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Event-Related Potentials Reveal Perceptual Simulation of Color in Language Comprehension

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Abstract

Two event-related-potential (ERP) experiments were conducted to investigate the perceptual simulation of color in language processing. ERP components measured from 80 to 150 ms (N1) and from 150 to 200 ms (P2) after the onset of congruent-color pictures both differed from the incongruent-color pictures in Experiment 1. However, there were no such patterns when a preceding object noun was added before the object pictures in Experiment 2. That is, the preceding object noun modulated the two early ERP components elicited by the following object picture that are known to be associated with perceptual processes. These results provided by far the strongest evidence that semantic processing cannot account fully for the congruence effects supposed to be indicate color representation.

Keywords: Perceptual simulation, Motor activation, Color, ERP

Introduction

Most of the existing evidence about sensori-motor simulation (e.g., Glenberg & Kaschak, 2002; Kaschak & Glenberg, 2000; Stanfield & Zwaan, 2001; Zwaan, 2004) investigate the activation of action representation in language processing. However, it would be incomplete to focus solely on action simulation in language processing. Other than actions and events, and even in actions and events themselves, language comprehension involves much representation for the full range of perceptual experience we ever have. However, there are only a handful of studies looking into perceptual simulation in language comprehension (Diane, Kiki, & Rene, 2007; Stanfield & Zwaan, 2001; Yaxley & Zwaan, 2007; Zwaan, Stanfield, & Yaxley, 2002), mainly in the area of visual shape. For the salient perceptual dimension of color, there is only one such study, though there are other two mainly focusing on the semantic representation of color (Klein, 1964; Naor-Raz, Tarr, & Kersten, 2003).

Connell (2007) is the only study which is claimed to show perceptual color simulation. In that study, participants were presented with a sentence first (e.g., "John looked at the *steak* on his plate."), and then judged whether the following picture (a brown steak or a red steak) was mentioned in the preceding sentence. What she found was that whether the color of the object matched the implied color of the object in the sentence made a difference in the response time. The most straight forward way to interpret her finding was to use color simulation so that the activation of perceptual color information occurred first when reading the sentence and such activation later affected the perception of the color information in the picture of the object.

However, there is still another possibility which is, perceptual simulation did not occur so that reading the sentence only produced the linguistic activation of a brown steak in the semantic memory. It is only when the steak picture was presented later, participants verbalize the object as brown or red steak and activate the respective semantic meaning of these verbalization. This semantic activation, depending on whether they matched the previous semantic activation from sentence comprehension, would either speed up or impede the behavioral performance. That is, this verbalization account would predict the same outcome as the color simulation account in terms of behavioral results but one attributed the interaction to the perceptual presentation while the other to the semantic representation level and the later possibility does not require adopting any embodied cognition stance. Thus, direct evidence is still needed to support the existence of perceptual simulation in language comprehension.

However, it is obvious that linguistic representation and perceptual simulation is mixed together. To distinguish these two types of representation, one needs to go beyond the behavioral results that do not provide the temporal profiles of the processing. Recently, Simmons et al. (2008) using fMRI have tried such attempt and found the psychological reality of these two types of representation. However, they used property generation task to elicit the situated/perceptual simulation during which participants tended to consciously apply imagery strategy to finish the task successfully though Simmons et al. assumed more unconscious simulation should be involved. That is, what Simmons and colleagues found may be the conscious part of perceptual simulation. Then, what is the unconscious part of the perceptual simulation?

The current study aimed to provide more definite evidence to support the 'purer' perceptual simulation of color information in language comprehension with event-related potentials (ERPs) that are known to offer millisecond temporal resolution and especially suitable for revealing the time course of mental processes. It has been well established that earlier ERP components with shorter latencies (within 200 ms) are linked with perceptual processing (Bentin et al., 1996; Johnson & Olshausen, 2003) and later ERP components with longer latencies such as N400 are associated with semantic processing. Two ERP studies were conducted to revisit the psychological reality of these two types of simulation by involving a more implicit task, which could help better investigate the existence of unconscious perceptual simulation. By examining whether the linguistic context affects early or later components in the ERP waveform, we would be able to discriminate activation of color information in the perceptual representation and semantic representation.

Experiment 1

Method

Participants Thirteen undergraduates (13 males, mean age =22.1 ± 1.3 years), were recruited with written informed consent form, following a protocol approved by the Institutional Review Panel of South China Normal University. All were strongly right-handed as assessed by the Edinburgh Handedness Inventory, and had normal or corrected-to-normal vision as well as normal color vision as assessed by the City University Color Vision Test (Fletcher, 1980). None had any history of neurological impairment or psychoactive medication use.

