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Language suppression effects on the categorical perception of colour as evidenced through ERPs

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ABSTRACT

It is unclear how language influences colour perception so as to lead to the categorical perception of colour. This is particularly true when considering visual tasks that involve minimal memory requirements. In the present experiment we investigated this question by employing a "same–different" judgment task in which participants were asked to compare the colours of two presented visual features (a square and its surrounding frame), presented to the left visual field (LVF) or the right visual field (RVF), while event-related potentials (ERPs) were recorded. The "different" colour trials were of two types, including those consisting of within-category differences (e.g. two different shades of blue) and those consisting of between-category differences (i.e. blue vs. green), with matching hue differences for within-category comparisons and between-category comparisons. The ERP results show that, over the midline fronto-central scalp region, responses to the within-category stimuli presented in the RVF demonstrated a more negative N2 component (260–310 ms post-stimulus) than either the responses to the between-category stimuli in the RVF, the between-category stimulus in the LVF, or the within-category stimulus in the LVF. Further, the responses for the within-category stimulus in the RVF resulted in a P3 component with a longer latency than that observed for the other three conditions. The results observed in this rapid colour discrimination task suggest that the categorical perception of colour stimuli presented in the RVF may result from an effect of language-related processes suppressing the capacity to discriminate two shades of colour within the same colour category.

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1. Introduction

It has been well documented that colour perception exhibits characteristics of categorical perception (Bornstein and Korda, 1984; Kay and Kempton, 1984). This has been demonstrated by faster or more accurate performance on between-category discrimination (e.g. comparing blue to green) than on within-category discrimination (e.g. comparing two different shades of blue). This is true even when the differences in hue for between-category and within-category differences are equated. A great deal of research on the categorical perception of colour has provided evidence supporting the idea that it is related to human language processes (Kay and Kempton, 1984; Roberson and Davidoff, 2000; Roberson et al., 2000, 2005; Pilling et al., 2003; Franklin et al., 2008a,b). If a speaker's verbal labels for two presented colours differ (e.g. blue vs. green), the categorical perception of colour will be observed at the boundary between the labeled colour categories (Roberson et al., 2005, 2000).

The question then arises as to how, specifically, language results in the categorical perception of colour. Most previous studies have measured the categorical perception of colour by using experimental tasks that involve memory (Franklin et al., 2005). An example of such a task is one in which participants are shown a coloured stimulus and subsequently (at some time interval later) shown two alternative stimuli and are asked which one is identical in colour to the originally shown target. It has been posited that in such experimental tasks, verbal coding may enhance colour discrimination so as to result in the categorical perception of colour (Roberson and Davidoff, 2000). This hypothesis has drawn support from evi-

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dence demonstrating that the categorical perception of colour is not observed when linguistic processing is suppressed, such as when a verbal interference task is performed (Roberson and Davidoff, 2000; Pilling et al., 2003).

Therefore, while it is clear that tasks with memory demands have demonstrated effects of language on categorical perception, these effects might be at least partially contributed by the effect of language on the colour *memory* rather than on colour *perception* per se. To demonstrate the role of language in colour perception specifically, recent studies have shown that the categorical perception of colour can also be observed in visual tasks that minimize the involvement of memory (Gilbert et al., 2006; Drivonikou et al., 2007; Roberson et al., 2008; Winawer et al., 2007; Franklin et al., 2008a,b). In these tasks, the categorical perception of colour is not observed when a verbal interference task is performed (Gilbert et al., 2006; Winawer et al., 2007). In particular, it was found that the categorical perception of colour was only observed (or more strongly observed) when a target was presented to the right visual field (RVF) compared to the left visual field (LVF), from which the stimuli information were processed in the left hemisphere that is specialized for language (Gilbert et al., 2006; Drivonikou et al., 2007). These results suggest that, even when a task has minimal memory requirements, language can still influence colour perception. This conclusion is further supported by two fMRI studies, which demonstrated that language areas are involved in colour target search tasks and colour discrimination tasks (Tan et al., 2008; Ting Siok et al., 2009). However, it remains unclear as to how verbal labels affect perceptual performance in a visual task involving minimal memory requirements.

The purpose of the present study was to investigate how the categorical perception of colour is affected by language in a visual task with minimal memory requirements. More importantly, the electrophysiological markers of such processes will be revealed by recording high-density (64 channels) event-related potentials (ERPs). ERPs are recordings of the brain's electrical activity that are time-locked to the presentation of external stimuli. Thus, ERPs provide a means to evaluate the timing of cognitive processes prior to the initiation of a behavioural response. ERP data will allow for a more precise examination of the time course of activation for the categorical perception of colour, thereby more effectively determining the stage at which language influences colour perception.

