be difficult with infant participants because infants cannot be instructed to fixate various points on the screen during the calibration procedure (Aslin & McMurray, 2004). A good eye track will not be obtained for some infants, and even when infants have been calibrated successfully, excessive head movement, scrunching up of the eyes, and not looking at the display can also lead to the loss of much data (Haith, 2004). For example, a good eye track will sometimes be achieved for only a small percentage of the trials (Johnson et al., 2004), and a good eye track can also be difficult to sustain over even short periods of time (Hunnius & Geuze, 2004).

In the current experiment, a number of measures were taken to try to deal with these problems. To increase the chance of getting enough trials per condition with a good eye track, the number of trials per condition was doubled compared with that in Experiment 1. However, this increased the length of the experiment, thereby also increasing the chance of attrition due to infants' short attention spans. Therefore, only one of the stimulus separation sizes (40ΔE) from Experiment 1 was tested. The larger separation size was chosen because this maximized the possibility of within-category discrimination. It was also hoped that having 4-s trials that did not start until after the infant fixated the flashing bull's-eye would increase the chance of a good eye track being obtained.

## *Method*

### Participants

A total of 21 infants took part in the study. Of these, 6 infants were not includedin the final sample due to a reported family history of color vision deficiencies

(1 infant), equipment failure (2 infants), and general fussiness (crying/excessive head movement) that made eye tracking difficult (3 infants). The mean age of the final sample of 15 infants (7 girls and 8 boys) was 19.53 weeks ($SD = 1.13$).

### Apparatus and experimental setup

The apparatus was the same as that in Experiment 1. The experimental setup differed slightly, with the monitor being on the floor and not on a table. Each infant was seated 70 cm away from the screen in a baby car seat that was also on the floor. A small pillow was placed behind the infant's head to make him or her upright enough for the pan/tilt camera to capture the eye. A U-shaped pillow was also placed on either side of the infant's head to stabilize the head and to gently discourage excessive head movement.

### Stimuli and design

The stimuli were the within- and between-category target and background stimuli, with a separation size of 40ΔE, from Experiment 1. Each infant saw six within- and between-category trials, with each lasting 4 s. As in Experiment 1, before each trial, a flashing bull's-eye image was presented in the center of the screen, followed by a gray screen that was shown for 250 ms.

### Procedure

The infant was shown a Powerpoint presentation of moving black and white shapes, faces, and patterns. This was shown to keep the infant fixated on the screen while obtaining the corneal reflection and pupil signals. A two-point calibration procedure (points 1 and 9) was used for the infants instead of the nine-point procedure used for the adults. Using two points rather than nine points is typical in infant eye-tracking studies (Aslin & McMurray, 2004) because infants might find it difficult to sustain attention for all nine points. Infants were shown the flashing bull's-eye at calibration point 1, a small movement of the eye was looked for in monitor A, and if the corneal reflection and pupil signals were registering, the location of these signals at point 1 was recorded. This was then repeated for point 9. After both points were completed, accuracy was checked by flashing the bull's-eye at three randomly chosen points shown consecutively. If the crosshairs did not hit the bull's-eye on one of the points or if no crosshairs appeared at all, the Powerpoint presentation was played again to reengage the infant's attention and the calibration procedure was repeated. After accurate calibration was achieved, the time code generator and video recording were started.

As in Experiment 1, the flashing bull's-eye was shown in the center of the display, and after the experimenter was sure that the infant was centrally fixated and that both the corneal reflection and the pupil signals were registering, the trial was started. This was repeated until all 12 trials were completed.

## *Results*

### Analysis of eye movements

Eye movements were analyzed and target fixation times were calculated as in Experiment 1. There were 180 trials in total (12 for each of the 15 infants). Of these trials, 75% (135 trials) were completed successfully. Trials were considered unsuccessful and excluded if the infant was not centrally fixated at the onset of the trial (1 trial), the infant's foot obstructed the camera's view (2 trials), the infant was crying or sick (6 trials), crosshairs were lost due to unstable corneal or pupil reflexes (9 trials), or the infant looked away during the trial and the eye track was lost (27 trials). The average number of trials completed by each infant was 9, and all infants completed a minimum of 2 trials per condition.