Materials Ninety-six pictures of everyday objects were selected from Photodisc collection (Photodisc Inc., Seattle, WA) with half used for test items and the other half for filler items. For test pictures, the objects they represent were chosen to be color-diagnostic objects, defined as objects that tend to have a color typically associated with them. Each test picture was edited in PhotoShop (Adobe Systems Inc., San Jose, CA) to create three versions so that an object was in its typical or congruent color for the congruent version, in a non-congruent color for the incongruent version, or in a gray achromatic control version. Objects in filler pictures involving man-made objects with lower shape-color consistency (e.g., stool) were randomly colored in one of three colors (purple, blue, and red) to reduce explicit attention to the color-object associations in the test items.

All pictures were resized to fit in a 250x250 pixel area (approximately 5.3x5.3 cm) in the center of the screen while maintaining their aspect ratios. The two versions of each test picture (i.e., congruent and incongruent versions) were pre-tested with 20 participants who would not do the ERP experiment. Participants rated whether the color matched the object in real life on a Likert scale from 1 (poorly-match) to 7 (well-matched). Mean ratings for the incongruent versions were significantly lower than that for the congruent versions (2.02 vs. 6.46, $p<0.001$). The same group of participants also rated the image quality in terms of their clarity for the three versions of all test items on a Likert scale from 1 (poor quality) to 7 (good quality). All pictures were given a high score of more than 5 and there was no significant differences in rating across the three conditions ($ps>0.1$). This was to ensure that all test pictures in all versions were of adequate clarity for object recognition.

Procedure Participants were seated in a dimly lit and sound-attenuated room, facing a monitor at 60 cm from their eyes. Pictures were presented in a white background and participants were instructed to restrain from blinking, eye movements, and swallowing during stimulus presentation.

A trial began with a fixation cross presented for a duration between 300 ms and 500 ms. A picture was then shown for 1000 ms followed by a 500 ms blank interval before the next trial started. Participants were required to detect an immediate picture repetition and responded with a bar press. The repetition only occurred for some of the filler pictures but never for the test pictures. Other than these repetition trials, each block contained 96 trials, involving 48 different test pictures and 48 different filler pictures. Within each block, no two test pictures were the same and there were 16 test pictures in their congruent version, 16 in their incongruent version, and 16 in the gray version. Similarly, no two filler pictures were the same in each block. There were 24 filler picture repetitions so that in 4/5 of the total 120 trials in each block, participants would simply passively view the objects without response. Each participant had 15 practice trials and then completed three blocks with the block order counterbalanced across subject. The primary focus of Experiment 1 was the three levels of object-color relationship (congruent, incongruent, and neutral gray conditions).

EEG recording and analysis

Electrical brain activity was continuously recorded from 64 non-polarizable Ag/AgCI sintered electrodes mounted in an elastic cap and positioned according to the 10-20 international system. All electrodes were on-line referenced to left mastoid M1. The EEG electrodes were referenced off-line to the mean of both mastoids. Vertical eye movements were monitored via supra- to sub-orbital bipolar montage. EEG and EOG data were amplified with a BrainAmp MR plus EEG amplifier. Electrode impedances were kept below 3 kΩ for the EEG recording and below 5 kΩ for the EOG recording. The EEG and EOG signals were digitized on-line with a sampling rate of 1000 Hz.

Data analysis

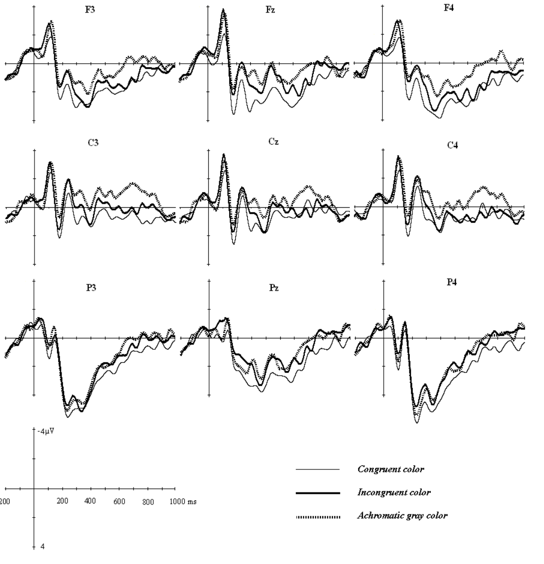
Prior to ERP analysis, eye movement artifacts were removed using regression-based weighting coefficients. Epochs containing artifacts exceeding ±80 μV were automatically excluded from further analyses. For each participant, average waveforms were calculated offline across all remaining trials for each of the three types of trials with a critical window ranging from 200 ms before and 1000 ms after picture onset. Grand averages were then conducted for each of the three critical conditions across all participants.

