Color Simulation: the Activation of Perceptual Color Representation in Language Comprehension

LU, Aitao

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

in

Psychology

June 2009

Abstract

Abstract of thesis entitled: **Color Simulation: the Activation of Perceptual Color Representation in Language Comprehension**

The present research was conducted to give a systematic treatment of color simulation in language processing to enrich understanding of perceptual simulation. Two main questions have been addressed here, namely 'what is the time course of color activation in language unites such as noun phrase and abstract words? ' and 'do linguistic simulation and perceptual simulation (especially the unconscious part) of color co-exist in language understanding? '

Results from all three experiments in the first study showed a robust demonstration of the activation of perceptual representation of color information or the presence of color simulation in phase processing. Results from prime-target stimulus-onset-asynchrony (SOA) manipulation provided time course information of the relative activation of the two types of colors.

The second study involving three experiments, further extended the finding in Study I to demonstrate the presence of color simulation to an even smaller and abstracter linguistic unit of single words. Results from SOA manipulation indicates a more rapid activation of color information for the words psychologically-related to color, followed by activation of color for object nouns, and slowest color activation for verbs.

In study III, two event-related-potential (ERP) experiments show a clear modulation from preceding object noun on the early ERP components of the following object picture that are known to be associated with perceptual processes and provide by far the strongest evidence that semantic processing

cannot account fully for the congruence effects supposed to indicate color representation.

In summary, color representaion is found to be present not only for color information implied by the global phrase context but also for color information irrelevant to the global phrase context, not only for words with direct and concrete associations with color but also for words where such associations are indirect and less concrete. ERP results also provide strong support that color simulation does occur at the perceptual level as argued by embodied cognition theorists and cannot be attributed totally to semantic processing. Briefly, the present research provides a rich dataset and valuable insights deepening the understanding of perceptual color simulation in phrase and words.

論文摘要

本研究主要考察了兩個問題：（1）顏色的表徵是否能存在於短語和詞語水平？（2）在語言理解中，顏色的表徵是存在於感知覺水平，語言加工水平，還是兩種表徵同時存在？

研究一的三個實驗一致的發現對短語顏色塊（即顏色塊的顏色與整個短語所隱含的顏色一致）的命名比對不一致顏色（即與短語中所可能隱含的任何一種顏色不一致）的命名要快。另外，短語中目標詞語的典型顏色也發現被激活了。這個結果表明顏色的自動激活可在一定程度上脫離上下文，并可爲生活經驗所影響。SOA 的結果表明，短語顏色和典型顏色在時間進程上存在不同，即短語顏色激活較快且程度較強，而典型顏色激活較慢且程度隨著 SOA 的增加而慢慢攀升。

在研究二中，顏色塊與物體的典型顏色一致時，命名時間較短。這樣的一致性效應同樣存在於動詞，以及那些與顏色有著相同心理聯繫的詞語（例如，危險隱含著紅色）。SOA 的結果表明心理顏色聯繫詞語激活最快，接著是物體詞語，最後是動詞。

總之，本研究考察了顏色表徵在短語和詞語加工中的作用，并表明了語言加工中顏色表徵的多層次性，以及感知覺層面的顏色表徵的存在，由此為具身認知理論提供了一定的證據。

Submitted by LU, Aitao for the degree of doctor at The Chinese University of Hong Kong in June 2009

Table of Contents

Acknowledgements

My utmost gratitude goes to my thesis advisors, Prof. John X. Zhang and Prof. Wai Chan for the continuous help and support of my Ph.D study and research, for their expertise, kindness, immense knowledge, and most of all, for their patience. I believe that one of the main gains of this 3-years program was working with Dr. John X. Zhang. His guidance helped me in all the time of research and writing of this thesis. My sincere thanks and appreciation also goes to the rest of my thesis committee: Prof. Jijia Zhang, Prof. Liqiang Huang, and Prof. Alan C.N. Wong, for their encouragement, insightful comments, and hard questions. I am greatly indebted to Ms. Annie W.F. Leung for helping make my work so much smoother. I would like to thank my department chairperson Prof. Fanny M. Cheung for providing me with this opportunity to acquire the knowledge. I thank my fellow classmates and labmates: Miranda Mak, Jenny Huan, Wenna Wang, and Mingxuan Jin. In particular, I am grateful to Prof. William S-Y. Wang for enlightening me to make critical thinking on research. I would thank my family: my parents Yaolin Lu and Pingzhen Liu; my sister and brothers: Wantao Lu, Hanjie Lu, and Hanxun Lu, for supporting me spiritually throughout my life. Last but not the least, I thank my friends, Kaiyi Wu, Jingxiang Peng,Yanqing Chen, and Xiaoling Chen, who stood beside me and encouraged me constantly.