In this experiment, participants viewed a display that included two discrete left and right sections, each containing a square and its surrounding frame separately positioned in the left and right side of the visual field respectively. Participants were required to perform a "same–different" judgment task where they were asked to detect whether there was a difference between the colour of the square and the colour of its surrounding frame on either the left or the right visual field. The stimuli were designed to facilitate the detection of colour differences based on information from one side of the visual field only, thus offering a more sensitive measure of laterality. Using this novel visual task, the ERP data was recorded and analyzed for the "different" judgments, involving a square and frame made up of different hues that were either from the same colour category (i.e. within-category comparison, such as two shades of blue) or from different colour categories (i.e. between-category comparison, such as blue and green), with matching hue differences for within-category comparisons and between-category comparisons. Based on the results of previous studies using visual search tasks (Gilbert et al., 2006; Roberson et al., 2008), we predicted that the differences between the ERP components for the between-category and within-category conditions would be larger for the items appearing in the RVF compared to the LVF.

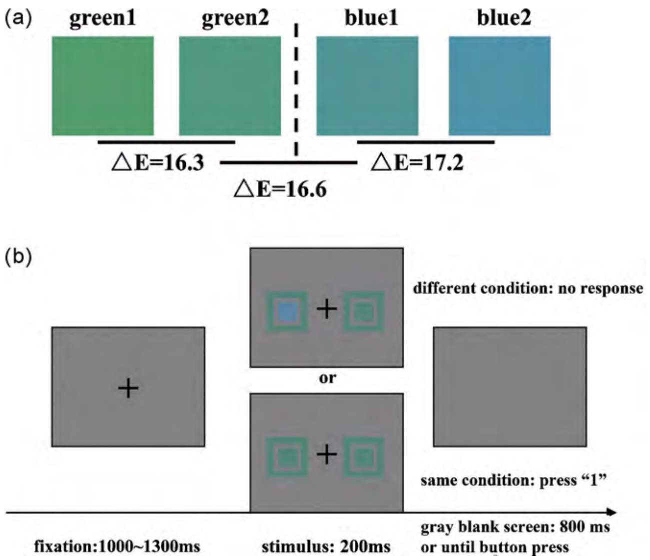

Fig. 1. (a) The four colours used in the current experiment. (b) Overview of the experimental procedure.

2. Experimental procedures

2.1. Participants

Fourteen undergraduate students (seven female, seven male with a mean age of 23.4 years) participated in the experiment as paid participants. All of the participants were right-handed, native Chinese speakers with normal or corrected-to-normal vision. None of the participants were colour blind. All of the participants gave their written informed consent before participating in the study. This research was approved by the Research Ethics Committee of Southwest University of China and was conducted in accordance with the Declaration of Helsinki.

2.2. Stimuli

The stimuli were displayed on a gray background on a 17 in. CRT monitor with a resolution of 1024×768 and a refresh rate of 100 Hz. The screen was positioned 70 cm away from the viewer's eyes. The presented stimuli consisted of two coloured squares, each surrounded by a coloured frame. The two squares and their corresponding frames were symmetrically positioned to the left and right of the fixation point (see Fig. 1). The size of each square was $1.2\,\text{cm} \times 1.2\,\text{cm}$ (with a visual angle of $1^\circ \times 1^\circ$). The outer edge of the surrounding frame was $4\,\text{cm} \times 4\,\text{cm}$ (with a visual angle of $3.3^\circ \times 3.3^\circ$) and the inner edge of the surrounding frame was $2.3\,\text{cm} \times 2.3\,\text{cm}$ (with a visual angle of $1.9^\circ \times 1.9^\circ$). The horizontal distance between the center of the coloured square and the central fixation point was 4 cm (with a visual angle of 3.3°).

The four colours that were used for the squares and their frames and their Munsell values were derived from those used by Gilbert et al. (2006). Here they were labeled "green1", "green2", "blue1", and "blue2" and their Munsell values were 7.5G 6/8, 2.5BG 6/8, 7.5BG 6/8 and 2.5B 6/8 respectively. We used approximate CIEL*u*v* values as follows: green1 = (62.3, −52.3, 23); green2 = (62.4, −50.4, 6.85); blue1 = (62.3, −48.3, −9.56); blue2 = (62.7, −46.4, −26.6). The corresponding CIE coordinates were measured with a Minolta CS-100A chroma meter. In 79% of the trials, one of the two coloured squares (left or right) had a different colour/hue than its surrounding frame (i.e. "different" condition), which had the same colour/hue as the square and frame on the other side of the visual field. For the remaining 21%, of trials, both squares had the identical colour as their surrounding frames (i.e. "same" condition).

For the different condition, there were two types of colour pairs that were presented, where a "pair" consisted of a square and its surrounding frame. These included, within-category (WC) pairs (i.e. green1–green2 and blue1–blue2) and between-category (BC) pair (i.e. green2–blue1). In reference to the CIEL*u*v* colour space, the distances between the stimuli were: green1–green2, 16.3; green2–blue1, 16.6; and blue1–blue2, 17.2. Thus, the average distance of the WC pairs (green1–green2 and blue1–blue2) was 16.75 and was approximately equal to the BC pair (green2–blue1) (see Fig. 1a).