Results

Inspection of the grand average waveforms indicated five time windows of interest: three early visual components: N1 (80-150 ms), P2 (150-200 ms), N2 (200-275 ms), and two semantically-related components N3 (275-375 ms) and N4 (375-475 ms). The width of the time widows were selected based on the waveform shape while consulting literature studies.

Three-way (3x3x3) repeated measure ANOVAs with Greenhouse-Geisser correction were conducted on mean amplitudes of these components in representative electrodes in frontal-central-parietal regions where ERP modulations by trial condition were mostly seen. The three factors were trial type (congruent, incongruent, and gray versions), laterality (left hemisphere, midline, and right hemisphere), and lobe (frontal: F3, Fz, F4; central: C3, Cz, C4; and parietal: P3, Pz, P4). Figure 1 present the average ERP responses to the target picture in all three conditions.

Figure-1: Grand average ERP waveforms, at 9 representative electrodes, for object pictures with congruent color, incongruent color, and achromatic gray color in Experiment 1. The thin line represents the congruent color condition, the solid line represents the incongruent color condition, and the broken line represents the achromatic gray color condition



N1 The time window for N1 was set from 80 to 150 ms post stimulus onset. The ANOVA revealed a main effect of lobe, F (1, 13) = 6.23, MSE= 530.89, p<.05, with stronger negativity in frontal lobe (-2.12 μV vs. 0.28μv, p<.05) and central region (-1.94 μv vs. 0.28 μv, p<.05) than parietal lobe. The main effect of trial type was significant, F (2, 23) = 4.57, MSE= 30, p<.05. Post-hoc comparisons showed larger negativity in the gray and incongruent trials than in the congruent trials (-1.75 μV vs. -0.89 μV, p<.05; -1.76 μV vs. -0.89 μV, p<.05) but no difference between the gray and incongruent conditions (p>0.5). There was no significant interaction between trial type and other factors (F<1).

P2 and N2 Analysis of the 150-200 ms P2 and 200-275 ms N2 components showed a significant main effect of trial type (F (2, 23) = 3.5, MSE= 41, p<.05; F (2, 21) = 5.24, MSE=

51, $p<.05$). For both components, the congruent condition showed more positivity than the gray condition and the incongruent condition (P2: 1.9 vs. 0.81 µV, $p<.05$; 1.9 vs.1 µV, $p=.06$; N2: 1.88 vs. 1.04 µV, $p<.05$; 1.88 vs. 0.86 µV, $p<.01$) and there was no difference between the gray condition and the incongruent condition (ps>0.1). There was no significant interaction between trial type and other factors ($F<1$).

N3 ANOVA on the 275-375 ms N3 component revealed a main effect for lobe, $F(1, 15) = 16.11$, $MSE= 771.59$, $p=.001$, and for trial type, $F(2, 22) = 10$, $MSE= 106$, $p=.001$, but no interaction effects involving trial type (ps>.1). Post-hoc comparisons showed larger positivity in this time window in parietal regions than frontal and central regions (3.9 vs. 0.25 µV, $p=.001$; 3.9 vs. 2.13 µV, $p<.05$), and more positivity in central regions than frontal regions (2.13 vs. 0.25 µV, $p=.001$). For trial type, N3 in the congruent condition was larger than the incongruent and the gray color conditions (2.82 vs. 2.0µV, $p<.05$; 2.82 vs. 1.31 µV, $p=.001$). There was a non-significant trend for the incongruent condition to show a larger positivity than the gray color condition (2.0 vs. 1.31µV, $p=.1$).

N4 ANOVA on N4 in the 375-575 ms time window revealed a main effect of lobe, $F(1, 17) = 7.69$, $MSE= 284$, $p<.01$, showing progressive and significant amplitude increase from the frontal to the center regions and to the parietal regions (0.57, 1.89, 2.82 µV, all pair-wise ps<.01).

The main effect of trial type was significant, $F(2, 23) = 3.54$, $MSE= 54$, $p<.05$. The congruent color condition showed more positivity than the gray color condition (2.35 vs. 1.03 µV, $p<.05$) but no other pair-wise comparisons were significant (ps>.1).