Color Simulation: the Activation of Perceptual Color Representation in Language Comprehension

Chapter 1 Literature Review

Embodied Cognition and Mental Simulation

As a major approach to cognition, theories in embodied cognition hold that thought resides in the same neural systems that serve sensation, perception and action (Barsalou, 1999; Connell, 2007; Glenberg & Kaschak, 2002; Johnson-Laird, 1983; Pecher & Zwaan, 2005). For example, Barsalou's (1999) Perceptual Symbol Systems theory claims that concepts themselves carry perceptual and motor information experienced through our senses. Such information is supposed to be retrieved later to mentally simulate the actual perceptual experience when we use these concepts. In a computation model, Bailey (1997) claims that when verbs were acquired in real life, there were typically accompanied by explicit motor experiences. For example, when a child learns 'kick', the parents may prompt them to carry out a kicking action to indicate that is what 'kick' means. Bailey argues that such motor experiences are explicitly built into and become part of the verb's conceptual representation, which can help understanding action verbs whenever they are encountered, such as when one reads a verb in a sentence.

Supporting these claims, a considerable number of recent findings have demonstrated that sentence comprehension, as one type of conceptual processing, involves a mental simulation of the scenes and events described in the sentences (e.g., Glenberg & Kaschak, 2002; Kaschak & Glenberg, 2000; Stanfield & Zwaan, 2001; Zwaan, 2004).

Specifically, mental simulation means that the perceptual-motor representation associated with these scenes and events are evoked as if the reader to some extent were having such perceptual and motor experience, even though in processing the abstract conceptual symbols in a sentence they are not subjected to any perceptual stimulation nor required to carry out any motor actions. And it has been further argued that such simulation is not just a by-product but can actually help sentence comprehension (Glenberg & Kaschak, 2002).

Given the claim that motor representations may be retrieved not only in performing physical actions but also in sentential and conceptual processes (Barsalou, Simmons, Barbel, & Wilson, 2003; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2002) is such a salient and central tenet of embodied cognition, not surprisingly, a growing body of studies have been conducted to test or demonstrate motor simulation in language processing. However, embodied cognition also predicts the presence of simulation of perceptual information including shape, texture, color, and so on in language comprehension. Surprisingly, there has been so far only limited research to demonstrate perceptual simulation.

We will start with reviewing major findings in motor and perceptual simulations in language comprehension, and then focus on a more specific topic in perceptual simulation involving activation of color information. We will finally describe the purposes of the present study, based on analysis of the literature.

Motor Simulation in Language Processing

Comprehending sentences or verbs depicting actions has been demonstrated to activate the motor and pre-motor cortex in many studies using both behavioral and neuro-imaging measures. For example, studies using Positron Emission Tomography (PET) to reveal the brain mechanisms involved in processing verbs related to a particularly conceptual category have found reliable activation in the left pre-motor cortex when right-handed subjects retrieved information about tools or named pictures of tools (Grabowski et al., 1998; Martin et al., 1996). Further studies using other functional imaging methods show similar results. For instance, a functional magnetic resonance imaging (fMRI) experiment conducted by Tettamanti et al. (2005) showed that visuo-motor circuits responsible for action execution and observation were activated when participants were listening to action-related sentences. These data provide the first direct evidence for the notion that the observation–execution matching system (i.e., the mirror-neuron system) may play an essential role in the understanding of actions even the actions are performed by others as depicted in the sentences.

Similarly, Hauk et al. (2004) applied event-related fMRI to demonstrate that a task involving passive reading of action words about face, arm, or leg (e.g., to lick, pick, or kick) differentially activated motor areas that are activated by actual movement of the tongue, the fingers, or the feet. Interestingly, such somatotopic activation seems to be highly automatic as they were found even when subjects were presented with action words, while simultaneously performing a secondary task (Pulvermüller, Shtyrov, & Ilmoniemi, 2005). In addition, judging whether a verb is a real word or a pseudo-word has been demonstrated to elicit stronger high-frequency EEG activity at the electrodes positioned above primary motor cortex for action words (Pulvermüller, Lutzenberger, & Preissl, 1999).