2.3. Experimental design

Participants were seated in a dark, sound-attenuating room for the entire duration of the experiment. A preliminary task was conducted before the formal experiment in order to ascertain whether participants could discriminate the two colours (blue and green) and to establish a normal language boundary. In each trial

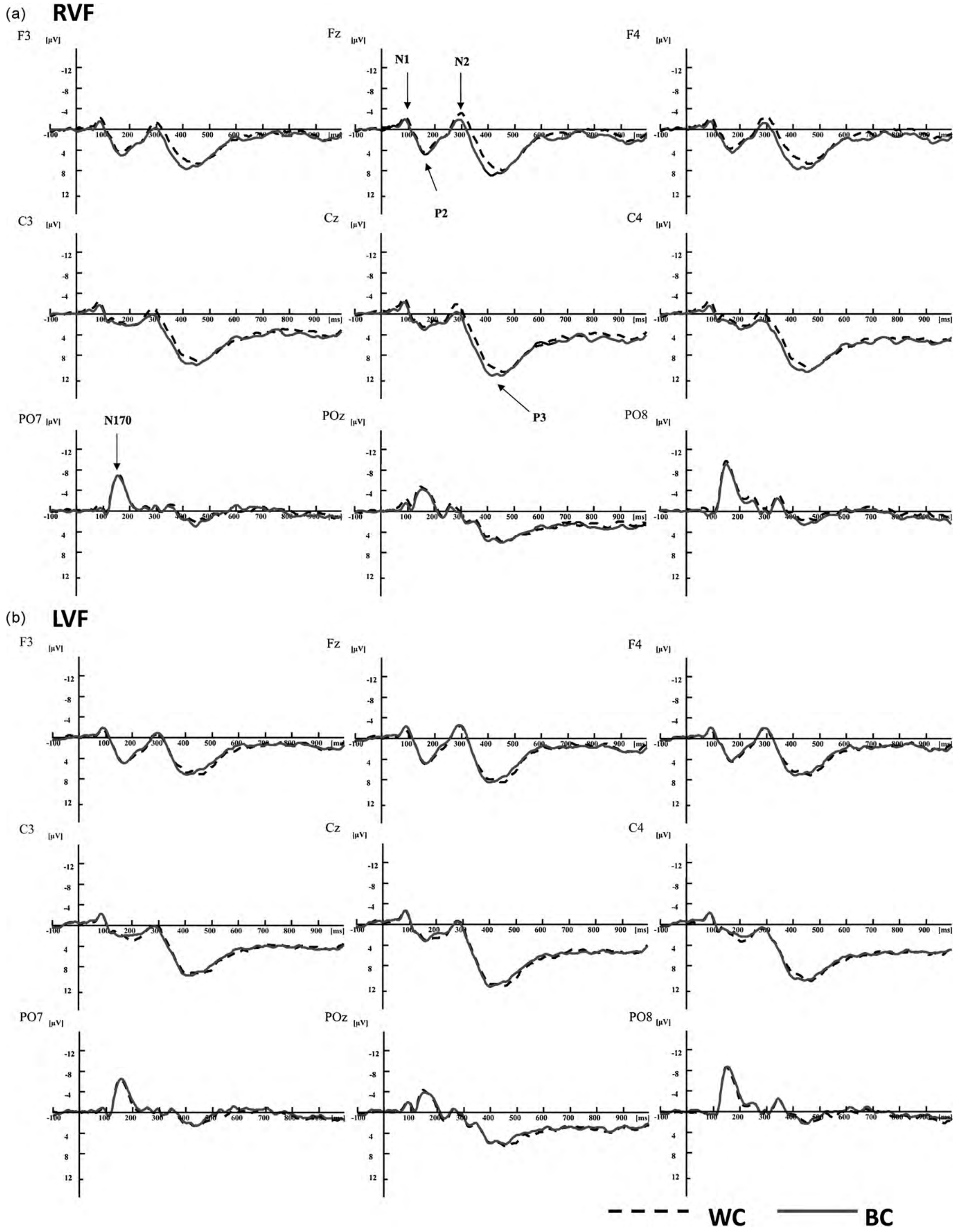

Fig. 2. (a) Grand average of the ERP data at the F3, FCz, F4, C3, Cz, C4, PO7, POz and PO8 sites for the WC and BC conditions in the RVF. (b) Grand average of the ERP data at F3, FCz, F4, C3, Cz, C4, PO7, POz and PO8 sites for the WC and BC conditions in the LVF.