Experiment 2

Method

Participants Thirteen undergraduates (13 males, mean age =24.7 ± 1.6 years), were taken from the same subject populations and formed the same inclusion criteria as in Experiment 1.

Materials In addition to the picture stimuli (144 test items consisting of 48 test objects in 3 colors and 144 filler pictures consisting of 48 filler items in 3 colors) used in Experiment 1, the materials here also included 96 object noun words (48 test words corresponding to the test pictures and 48 filler words corresponding to the filler pictures).

Procedure In the current experiment, a trial began with a fixation cross presented for a duration between 300 to 500 ms, followed by a word which lasted for 800 ms. After a 500 ms blank screen, a picture appeared with a duration of 1000 ms. Participants should judge whether or not the object word and the object picture referred to the same object, regardless of the color. However, they only need to make an overt response (pressing 'S' or 'L' for yes or no) in some catch trials that would always be a filler trial. There were 20 catch trials in each block, indicated by a red 'x' following the picture offset, and half of them required a yes response and the other half a no response. The next trial started 800 ms later after the picture offset in non-catch trials or after the response in the catch trials.

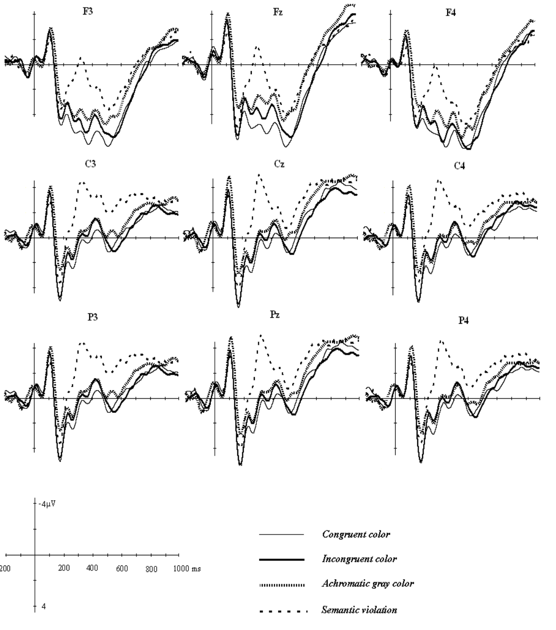
Each of the 48 test words was paired with six different pictures, three involving the same object in different colors (congruent, incongruent, and gray), and three involving mismatched filler objects in three different colors. Among these 288 (48*6) trials involving test words, 144 (48*3) trial were the critical trials of interest, producing the three word-picture relationships (congruent, congruent, neutral gray conditions). For all the critical trials, the word and the following picture referred to the same object. We also put the trials where the test word was followed by filler pictures into a forth condition for semantic violation as the word and the picture referred to different objects. This condition was analyzed only for a validity check of our procedure and results as the ERP responses to semantic violation condition was robust and should be observed, if our procedure was right and our results reliable.

There were also 288 (48*6) additional filler trials involving a filler word followed by a filler picture. In half the trials, the word and the picture matched or referred to the same object and in the other half they did not match. All types of trials were distributed to 6 blocks (each with 96 trials) as evenly as possible, with proper counterbalance across different conditions. Each participant was given 20 practice trials before completing all 6 blocks.
Same as Experiment 1, Experiment 2 also paid attention to the three levels of object-color relationship (congruent, incongruent, neutral gray), except an additional semantic violation condition was also examined for validity check.

Results

As Experiment 2 was planned to use Experiment 1 as a reference baseline, analysis was conducted in exactly the same way as in Experiment 1 on the same set of components during the same time windows (see Figure 2).

Figure-2: Grand average ERP waveforms, at 9 representative electrodes, for object pictures with congruent color, incongruent color, and achromatic gray color as well as semantic violating pictures in Experiment 2. The thin line represents the congruent color condition, the solid line represents the incongruent color condition, the broken line represents the achromatic gray color condition, and the dotted line represents the semantic violation condition.



N1 The main effects of lobe, laterality, and trial type were all significant (F (1, 14) = 28.38, MSE= 628.17, p<.001; F (2, 20) = 4.83, MSE= 21.92, p<.05; F (2, 28) = 5.28, MSE= 84.2, p<.05), but not any of the interactions. Post-hoc analysis showed a stronger positivity in parietal lobe than frontal lobe (1.6 vs. -2.23 µV, F (1, 12) = 31.13, MSE= 190.29, p<.001) and central region (1.6 vs. -1.46 µV, F (1, 12) = 40.23, *MSE*= 121.66, *p*<.001), respectively. In addition, there was a greater negativity in frontal lobe than central region (*F* (1, 12) = 5.91, *MSE*= 7.64, *p*<.05). For laterality, the midline showed the strongest negativity (-1.06 µV), left hemisphere the next (-0.66 µV), and right hemisphere the least (-0.37 µV).