### Percentage of target fixations

Of the 75% of trials included in the analysis, the target was fixated on 86.5% of the trials (117 trials). Therefore, the average number of trials on which the target was fixated was 7.8 trials per infant, and all infants fixated the target on a minimum of 2 trials per condition. The percentage of trials on which the target was fixated was not significantly different for within-category trials (85% of the trials, $SD = 20.2$) than for between-category trials (88% of the trials, $SD = 18.8$), $t(14) = 0.71$, $p = .49$.[7]

### Analysis of target fixation times

The mean target fixation for each condition was calculated using the fixation times for successful trials when the target was fixated. All infants fixated the target at least twice for each condition. Fig. 4 gives the mean target fixation times for the within- and between-category conditions for the infants in the current experiment and, for comparison, the equivalent within- and between-category conditions for the adults in Experiment 1 (see also Table 2). Considering the infant target fixation times, it appears that target fixation is faster when the categorical status of the target and background is between-category than when it is within-category.

This was supported by a *t* test comparing mean fixation times for within- and between-category conditions. Target fixation time was faster for the between-category condition ($M = 1101$ ms, $SD = 539$) than for the within-category condition ($M = 1529$ ms, $SD = 660$), $t(14) = 3.66$, $p < .005$.

## *Discussion*

There was no effect of categorical status on the percentage of targets fixated for within- and between-category trials. Although the target was fixated more on

[7] For arcsine transformed data, $t(14) = 0.75$, $p = .47$.

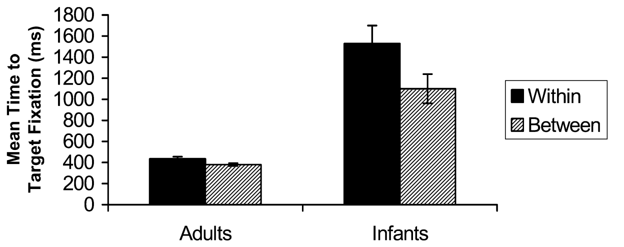


Fig. 4. Mean target fixation times (±1 *SE*) for the within/far and between/far conditions for adults (Experiment 1) and for infants (Experiment 2).

Table 2
Mean target fixation times (ms) for two conditions (within/far and between/far) in Experiment 1 (adults) and the two equivalent conditions in Experiment 2 (infants)

| Participants | Within | Between |
|---|---|---|
| Adults (Experiment 1) | 434 (118) | 380 (70) |
| Infants (Experiment 2) | 1529 (660) | 1101 (539) |

*Note.* Standard deviations are in parentheses.

between-category trials (88% of trials) than on within-category trials (85% of trials), this difference was not significant. However, there was a significant effect of categorical status on target fixation time. Infants were on average approximately 400 ms faster when searching for the target on a between-category background than when searching on a within-category background.

## Categorical status and target fixation accuracy

Why was there no effect of categorical status on target fixation accuracy? One explanation is that the length of the trial (4 s) was sufficiently long for targets to be found most of the time whether within- or between-category. The average times to find a target were 1529 ms ($SD = 660$) for within-category stimuli and 1101 ms ($SD = 539$) for between-category stimuli. Therefore, if the trial length had been 1.5 s instead of 4 s, a categorical effect on accuracy would have appeared. In addition, if the chromatic separation size between stimuli had been smaller, target detection would have been harder and categorical effects on accuracy also may have appeared.

Considering the lack of novelty preference and dishabituation for within-category stimuli in past studies of infant color categorization, it is interesting that in this experiment targets were detected even if the background was within-category. We discuss this further in the General discussion.

### *Categorical status and target fixation time*

What does the effect of categorical status on target fixation time indicate? The effect of categorical status shows that the chromatic discrimination was faster when the chromatic difference between target and background was between-category than when it was within-category. Therefore, infants were responding categorically on the task. As mentioned in the Experiment 1 discussion, the target detection task is considered to be a perceptual task. Therefore, we claim that the origin of categorical responding during infancy is in perceptual processes.

## General discussion

In Experiment 1, the categorical status of the target and background affected target detection time in adults. Adults were significantly faster at detecting the target when the background was from a different color category than when it was from the same color category, even though target–background stimulus separations were equated in CIE color space (L*u*v*). In Experiment 2, a comparable effect of categorical status was found, as 4-month-olds were significantly faster at detecting the target when the background was from a different color category than when it was from the same color category.