Most recently, Kemmere et al. (2008) demonstrate that there were brain regions activated when participants made semantic judgments about verbs and more interestingly the regions activated were different depending on the semantic contents of the verbs. They used several classes of verbs in their study, namely, running verbs (e.g., run), speaking verbs (e.g., shout), hitting verbs (e.g., hit), cutting verbs (e.g., cut), and change of state verbs (e.g., shatter), which vary in the level of their involvement of five distinct semantic components, e.g., action, motion, contact, change of state, and tool use. For example, running verbs involve only two components which are action and motion, and cutting verbs involve all five components. Their results showed that the action component elicits activation in the primary motor and pre-motor cortices, the motion component in the posterior-lateral temporal cortex, the contact component in the intra-parietal sulcus and inferior parietal lobule, the change of state component in the ventral temporal cortex, and the tool use component in a distributed network of temporal, parietal, and frontal regions.

Different from Kemmere et al. (2008), Bub, Masson, and Cree (2008) focus on the same type of action words with diverse motor properties. They differentiated between gestures which involve using an object for particular purposes (functional) and those for picking up an object (volumetric). For example, door bell and pocket calculator were the objects associated with the functional gesture of poke, and lotion bottle and spray bottle were the objects associated with the volumetric gesture of vertical grasp. Their participants were first trained to associate different colors with different gestures. In the test session, participants were presented in each trial with an item in a certain color. The task was to perform the gesture indicated by the color, as they previously learned. The colored item, whose identity was irrelevant to the main task of gesture production, was either a picture of an object or a word about an object. In the congruent trials, the gesture to be performed matched the irrelevant object in either functional or volumetric properties, i.e., when the item was a pocket calculator and the color the item appeared in cued a poke gesture. In the incongruent trials, they were matched in neither, i.e., when the item was a pocket calculator but the color cued for a gesture of triggering. For pictures items, response latency was longer for the incongruent trials, which demonstrated automatic activation of functional and volumetric knowledge in object manipulation. Most interesting is that such congruence effect was also observed when the items were object words, indicating the activation of such knowledge when processing words.

Buccino et al. (2005) found that listening to sentences containing information about hand-related actions moderated motor evoked potentials of the hand muscles, but listening to sentences containing information about foot-related actions moderated motor evoked potentials of the foot muscles.

Using action-sentence compatibility effect, Glenberg and Kaschak (2002) found that sentences describing a movement in a certain direction could interfere with responses executed in a different direction. They required subjects to determine the sensibility of sentences by making a response, namely, moving towards or away from their bodies. The results showed that it took longer for participants to judge the sensibility of sentences when the directions implied in these sentences were opposite to the response. For example, if the direction of the response was moving towards our body, then the sentence "Close the drawer" whose meaning is to move away from the body would delay the response.

Similarly, it was shown that hand responses to sentences describing manual rotation are faster when both the manual response and the sentence share the same direction of rotation than when they differ in rotation direction (Zwaan & Taylor, 2006). Accordingly, it has been suggested that sentences involving rotations activate a motor program for manual rotation in the listener.

Finally, Glover (2004) first primed participants with names of objects (e.g., apple or grape) who then had to reach and grasp a following target. The target size (wide or narrow) was either consistent or inconsistent with that of the object. Early in the reaching movement the prime had an impact on the aperture size between thumb and forefinger of the action grasp, but this aperture size would change to match the target's size during later stages, which suggest that the comprehension of an object word involves automatic simulation of components afforded by the related motor action.

What the above studies have in common is that they suggest that representations of action information associated with a verb, phrase, sentence is part of their conceptual meaning and can be simulated or automatically triggered when they are processed in a linguistic context.

There is another type of evidence from the opposite direction showing the effects of motor action on subsequent or simultaneous language processing, demonstrated with Transcranial magnetic stimulation (TMS). One study shows that sub-threshold TMS stimulation of the hand area of left primary motor cortex resulted in faster response time in a lexical decision task for arm-related action words, compared to leg-related action words, and stimulation of the leg area speeded up decisions on leg-related action words, compared to arm-related action words (Pulverműller, Hauk, Nikulin, & Ilmoniemi, 2005).