N1 was significantly larger in the gray trials than the congruent trials (-1.73 vs. -0.51 µV, *F* (1, 12) = 7.94, *MSE*= 19.37, *p*<.05), the incongruent trials (-1.73 vs. -0.65 µV, *F* (1, 12) = 7.24, *MSE*= 15.22, *p*<.05), and the semantic violation trials (-0.85 µV, *F* (1, 12) = 3.44, *MSE*= 7.53, *p*=.06, marginal). However, no significant differences were found among congruent color, incongruent color, and semantic violation (*F*s<1).

P2 The main effect of laterality was significant, *F* (2, 20) = 4.3, *MSE*= 24.48, *p*<.05, with strongest positivity found in midline (4.02 µV). The main effect of trial type was also significant, *F* (3, 33) = 6.84, *MSE*= 107.09, *p*=.001, with no interaction with other two factors (*F*<1). Similar to N1, the gray condition was smaller than the congruent condition (2.26 vs. 4.35 µV, *F* (1, 12) = 22.06, *MSE*= 170.5, *p*=.001), the incongruent color (2.26 vs. 4.0 µV, *F* (1, 12) = 10.63, *MSE*= 113.06, *p*<.01), and the semantic violation condition (3.24 vs. 4.0 µV, *F* (1, 12) = 4.2, *MSE*= 12.38, *p*=.06, marginal). The semantic violation condition (3.24 µV) showed a smaller P2 than the congruent color condition (3.24 vs. 4.35 µV, *F* (1, 12) = 6.09, *MSE*= 16.16, *p*<.05). However, no significant differences were found between the incongruent and congruent, incongruent and semantic violation conditions.

N2 Lobe, trial type, and laterality all showed significant main effects (*F* (1, 13) = 12.26, *MSE*= 2269.87, *p*=.003; *F* (2, 23) = 3.35, *MSE*= 30.42, *p*<.05; *F* (2, 30) = 7.81, *MSE*= 128.04, *p*=.001) but no interaction effect involving trial type was significant (*p*s>0.1). Post-hoc tests showed that the mean amplitude of N2 was significantly larger at parietal lobe than central and frontal regions (7.1 vs. 3.44 µV, *F* (1, 12) = 12.37, *MSE*= 410.74, *p*=.004; 7.1 vs. 1.48 µV, *F* (1, 12) = 18.73, *MSE*= 173.91, *p*=.001). Significant difference was also found between frontal and central regions, *F* (1, 12) = 4.73, *MSE*= 50.11, *p*=.05). For laterality, significant difference was only found between right hemisphere and midline, *F* (1, 12) = 7.74, *MSE*= 9.93, *p*<.05.

N2 was also significantly more negative for the semantic violation condition compared to the congruent, incongruent, and gray conditions (2.56 vs. 4.88 µV, *F* (1, 12) = 28.18, *MSE*= 69.98, *p*<.001; 2.56 vs. 3.95 µV, *F* (1, 12) = 9.88, *MSE*= 25.16, *p*=.008; 3.84 µV, *F* (1, 12) = 5.49, *MSE*= 21.29, *p*<.05). Additionally, significant differences were found between congruent and gray color conditions, *F* (1, 12) = 7.74, *MSE*= 9.93, *p*<.05, while marginally significant differences between congruent and incongruent conditions, *F* (1, 12) = 3.8, *MSE*= 11.22, *p*=.07, but not between incongruent and gray color trials (*p*>.05).

N3 There was a significant main effect for lobe (*F*(1, 13) = 31.38, *MSE*= 3340, *p*<.001), and trial type (*F*(2, 27) = 25.28, *MSE*= 686, *p*<.001), but not for laterality (*F*<1) and there was no significant interaction between trial type and the other two factors (*p*s>.05).

The mean amplitude of N3 was significantly different (*p*s<.001) across all three brain regions, with parietal lobe having the highest positivity (8.37 µV), followed by central (3.33 µV), and frontal lobe (-0.87 µV).