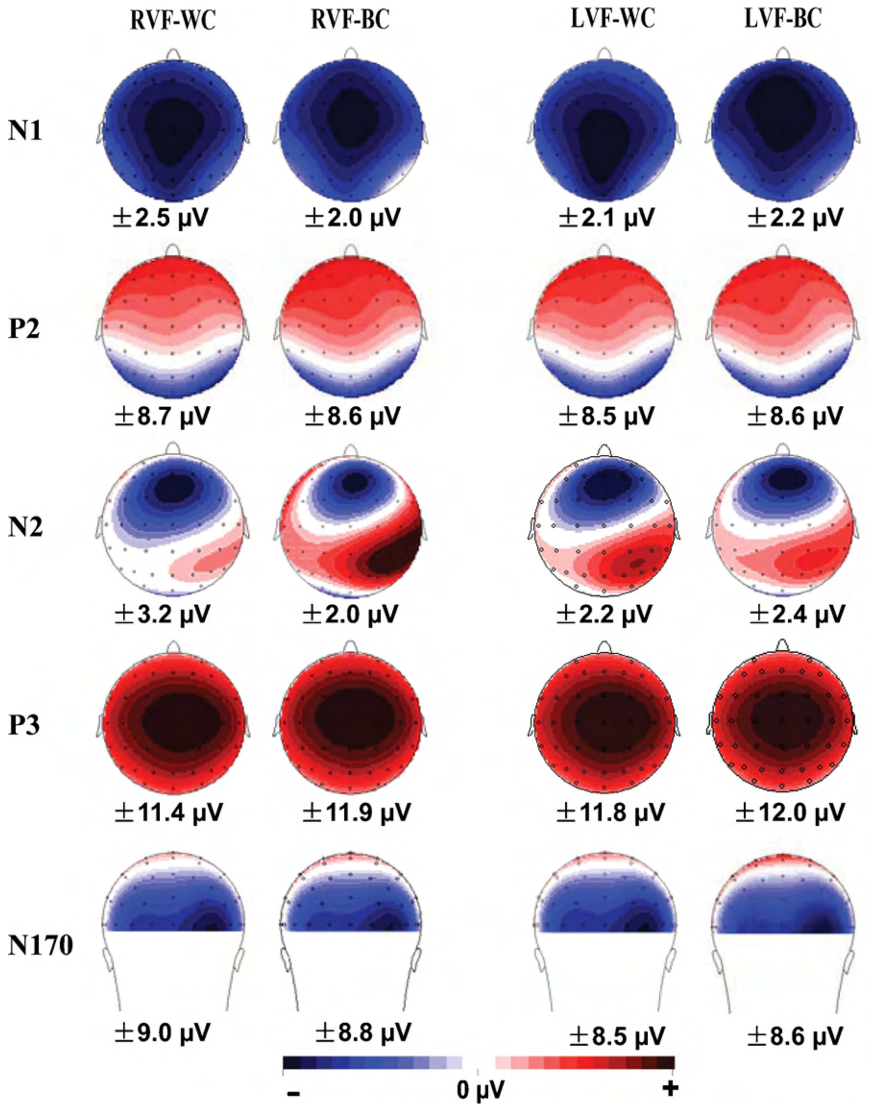

Fig. 3. The scalp topograph of N1, P2, N2, P3 and N170 for RVF-WC, RVF-BC, LVF-WC and LVF-BC.

of the preliminary task, one coloured square (one of the four colours: green1, green2, blue1 or blue2) was presented centrally on a neutral gray screen for 200 ms. Participants were required to label this stimulus as either green or blue by pressing the “G” or “B” key on the computer keyboard. Each coloured square was randomly presented 10 times, for a total of 40 trials. A criterion was set such that, only the participants who named all of the green1 and green2 squares as being green and all of the blue1 and blue2 squares as being blue, were allowed to participate in the formal experiment. Thirteen out of the 14 participants tested met these criteria.

In the formal experiment, participants were asked to judge whether there was a difference between one of the presented squares and its surrounding frame. If both of the squares and surrounding frames were of the identical colour, this was considered a “same” trial. If one of the two squares was of a different colour/hue from its surrounding frame, this was considered a “different” trial. Participants were not asked to specifically attend to one of the two square/frame pairs (presented on the left and right of the screen simultaneously), but rather to note any differences in either pair.

Each trial was performed in the following sequence (also illustrated in Fig. 1b). First, a fixation-cross appeared for a random duration ranging from 1000 to 1300 ms at the center of the screen. Next, the visual stimulus, which consisted of two squares each surrounded by a frame, was presented for 200 ms. Then, a blank gray screen was presented until either a response was made or 800 ms had elapsed. Participants were instructed to respond as quickly and accurately as possible. If a “different” trial was detected, no response was required. This response mode was used to avoid any ERP artifacts due to movement. If a “same” trial was detected, participants were instructed to press “1”. During all experimental trials, participants were instructed to maintain fixation.

Each block had 76 experimental trials comprised of 16 trials for the same condition (four trials for each of the four colours) and 60 trials for the different condition (20 for green1–green2, 20 for blue1–blue2 and 20 for green2–blue1). Within the different trials, the probability of each colour occurring as the colour of the square or the frame in each colour pair was equal. Square/frame pairs that differed in colour/hue were randomly presented in the LVF for half of the trials and in the RVF for the other half. The order of trials in the different conditions was randomized. Each participant first completed 20 practice trials, followed by eight 76-trial blocks.