Other studies show that irrelevant motor representations established can affect sentence meaning construction. For example, Masson, Bub and Warren (2008) require participants to produce a hand action for a visual cue while they were listening to a sentence. Although the action was supposedly irrelevant to the sentence comprehension task, reliable hand action priming effects were found showing enhanced sentence processing when the sentences referred to manipulable objects associated with actions consistent with the hand action, relative to when the objects were associated with actions inconsistent with the hand action. Taylor, Lev-Ari, and Zwaan (2008) further found that verbs leaving direction ambiguous (e.g. "turned") do not necessarily produce such effects.

There are also studies indicating that motor simulation can be modulated by body-object interaction (BOI) and its presentation context. Siakaluk et al. (2008) investigated sensori-motor simulation in two types of words selected based on the degree of BOI, namely how easily a human body can physically interact with an external referent. Thus, a set of high BOI words (e.g., mask) and a set of low BOI words (e.g., ship) were chosen with matched imaginability and concreteness. High BOI words refer to objects that presumably engage more bodily actions when dealing with the objects. Facilitative effects of high BOI words relative to the low ones were found in both the visual and phonological lexical decision tasks, suggesting the occurrence of motor simulation and also that its level was modulated by BOI so that high BOI words would, relative to the low BOI words, evoke more associated motor representations, which would provide more information to help decide the word was a real entry in the lexicon.

While understanding a sentence like "Mother gives me a beautiful bag" requires the retrieval of motor information to simulate the action predicate 'give', is it also true for the comprehension of figurative language (e.g., Mother gives me a lot of mental support)? Raposo et al. (2009) used fMRI and scanned participants who listened to verbs related to arm or leg, presented in isolation (e.g. kick), in literal sentences (e.g., kick the ball), and in figurative idiomatic sentences (e.g., as in kick the bucket). Significant activation in motor areas was found for the verbs in isolation and in literal contexts. In the idiomatic contexts, fronto-temporal areas closely associated with language processing was activated but not motor and pre-motor cortices. That is, motor simulation of action verbs may not always occur but can be modulated by the semantic context the verb appears.

However, such findings have met with contradictory results. Using fMRI, Rohrer (2001) did find the sensori-motor area activation in the somatotopic representation of the hand area (Moore et al. 2000) in a semantic comprehension task including literal and figurative sentences about hand, consistent with previous results about. More recently, Rohrer (2005) reviewed fMRI and ERP studies and confirmed that both literal and metaphoric language stimuli activate areas of sensori-motor cortex.

<u>Perceptual Simulation in Language Processing</u>

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. There are less but growing number of studies on perceptual simulation, i.e., the activation of other sensory properties like object shape, orientation and resolution in language processing, which complements evidence about motor simulation to more fully support claims of embodied cognition.

One of the first evidence for perceptual simulation was from Zwaan, Stanfield, and Yaxley (2002) who asked their participants to read and comprehend a sentence for later recognition. A picture depicting an object would then be shown and participants did speed naming of the picture. The sentence could be consistent or inconsistent with the picture, depending on whether the object descried in the sentence implied a visual shape same as or different from the shape of the object depicted in the picture. For example, if the sentence was, 'The ranger saw the eagle in the sky'), it would be consistent with picture depicting a flying eagle but inconsistent with a picture depicting a sitting eagle. This pattern was exactly the opposite for the sentence, 'The ranger saw the eagle in its nest'. Naming latency was found to be significantly shorter for the consistent sentence-picture pairs than for the inconsistent pairs, suggesting that the shape information of the object referred by the word in the sentence (i.e., the eagle) was activated and interacted with the shape information perceptually given in the picture.

Stanfield and Zwaan (2001) investigated another type of sentences which implied objects' direction. For example, 'He hammered the nail into the wall' or 'He hammered the nail into the floor'. The former sentence implies the direction of nail is horizontal, while the latter one is vertical. Both of these two types of sentences were followed by a line drawing of an object. This following object was presented either in a horizontal or in a vertical orientation, thus creating a match or a mismatch condition. When primed by an auditory sentence, participants made faster recognition response in match condition relative to the mismatch one. Thus, this result indicates that orientation of an object as implied in the sentence (e.g., whether the nail was position horizontally or vertically) was explicitly activated in comprehending the sentence and such activation interacted with the orientation information perceptually given in the following picture.