Semantic violation showed the strongest effect of N3 (0.57 µV) than each of congruent (5.39 µV), incongruent (4.62 µV), and gray color conditions (3.86 µV), *p*s<.001. In addition, there were significant differences between congruent and incongruent (5.39 vs. 4.62 µV, $F(1, 12) = 4.73$, $MSE = 8$, $p = .05$), and between congruent and gray condition (5.39 vs. 3.86 µV, $F(1, 12) = 7.45$, $MSE = 30.47$, $p < .05$), while the gray condition showed a non-significant trend for greater negativity relative to incongruent conditions ($F(1, 12) = 2.01$, $MSE = 7.58$, $p = .18$), also found in Experiment 1.

N4 There was a main effect of lobe was significant ($F(1, 13) = 43.31$, $MSE = 3806$, $p < .001$), with a stronger positivity in parietal lobe (8.53 µV), followed in by central and frontal lobes (3.8 and -1.34 µV). The main effect of trial type was also significant ($F(3, 32) = 9.66$, $MSE = 184$, $p < .001$). The semantic violation trials elicited a stronger N4 effect (2.13 µV), relative to congruent (4.99 µV, $F(1, 12) = 21.69$, $MSE = 105.88$, $p = .001$), incongruent (4 µV, $F(1, 12) = 13.47$, $MSE = 45.61$, $p < .01$), and gray conditions (3.59 µV, $F(1, 12) = 9.03$, $MSE = 27.59$, $p < .05$), respectively.

The congruent condition showed a smaller N4 than both the incongruent ($F(1, 12) = 4.22$, $MSE = 12.51$, $p = .06$) and the gray conditions ($F(1, 12) = 5.94$, $MSE = 25.38$, $p < .05$). However, no significant differences were found in other contrasts, neither in any interaction involving Trial type.

Discussion

In Experiment 1, participants viewed a set of object pictures presented either in their congruent (i.e., typical) color, incongruent color, or achromatic gray color.

Focusing on the comparison between the congruent and the incongruent conditions, the ERP results showed that shortly after the onset of the object starting from around 100 ms, the brain already differentiated between an object in its appropriate color from the object in an incongruent color, demonstrating significant positive shifts of N1, P2, and N2 in the former relative to the latter. The gray color condition was essentially overlapping with the incongruent condition.

As the same set of objects was used, object shapes were balanced across the three experimental conditions, the observed congruence effects, i.e., the ERP differences between the congruent and incongruent conditions, should be attributed only to the nature of the color-shape associations but not to any sensory or physical characteristics of the stimulus set.

The finding that the gray color condition essentially overlapped with the incongruent condition in the waveforms of N1, P2, and N2, seems to indicate that gray color was processed like an incongruent color, at least for the objects used here that all have a typical color. Alternatively, one can consider the gray condition as a non-color neutral control against which to assess the benefits and costs (or facilitation vs. interference) color information brought to object recognition. Then the result that the ERP responses were different between the congruent condition and the gray condition but not between the incongruent condition and the gray condition indicates that the congruence effect we observed reflects primarily a benefit but not a cost. That is, color information would facilitate object recognition when it matched an object’s typical color but it would, however, not impede object recognition when it did not match the typical color. Although not documented in the literature before, this is an interesting finding needing further investigation. The message seems at least reasonable as it is consistent with the general conceptualization of color effects as facilitative to object recognition (Wichmann & Sharpe, 2002).

As described earlier, N3 is generally recognized to be associated with semantic processing of pictures (e.g., Federmeier & Kutas, 2002). The finding that object color knowledge also has an effect in N3 indicates the representation of such knowledge in semantic memory of pictures. The gray color condition started to diverge, though not significantly from the incongruent condition during the N3 interval to be of greater negativity than for the other two color conditions, possibly reflecting a processing distinction between color and non-color objects. The same pattern was also present in the N4 component. Unlike N3 and earlier components, for N4, the difference between congruent and incongruent conditions disappeared, suggesting that N4 is not sensitive to the object color knowledge. This is consistent with the general understanding that N4 can be demonstrated with a wide variety of stimuli and tasks and reflects modality-non-specific semantic representations. The fact that there was no congruence effect for N4 shows that the current task did not tap into this amodal representation, given the task did not explicitly require processing of the semantic content of the objects.

In total, the above results indicated that object color knowledge manipulation modulated ERP components indexing both early perceptual and late perceptual processing. Although it has been proposed that color information is represented both in perceptual and semantic memory for picture objects (Wichmann & Sharpe, 2002), there is only one ERP study in support of such proposal using a task where color information must be actively attended (Proverbio et al., 2004). As real life object recognition does not typically require explicit attention to color, Proverbio et al. study may lack sufficient ecological validity.