### *Can infants discriminate within-category stimuli?*

Category effects have been found in past studies of infant color perception (Bornstein et al., 1976; Franklin & Davies, 2004). Novelty preference or dishabituation is shown if the novel stimulus is from a different category but is not shown if the novel stimulus is from the same category. Even for large within-category separation sizes, a significant novelty preference or dishabituation to a novel within-category stimulus has not been found. Using a target detection task here, we showed that 4-month-olds are indeed capable of discriminating two stimuli from the same color category. Infants detected a green target on a green background on 85% of the trials.

Why do infants show evidence of within-category discrimination on the target detection task but not on novelty preference or habituation tasks? Could it be that the within-category stimuli in the current investigation were more easily discriminable than those in Bornstein and colleagues' (1976) and Franklin and Davies's (2004) investigations? This is highly unlikely. Here the within-category stimuli were separated by 40ΔE units. Some of the within-category separation sizes in Bornstein and colleagues' investigation were much larger than 40ΔE. For example, if Bornstein and colleagues' highly saturated wavelength separation sizes are converted to the CIE metric, some of the within-category separations are as large as 252ΔE—more than six times larger than the separation size in the current investigation. In addition, the within-category stimuli of the current investigation differed only in hue. In Franklin and Davies's investigation, for one of the within-category stimulus pairs, a lightness difference was introduced to maximize within-category stimulus separation. The stimuli of the current investigation, according to CIE color space, should actually be much less discriminable than the stimuli from Bornstein and colleagues' and Franklin and Davies's investigations. Therefore, the presence of within-category discrimination in the current investigation was not due to the within-category stimuli being more discriminable than those in past studies.

Another explanation could be that there is something in the nature of the novelty preference and habituation techniques that changes the nature of infants' responses so that novelty preference and habituation do not measure pure discrimination. Perhaps novelty preference and habituation encourage infants to respond prototypically. For example, perhaps on these tasks effects such as Huttenlocher and colleagues' (2000) shift toward prototype are at play. If stimuli are represented as their prototype on these tasks, within-category stimuli having the same prototype would be not be discriminable. There is no direct evidence, however, to suggest that infants respond prototypically on these tasks, so this explanation is highly speculative. The explanation could be empirically tested by manipulating the distance of the novel stimulus from a habituated or familiarized prototypical stimulus. If shift toward prototype effects are at play, novelty preference would not be affected by the stimulus manipulation.

A more likely explanation for the presence of within-category discrimination on a target detection task, but not on a novelty preference or habituation task, is that the target detection task is more sensitive to infants' discrimination. The target detection task does not rest on assumptions about preference and does not require multiple trials to be able to assess whether discrimination can be made. Recording eye movements allows the experimenter to see instantly and accurately whether infants are discriminating the two stimuli. It is possible that infants actually discriminate the within-category stimuli on the novelty preference and habituation tasks but that the measure of discrimination on these tasks is not sensitive enough to detect this. The implications of this are that novelty preference and habituation tasks might seriously underestimate infants' perceptual abilities.

So, in the current investigation, we found that infants can discriminate two within-category stimuli after all. Therefore, the argument that categorical responding to color in infants is more absolute than it is in adults no longer seems to hold. On a target detection task, infants showed the same pattern of categorical responding as did adults. Infants could discriminate within-category stimuli; they were merely slower at doing so than when they were discriminating stimuli from different color categories.

### *Is infant color categorization perceptual?*

Category effects shown by adults on 2-AFC tasks (e.g., Roberson et al., 2000) are not necessarily perceptual; they may be memory based (Huttenlocher et al., 2000), or they may even be due to a verbal labeling strategy (Roberson & Davidoff, 2000). However, category effects shown by adults on visual search tasks (e.g., Daoutis et al., 2005), due to the perceptual nature of the tasks, are likely to be perceptual. In the same way, the categorical responding by infants on novelty preference or habituation tasks need not necessarily be perceptual; this too could be based on a memory process. However, in the current study, we showed categorical responding by infants on a perceptual task that cannot be completed using memory. Therefore, we suggest that a truly perceptual form of color categorization during infancy does exist.