2.4. Electrophysiological (EEG) recording and analysis

Brain electrical activity was recorded from 64 scalp sites using tin electrodes mounted on an elastic cap (Brain Product), with references on the left mastoid. Vertical electrooculogram (EOG) recordings were obtained using electrodes placed above and below the left eye. The total inter-electrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified by a 0.01–100 Hz bandpass and continuously sampled at a 500 Hz channel for offline analysis. All signals were digitally re-referenced to the average of the mastoids offline. Eye movement artifacts were rejected offline. Trials with eyeblinks (vertical EOG amplitudes exceeding ±100 μV), horizontal eye movements (horizontal EOG amplitudes exceeding ±25 μV), and response errors, were excluded from the analysis. In order to identify participants with small, yet systematic, eye deviations toward the target positions that were not detected by the horizontal EOG artifact rejection procedure, the average horizontal EOGs in response to stimulus arrays containing targets on the left and right side were computed. Using these waveforms, any systematic deviations of the eye position toward the target position were determined for each individual participant. The data from any participant who had a maximal residual EOG deviation exceeding ±3 μV (i.e. residual eye movement >0.2°) was rejected. However, all participants' EOG deviations were below this criterion. After all the data rejection steps, at least 86% of trials survived for each condition for each participant.

The ERP waveforms were time-locked to the onset of the stimulus. Only response waveforms for the different trials were analyzed. The averaged epoch for the ERP data was 1000 ms, including a 100-ms pre-stimulus baseline. The RVF and LVF ERP waveforms for each of the conditions were obtained after the ERP waveforms were averaged and after trials with incorrect responses were eliminated. On the basis of the grand average of the ERP data and topographical maps, the following nine electrode sites were selected for statistical analysis of the anterior N1 (90–110 ms) and P3 components (350–450 ms): [FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2]. Anterior P2 (130–190) and N2 (260–310) components were analyzed at the nine frontal and central sites [F1, Fz, F2, FC1, FCz, FC2, C1, Cz, C2]. For the interval of 260–310 ms, we also analyzed data from four additional parietal-posterior electrodes [CP4, CP6, P4, P6]. The posterior N170 component (140–190 ms) was analyzed at four posterior sites [PO7, P7, PO8, P8].

Amplitudes (baseline to peak) of these components (N1, P2, N2, P3 and N170) were analyzed using three-way, repeated measures, analyses of variance (ANOVA), with the following factors: electrode site, visual field (LVF and RVF) and colour-pair type (WC and BC). Peak latencies were analyzed using a 2 (visual field) × 2 (colour-pair type) ANOVA. For all ANOVAs, p-values were corrected for deviations according to Greenhouse Geisser when their degrees of freedom were more than one.

3. Results

3.1. Behavioural performance

The mean accuracies for the WC and BC pairs were 97 ± 3.46% and 98 ± 2.34% respectively when the target was presented in the right visual field, and 96 ± 6.79% and 97 ± 2.98% ms respectively when the target was presented in the left visual field. The data for mean accuracies for each participant were analyzed by conducting a 2 (pair types: within-category vs. between-category) × 2 (visual field: left vs. right) repeated measures ANOVA. The results showed no main effects and no interaction.

3.2. ERP waveform analysis

As shown in Fig. 2 (grand average of the waveforms) and Fig. 3 (scalp topograph), the N1, P2, N2, P3 and the N170, were elicited in all four conditions (RVF-WC, RVF-BC, LVF-WC and LVF-BC) and all of these components had similar scalp distributions. Repeated measures ANOVAs showed no main effects for colour-pair type with regards to the latencies and amplitudes of N1, P2 and N170.

For the N2 amplitude, results of the ANOVA revealed a significant main effect of colour-pair type ($F(1,12) = 5.983$, $p = .031$) and electrode site ($F(8,96) = 5.118$, $p < .001$). Significant interactions effects were also observed for colour-pair type × electrode site ($F(8,96) = 2.902$, $p = .042$), visual field × electrode site ($F(8,96) = 3.255$, $p = .041$) and colour-pair type × visual field ($F(1, 12) = 7.291$, $p = .019$). Based on a simple main effects analysis it was evident that in the RVF, the WC condition elicited more negative N2 amplitude than did the BC condition ($F(1,12) = 14.46$, $p = .003$). However, no significant difference was observed between the WC and BC conditions in the LVF ($F(1,12) = 0.05$, $p = .823$). Furthermore, there was a main effect of visual field for the WC condition ($F(1,12) = 4.79$, $p = .049$), but not for the BC condition ($F(1,12) = 1.45$, $p = .251$). Taken together, these results indicate that the N2 amplitude was more negative for the RVF-WC condition than for any of the RVF-BC, LVF-WC and LVF-BC conditions. A two-factor repeated measures ANOVA showed that there was no main effect of visual field or colour-pair type for the anterior N2 latency.