As the current task involved only repetition detection focusing on shape information as often found in real life situations, the demonstration of clear object color knowledge effects in Experiment 1 represents an extension of the Proverbio et al. results for more ecological validity. Therefore, Experiment 1, in itself, is a significant contribution to the theoretical perspective that color as a surface property is stored in a multiple-memory system where pre-semantic perceptual and semantic conceptual representations interact during object recognition.

However, for the present interest in color simulation, the most important message from Experiment 1 was that presenting object pictures in different colors, congruent or incongruent with the object's typical color, does significantly affect the ERP responses elicited by the object. For our interest, it was necessary to consider these congruence effects and discount them from the observed ERP differences when studying the effects of preceding word reading on picture perception.

The first result to note in Experiment 2 is that the ERP waveform elicited by the picture stimuli in the violation condition showed a significantly more negative going effect relative to the rest three conditions which were all consistent conditions (i.e., the word and the picture referred to the same object) in mostly N2, N3, and N4, consistent with literature findings that all these components have been shown to reflect some processing related to mismatch, conflict, inhibition, or violation. This serves as a validity check suggesting that our data collection and analysis were generally acceptable and reliable.

Figure-3: Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in N1 (80-150 ms interval) between Experiment 1 and 2.

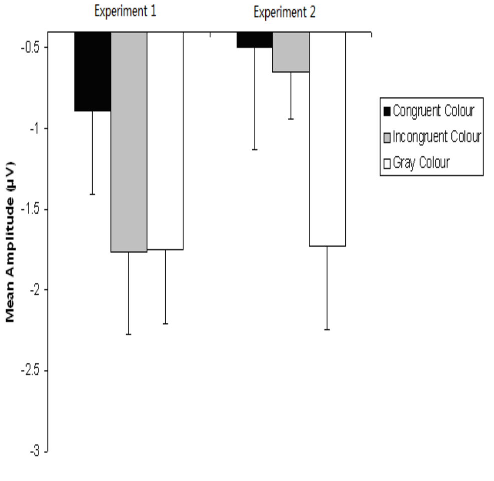


Figure-4: Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in P2 (150-200 ms interval) between Experiment 1 and 2.

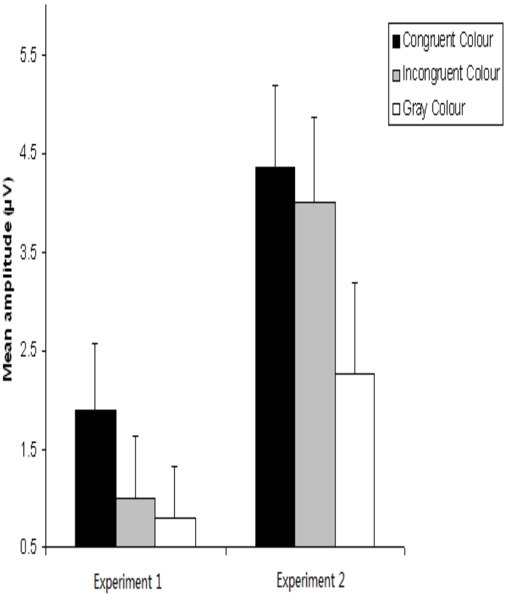
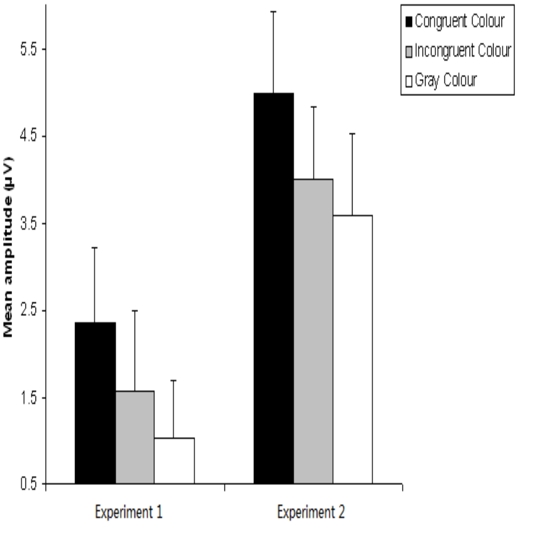


Figure-5: Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in N4 (375-475 ms interval) between Experiment 1 and 2.