### *Comparisons of infants' and adults' responses*

There were some differences in the ways that the adults and infants responded on the target detection task. For example, infants were on average approximately three times slower than adults at fixating the target than were adults. This was likely due to various factors. First, infants are less sensitive to chromatic differences than are adults (e.g., Knoblauch et al., 2001). Second, infants' eye movements are generally slower than adults' eye movements (e.g., Adler & Orprecio, 2005). Third, at 4 months of age, infants' attention is still developing (e.g., Shaddy & Colombo, 2004). Another difference between the infant and adult data was that the mean difference of within- and between-category fixation times was much smaller in adults than in infants, although the standard errors for adults were also much smaller. Unfortunately, it is difficult to sensibly compare the size of the category effect statistically in adults and infants due to the large difference in overall target fixation times. However, despite these differences, we believe that the category effect shown by infants is comparable to that shown by adults. The task was the same for the two samples—both infants and adults were just required to look—and the method of assessing target fixation (with eye tracking) was also the same for both infants and adults. Further studies are needed to verify the equivalency of the infant and adult category effect. For example, ERPs have been used to explore the underlying neural mechanisms of categorization (e.g., Campanella, Quinet, Bruyer, Crommelinck, & Guerit, 2002), and using this technique on both infants and adults could highlight differences and similarities in infant and adult perceptual color categorization.

### *Origin and nature of color categorization*

These findings have implications for the current debate about the origin and nature of color categorization. Linguistic relativists, who argue that color categorization is linguistically constructed, have been skeptical of the categorical responding shown by infants on habituation and novelty preference measures, stating that "it is difficult to know exactly what perceptual ability [the measures] tap into. ... [Infants may] 'prefer' to look at certain stimuli rather than others for a reason that is not related to perceptual sensitivity" (Özgen, 2004, pp. 97–98). It has been argued that using "a measure more suitable for assessing infants' ability to discriminate colors would be likely to provide crucial insight into the origin of color categorical perception" (pp. 97–98). The findings of the current investigation clearly show that prelinguistic infants respond categorically to color on a task that is sensitive to discrimination (i.e., on a task that is not a novelty preference or habituation task), that this categorization is perceptual, and that the category effect shown by infants is comparable to the category effect shown by adults. Therefore, the findings of the current study are problematic for the idea that color categorization is linguistically constructed.

An alternative account of color categorization is that perceptual color categorization is hardwired and universal, yet the locations of category boundaries are reorganized by language later on in development. Parallel models can be found for speech perception (Werker & Tees, 1984) and spatial perception (Hespos & Spelke, 2004).

What evidence is there that color categorization is perceptually reorganized? There is evidence that perceptual color categorization is universal before color term acquisition (Franklin et al., 2005) and that there are differences in perceptual color categorization in children after color term acquisition (Daoutis et al., in press). However, further research is needed to explore the plausibility, and to specify the mechanisms, of the perceptual reorganization model.

### *Future applications of the target detection task*

Recording infants' eye movements when they perform the target detection task has proved to be a sensitive, efficient, and accurate way of assessing infants' perceptual abilities. Infants' attention seems to be captured by the task—by the flashing bull's-eye and the sudden onset of color—and this is reflected in the fact that good eye tracks were obtained on 75% of the trials. The target detection task was designed to investigate the nature of infant color categorization. However, the task can also be used to investigate other aspects of infant color perception, for example, to estimate discrimination thresholds at different points of the color space and to investigate infants' attention to color. If techniques based on preference or habituation underestimate infants' perceptual abilities, it is possible that the target detection task coupled with eye tracking will reveal that infants' color perception is more developed than contemporary research suggests.

## Conclusions

Infants and adults were faster at fixating a colored target when the color of the background was between-category than when it was within-category, even though between- and within-category separation sizes in CIE color space ($L^*u^*v^*$) were equated. Contrary to the findings of previous studies of infant color categorization that have used novelty preference and habituation techniques, infants were capable of discriminating a within-category chromatic difference on a target detection task. It is suggested that novelty preference and habituation techniques seriously underestimate infants' ability to discriminate color. Because the target detection task is a perceptual task, it is claimed that the categorical responding shown by adults and infants on this task is perceptual. Further research is needed to explore the underlying retinal, neural, and/or cortical mechanisms of perceptual color categorization in infants and adults.

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