Diane, Kiki, and Rene (2007) in the study phase asked their participants to do a property verification tasks deciding whether a concept name (e.g., apple) matched with a property that was either visual (e.g., shiny) or a non-visual (e.g., tart). They later in the test phase presented pictures of objects and asked participants to recognize which of these objects were studied earlier. The results show better recognition memory of the object in both response time and accuracy measures if the concept name for the object had been presented with a visual property than with a non-visual property. These results indicate that the perceptual (i.e., visual) properties of a concept is more closely tied or may be part of the meaning representation of the concept itself, relative to non-perceptual (i.e., non-visual) properties. That is, when judging about the visual properties of the concept, the concept itself is activated more and hence recognized better later, relative to the non-visual properties. Concept representation is not totally abstract and modality-free as it consists in part of the explicit representation of modality-specific information (e.g., visual properties) and concept understanding leads to simulation of such modality-specific information. This supports the perceptual symbols theory (Barsalou, 1999) that sensorimotor simulations underlie the representation of concepts.

Yaxley and Zwaan (2007) showed participants a sentence describing an object (e.g., moose) making them either visually clear or fuzzy, as in the following sentences, "Through the clean goggles, the skier could easily identify the moose." or "Through the fogged goggles, the skier could hardly identify the moose." Each sentence was followed by a picture showing an object clear or fuzzy, and thus being consistent or inconsistent in visibility with the image of object implied in the sentence. In verifying whether the object showed in the subsequent picture was consistent with the one mentioned in the previous sentence, participants were found to respond faster for the consistent sentence-picture pairs, relative to the inconsistent pairs. Apparently, the results suggest that during sentence comprehension visual simulation must have occurred, that is, a visual image must have been formed, clear or fuzzy in visual quality, depending on the sentence context and interacted with the visual quality information perceptually given in the following picture.

Color Simulation

While the studies on perceptual simulations have been concerned with shape, direction, size, the work demonstrating mental simulation of color information was scant, even though color is a very salient feature in vision and color information is also prevalent.

Klein (1964) used words denoting color-diagnostic objects in Stroop paradigm, requiring subjects to name the ink color of each word. The object noun could be in its typical or an incongruent color. A standard Stroop effect was found- color naming was faster in typical color condition. Following Klein's work, Naor-Raz, Tarr, and Kersten (2003) also demonstrated such Stroop effect by further arguing the semantic representation of color in object nouns.