When we examined the N2 component (260–310 ms) through the scalp topograph (Fig. 3), it appeared as though, for the RVF, there was a strong posterior right positivity in the BC condition, but not so much in the WC condition. When we examined the activity of each electrode, four electrodes (CP4, CP6, P4, P6) showed this positivity. However, at the N2 component interval (260–310 ms), we did not find any obvious peaks, thus we did not treat them as distinct ERP components. We performed a 4 (electrode site) × 2 (visual field) × 2 (colour-pair type) ANOVA. The results of the ANOVA revealed a marginally significant main effect of colour-pair type ($F(1,12) = 4.264$, $p = .061$) and a marginally significant interaction effect between electrode site and colour-pair type ($F(3,36) = 2.563$, $p = .089$). It should be stressed, however, that the central and parietal electrode site is the major site in which P3 was observed and it is located next to the central site in which the N2 was observed. It is therefore possible that the modulation of this component by the colour pair in the RVF is due to the overlap of N2 and P3 components at the four electrode sites (CP4, CP6, P4, P6).

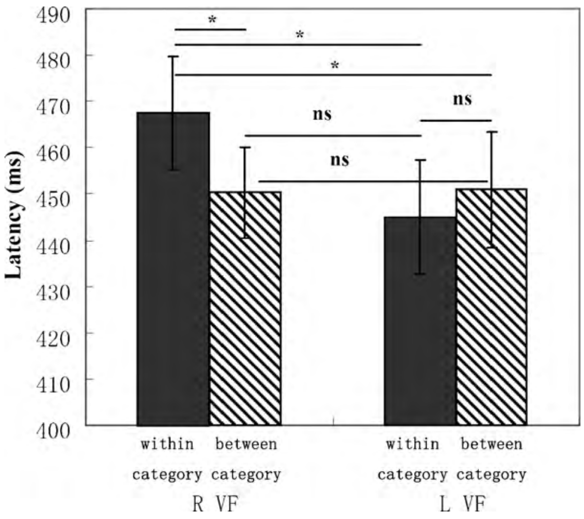

Fig. 4. The latency (with standard error bars) of the P3 component for RVF-WC, RVF-BC, LVF-WC and LVF-BC. $^{*}p < 0.05$, two-tailed t-test, $df = 12$ and $^{ns}p > 0.1$.

The ANOVA conducted on the P3 component amplitude revealed that neither of the main effects of visual field or colour-pair type, nor any of the interaction effects was statistically significant. Only a significant main effect of electrode position was observed ($F(8,96) = 3.678$, $p = .035$). The P3 amplitudes recorded at Cz were larger than those at other sites. However, with regards to the P3 latency, we found a significant main effect of visual field ($F(1,12) = 6.316$, $p = .027$) and a significant visual field × colour-pair type interaction ($F(1,12) = 17.978$, $p = .001$). Latencies of the P3 component were 467 ± 44, 450 ± 45, 445 ± 35, 450 ± 45 ms respectively for RVF-WC, RVF-BC, LVF-WC and LVF-BC conditions (see Fig. 4). A simple main effects analysis revealed a significant main effect of colour-pair type within the RVF ($F(1,12) = 18.64$, $p < .001$), but not within the LVF ($F(1,12) = 1.7$, $p = .216$). Furthermore, a significant main effect of visual field was observed for the WC condition ($F(1, 12) = 15.51$, $p = .002$), but not for the BC condition ($F(1,12) = 0.02$, $p = .893$). This indicates that the latency of the P3 was longer for the RVF-WC condition than for any of the RVF-BC, LVF-WC and LVF-BC conditions.

4. Discussion

In the present study, a visual discrimination task was used to investigate the ERP components related to language-based effects on colour perception. Scalp ERP analyses showed that, during the post-stimulus period (260–310 ms), a more negative N2 component was elicited over the midline fronto-central scalp region in the RVF-WC condition than in the RVF-BC, LVF-WC or LVF-BC conditions. Subsequently, the RVF-WC condition elicited a longer P3 latency than did the RVF-BC, LVF-WC or LVF-BC conditions. These results support the prediction that the differences between the ERP components for the BC and WC conditions would only be observed when the different square/frame pair appeared in the RVF.

There has been converging evidence from previous research showing that the fronto-central N2 component reflects an early monitoring of conflict (Lange et al., 1998; Nieuwenhuis et al., 2003; Yeung et al., 2004; Yeung and Cohen, 2006; Chen et al., 2008). For example, the fronto-central N2 has been observed in a go/no-go task in which participants were instructed to make speeded responses to frequent targets ("go") and to withhold responses to infrequent distractors ("no-go"). It has been found that the fronto-central N2 amplitude is more negative for infrequent no-go trials (Nieuwenhuis et al., 2003). The fronto-central N2 has also been observed in the Eriksen flanker task, in which participants are required to respond to a central item (i.e. an arrow or a letter) that is surrounded by distractor items. For example, this might involve reporting the direction of a rightward pointing arrow when it is surrounded by arrows pointing in either the same direction (no conflict) or in an opposite direction (conflict). In such a task, the amplitude of the fronto-central N2 has been shown to be enhanced under conflict conditions (Heil et al., 2000; Kopp et al., 1996; van Veen and Carter, 2002). In addition, Holmes and Pizzagalli (2008) found that for normal participants, the amplitude of the fronto-central N2 in a Stroop colour word interference task was more negative for incongruent colour words than for congruent colour words. However, for participants with impaired executive functioning, no amplitude differences were observed.