Turning to the central comparison between the three critical conditions, the results showed no difference between the congruent and the incongruent conditions, both of which were more positive than the gray condition. P2 showed a similar pattern. By itself, Experiment 2 shows no congruence effect in N1 and P2, as illustrated in Figure 3 and 4. Note however that there was congruence effect in Experiment 1 for the same two ERP components, the present results then indicated that word reading in Experiment 2 did modulate ERP differences between object pictures in their congruent and incongruent colors. Put the gray condition along with these two conditions, word reading in Experiment 2 seems to have made the incongruent condition less negative and shifted it to the merge with the congruent condition. However, word reading did not seem to modify the difference between the congruent and the gray color condition, i.e., the gray condition was more negative-going than the congruent condition in both Experiment 1 and 2. This finding implies that results differences caused by changes from Experiment 1 to 2, mainly adding the word reading component and using word-picture matching task instead of passive viewing, should not be attributed to generic factors unrelated to color. That is, the different results between Experiment 1 and 2 in N1 and P2 should indeed reflect difference in color information, the only information that distinguished the congruent and incongruent conditions.

Note the overlapping of congruent color and incongruent color in N1 and P2 showed in Experiment 2, relative to their salient differences demonstrated in Experiment 1, may be attributed to the perceptual simulation formed in the processing of the priming words in Experiment 2. We argued that the perceptual simulation of the words has an impact on the retrieval of the familiar visual memory which help differentiate the difference between congruent color and incongruent color in early components such as N1 and P2 in Experiment 1, thus, the 'malfunction' of these familiar tracks result in the reduced difference of N1 and P2 between congruent color and incongruent color. Note the salient difference between achromatic gray color and congruent color remain relatively constant between these two experiments, which further elucidated that the perceptual simulation of object words should involve color property.

Briefly, assessed against Experiment 1 as a baseline situation, results in Experiment 2 revealed activation of color information in word reading that affected later processing of object pictures. As the effects of color information were manifested in N1 and P2 ERP components indexing early perceptual processing, it suggests that such color information was available very early and cannot result from later verbalization process that translate pictorial object into verbal semantic codes. This therefore provides direct evidence that the color simulation does occur at perceptual level but cannot be totally accounted for with interaction effects at the semantic level.

Different from N1 and P2, the congruence effects shown in N2, i.e., the difference between the congruent condition and the incongruent conditions, were not altered by experiment. That is, as in Experiment 1, N2 was more negative-going in the incongruent condition than in the congruent condition in

Experiment 2

N2 has been quite often associated with some generic mismatch detection in both perceptual and linguistic tasks and/or inhibition control or conflict monitor. The fact that this component was not affected by word reading suggests that its difference between the congruent and incongruent conditions in Experiment 1 may reflect a qualitative signal for match vs. mismatch, unaffected by the level of the mismatch. So as long as the object mismatched with its typical color, it does not matter whether there was additional activation of color information from previous word reading. Or it could be that N2 is relatively late in perceptual processing, its congruence effect in Experiment 1 already reflects a rather high level of color activation, not be affected much by extra color activation from the preceding word reading.

The pattern of N3 was also similar to that in Experiment 1 being more negative-going in the incongruent condition than the congruent condition, though the difference was non-significant. And the gray condition was the most negative, significantly more so than the congruent condition. For N4, although no difference between the congruent and incongruent conditions in Experiment 1, now showed a significant difference between the two with the incongruent being more negative-going relative to the congruent condition.

Although N3 and N4 are both related to semantic processing, they differ from each other in that N4 is sensitive to the linguistic semantic processing while N3 is highly related to pictorial semantic processing (e.g., Hamm, Johnson, & Kirk, 2002). The finding that N4 but not N3 was modified by experiment indicates that word reading in Experiment 2, in addition to activating perceptual color information, also activated color information in the semantic memory level but such semantic memory seems to be at modality-free linguistic level but not at the modality-specific visual picture level. See Figure 5.

The experimental tasks were different between Experiment 1 and 2 so that participants were asked to detect occasional catch trials involving shape repetition in Experiment 1 but determine whether the word and the picture in each trial referred to the same object. This raises the possibility that the two experiments are not directly comparable so that Experiment 1 may not serve as a good reference baseline for Experiment 2. However, as task differences typically engage different response strategy but should not affect early automatic processing, this problem would be more relevant to the later ERP components on semantic processing than to the earlier perceptual components which is our main focus here.

In summary, using ERP that provide temporal profile information of activation of mental representation, the present study shows that the comprehension of object words involves constructing perceptual simulation including color information associated with the object described. Effects from such color simulation are automatic and occur early, arguing against the notion that previous demonstrations of perceptual and color simulations are due to interaction between codes occurring at the semantic level. Side to our main finding, it was also demonstrated that color information is also part of the semantic memory of object words, along with its perceptual representation.

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