In light of this, we infer that the more negative fronto-central N2 component for the RVF-WC condition seen in the current experiment is likely indicative of a high-level conflict monitoring system. Clearly, two colours from the same colour category have the same verbal label, yet their physical properties differ. In our experiment, we asked participants to judge whether there were differences between a square and its surrounding frame in terms of their physical colour properties. If the colour of the square and the surrounding frame came from the same category (e.g. blue1–blue2) and participants were asked to compare them, the congruent name would conflict with the incongruent physical properties. This type of WC suppression has been described in detail by Roberson and Hanley (2010), who proposed that the nature of the categorical perception of colour does not result from superior colour discrimination for cross-boundary categories. Instead, they suggest that the discrimination of WC colours is hindered when perceptual properties and verbal labels are in conflict. Also, given that the left hemisphere is more highly specialized for language, it is reasonable to hypothesize that the automatic naming of colours would occur more readily in this hemisphere. Thus, a conflict would be more likely to occur for the stimuli presented in the LVF when comparing the physical properties of WC stimuli that are of different shades.

The stimulus difference in the RVF-WC condition elicited a later P3 component than it did in the RVF-BC, LVF-WC or LVF-BC conditions. Many previous studies have found that P3 latencies increase when the time required for low-level sensory processing or higher-level categorization also increases. However, P3 latency is not sensitive to the amount of time required to select and execute a response once a stimulus has been categorized (Polich, 1986, 1987; Magliero et al., 1984; Kutas et al., 1977). Thus, P3 latency has been thought to reflect the time it takes to categorize a stimulus before a response is made (Donchin and Coles, 1988). In light of the above evidence, the longer P3 latency that we observed in the RVF-WC condition suggests that participants needed more time to categorize the two stimulus colours as being different compared to the time required in the RVF-BC, LVF-WC and LVF-BC conditions. This result demonstrates that a clear feature of the categorical perception of colour (i.e. slower response for WC pairs than for BC pairs) was observed in the RVF, but not in the LVF. Thus, the pattern of results in the current study indicates that language-based processes can prolong the time required to discriminate two shades of the same colour. Accordingly, the results suggest that the longer P3 latency for the RVF-WC condition resulted from the need to differentiate two colours from the same language-assigned category based on their differing physical properties.

The similar differences in response times for stimuli presented to the RVF have been reported by Gilbert et al. (2006) in behavioural studies using a visual search task. They reported that the categorical perception of colour was only observed when the stimulus appeared in the RVF. Based on this result, it has been proposed that the categorical perception of colour in the RVF is verbally mediated by the left hemisphere language system (Gilbert et al., 2006; Drivonikou et al., 2007; Roberson et al., 2008). However, the response differences for the BC and WC pairs observed in the RVF trials cannot, by themselves, tell us whether the nature of the categorical perception of colour results from a facilitation of BC discrimination or a deficiency in WC discrimination (although the facilitation of BC discrimination as the mechanism of categorical perception is often assumed). The comparison of responses between stimuli presented to the RVF vs. the LVF can potentially answer this question. In our study, we found a later P3 and a more negative N2, in the RVF-WC condition than in the RVF-BC, LVF-BC and LVF-WC conditions. Thus, these results provide evidence for a deficiency in WC discrimination rather than a facilitation of BC discrimination. However, studies using visual search tasks, have found faster responses in the RVF-BC condition than in the RVF-WC, LVF-BC and LVF-WC conditions (Gilbert et al., 2006; Drivonikou et al., 2007). A potential reason for the different results observed in our study compared to others could be that in other visual search tasks participants were required to respond to targets presented in the LVF or RVF with a left-hand or right-hand key-press respectively. For right-handed participants, reaction times are likely to be faster for the right-hand than those for the left-hand, thus leading to overall faster responses for the RVF than LVF. This explanation is supported by the data from Franklin et al. (2008a,b) who investigated the categorical perception of colour by measuring the time that it took for participants to initiate an eye movement to the target, rather than to perform a button press. In their case, the results did not show a difference between stimuli presented to the RVF vs. the LVF in the BC condition.

Winawer et al. (2007) also used a same–different judgment task to investigate the categorical perception of colour. In their experiment, participants were shown three colour squares arranged in a triad and were asked to report which of the bottom two colour squares was perceptually identical to the square on top. The non-matching/distracter colour name was either the same as the name of other two squares or different. The results demonstrated that the observers' response times were faster when differentiating two colours with different names. Winawer et al. (2007) and Lupyan (2009) suggest that language-mediated distortions in perceptual performance arise as a function of the online interaction between lower-level perceptual processing and higher-level knowledge systems (e.g. language). It could be that language processes directly influence primary perceptual areas through feedback connections, or that a later decision-based mechanism combines inputs from these two processing streams. Mitterer et al. (2009) argue that a "different" response is informed by corresponding perceptual input and declarative knowledge, which therefore, leads to faster response times. Conversely, when declarative knowledge does not easily correspond to the perceptual input (i.e. "same" response for the same colour, but different hues), this leads to slower response times. In our current results, the longer P3 latency for the RVF-WC condition further supports these conclusions.

The categorical perception of colour in tasks with limited memory requirements has also been investigated using fMRI. For instance, in a study by Tan et al. (2008), participants were asked to perform a perceptual discrimination task on "easy-to-name" and "hard-to-name" coloured squares. The results showed that the discrimination for easy-to-name colours evoked stronger activation in the left brain area involved in language processing. Furthermore, Ting Siok et al. (2009) performed an fMRI study using the same experimental task as that used by Gilbert et al. (2006). They found that a stronger activation of the left brain area involved in language processing was observed in the RVF-BC condition compared to the RVF-WC condition. However, in our experiment we did not observe a hemifield difference. It is possible that, due to the limited spatial resolution, the ERP signal was not sensitive enough to pick up a localized difference as can be revealed using fMRI.

Recently there have been a few ERP studies dealing with the categorical perception of colour using visual oddball tasks (Holmes et al., 2009; Thierry et al., 2009; Fonteneau and Davidoff, 2007). In such tasks, participants were asked to view coloured patches presented centrally on a screen and to report the occurrence of less frequent, “deviant” stimuli when they appeared amongst a series of more frequently presented “standard” stimuli. These two types of stimuli (deviant and standard) were either drawn from colours of the same category or colours from different categories. ERP components reflecting the mismatch between the deviant visual input and a sensory-memory trace representing the standard stimuli were analyzed. In addition to the ERP components found in later stages of processing, these studies demonstrated that colour category can modulate ERP components related to early visual processing (e.g. posterior N1 and P1), providing evidence that the categorical perception of colour may occur at earlier perceptual stages. For example, Fonteneau and Davidoff (2007) found that the peak of the change-related positivity component related to N1 modulation for the BC difference waveform occurred earlier than for the WC difference waveform. This difference in peak latency for WC and BC conditions was interpreted as a neural correlate for the categorical perception of colour.

These results are in contrast to our results, in which we observed no significant modulation of colour category in the ERP components related to early visual processing. It is important to note that the visual oddball tasks in the abovementioned studies did not involve explicit colour discrimination per se, but instead focused on change detection. In our experimental task, however, the explicit discrimination of two simultaneously presented coloured stimuli was required. It has been suggested that the comparison of two colours, such as that required by our task, may be performed in the pre-frontal cortex after information about colour reaches that area (Danilova and Mollon, 2009). Further, it is reasonable to assume that the colour category should modulate some ERP components related to post-perceptual processes. It is possible that the two stimuli that participants were required to discriminate (regardless whether they were BC or WC) had a much larger difference than the difference between the BC and WC pairs. Consequently, even if the BC stimuli evoked a slightly different ERP signal than the WC stimuli, the difference might be too small to be detected. Thus, the categorical perception of colour might not be apparent in the modulation of the ERP in the early phase.

Another difference between our results and the other three studies that used a visual oddball paradigm (Holmes et al., 2009; Thierry et al., 2009; Fonteneau and Davidoff, 2007) relates to the laterality of the visual stimuli. Our stimuli were presented to both the LVF and the RVF, with colour differences between the central square and surrounding frame occurring on only one side. However, the stimuli used in the three ERP studies using a visual oddball paradigm were presented in the middle of the visual field, which could make it less effective for revealing differences in the extent of activation between hemispheres.

In addition, in our previous ERP study using a visual search task (locating a colour pop-out item) we found an “N2pc” component related to the lateralization effect of language on colour categorical perception (Liu et al., 2009). However, no N2pc component was evident in the current results. The N2pc is an ERP component defined literally as an enhanced negativity at electrodes that are contralateral and posterior to the position of the attended visual stimuli. This has typically been considered to be an index of visuospatial selective attention (Eimer, 1996, 1998). Previous studies on the N2pc component have typically used tasks that require participants to detect or locate pop-out items. This means that performance during these experimental tasks requires attention to be allocated to the position of the pop-out item. In contrast, in the current experiment, participants were required to judge whether or not a pop-out item was presented or not. Therefore, little or no attention to the position of the pop-out item was required and consequently, the presence of an N2pc component would not be expected.

5. Conclusions

The present study used ERP data to investigate how language influences the categorical perception of colour in tasks with a low memory demand. Results showed that a more negative N2 component was elicited by the RVF-WC condition compared to RVF-BC, LVF-WC and LVF-BC conditions between 260 and 310 ms post-stimulus over the midline fronto-central scalp region. Subsequently, the RVF-WC elicited a longer latency for the P3 component than did the RVF-BC, LVF-WC and LVF-BC. Together, our ERP data was consistent with the notion that the categorical perception of colour obtained using an experimental task that minimized memory requirements, may result from an effect of language-related processes that suppress the capacity to distinguish two different shades of colour within the same colour category.

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