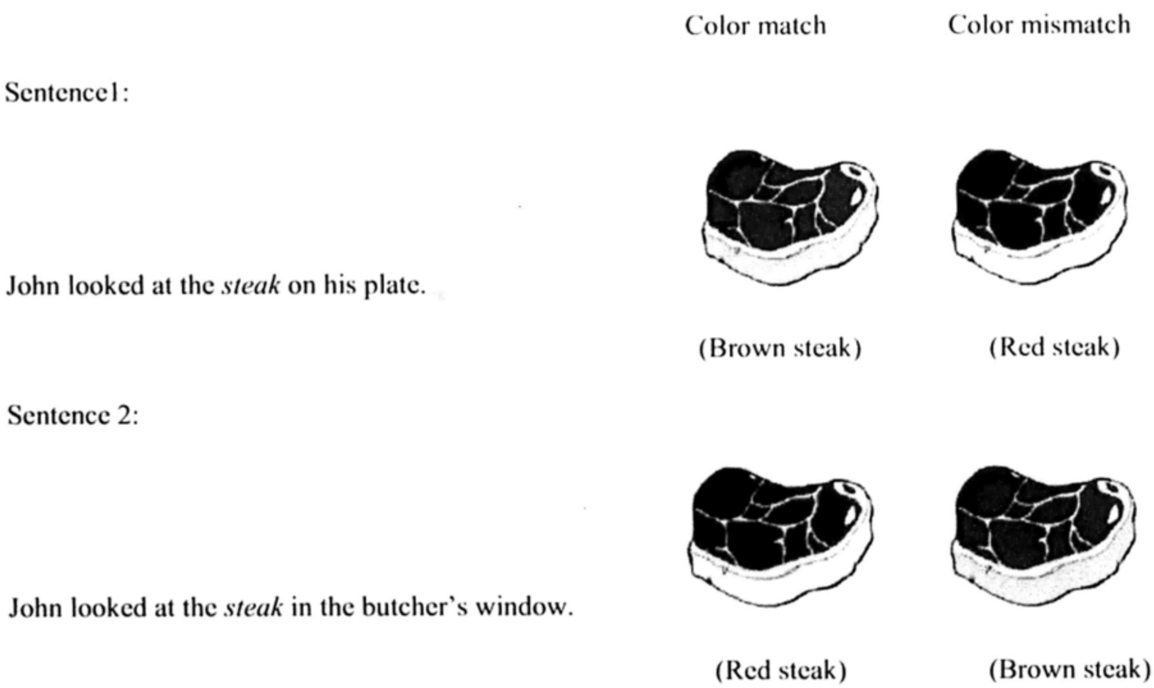


Fig. 1 Sample sentences and pictures used in Connell's study. Note that the color in each picture condition is natural for that particular object. For example, brown and red are two

natural colors for steak.

Besides these available evidence on the semantic representation of color in language processing, most recently, Connell (2007) examined whether implicit perceptual information such as object color is represented during sentence processing. On a trial, a sentence denoting a particular color for a target object was presented to participants, followed by a picture of that object either with the same color or different color from the one implied in the preceding sentence (Fig. 1). When judging whether the pictured object was stated in the preceding sentence, participants made a faster response to the objects with mismatched color than the matched one. Though the inhibition effect in Connell's study seems violating the facilitation effect in other available literatures (e.g., Glenberg & Kaschak, 2002; Stanfield & Zwaan, 2001; Yaxley & Zwaan, 2007), such result pattern did provide evidence to support that color is automatically represented in language comprehension.

Studies reviewed above have provided strong support for the psychological reality of perceptual simulation in language comprehension. Among the existing literature, motor actions, being salient manifestations of the body-environment interactions, attract most research attention and have been consistently demonstrated to be simulated in reading action-related words and sentences.

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, 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.

Apparently, there is much more research needed in this area to enrich our understanding of mental simulation as a window to examine the specific mechanisms involved embodied cognition. This motivates the present study to using color simulation as a specific topic to explore the more general phenomenon of perceptual simulation.

Chapter 2 Objective of the present research

1) I start with the recognition that it may not be necessary to use a full sentence to demonstrate color simulation as the effects in Connell (2007) may be only elicited by one additional critical word, other than the target object noun itself, which constrains interpretation of the object to imply a specific color. For the example, in 'Susan put the steak for dinner on the table.', the word 'dinner' is the critical word to generate the implicit inference that the steak mentioned in this sentence should be brown as opposed to red.

Therefore, I would first try to explore whether a simple phrase, e.g., night sky, in the form of adjective + noun would suffice to produce color simulation. That is, when participants are only reading such a phrase which implies a certain color (e.g., black), whether the representation associated with physical color perception would be evoked. Positive results for such a situation would be a strong piece of evidence for the presence of color simulation in language comprehension and also very informative as to how small a linguistic context can constrain such simulation. A recent study of Wu and Barsalou (2009) showed that participants could generate different properties for words and their corresponding noun phrases, which shed light on that one critical word may constrain the property of the following target words. Thus, it was expected that an adjective in the present study could help the following object nouns implicitly elicit particular color.

In the current study, two types of colors were manipulated to possibly implied in the noun phrases, one being the color based on interpretation of the phrase as a whole (e.g., black for 'night sky'), and the other being the typical color associated with the noun (e.g., blue for 'sky'). Specifically, the phrase color is a color from the contextual linguistic processing, that is, a color at the global level resulting from linguistic construction integrating meaning of the local elements of the adjective and the noun. However, the typical color of the noun object is a stable attribute of the object that does not depend on specific linguistic context.

This dissociation between phrase color and typical color provides a very interesting opportunity to investigate the dynamic changes of these two types of color activation under the same linguistic context by manipulating the stimulus onset asynchrony (SOAs) between the preceding phrase and the color patch, a technique that has been widely adopted in language research to compare time course of different linguistic codes. The theories of embodied cognition assume that not all possible affordances of perceptual simulation are activated in language processing; rather, only those relevant to the understanding are evoked.

Thus, it is not surprising that only those affordances directly relevant to the language comprehension are of primary interest (e.g., phrase color in the present study), while those less relevant ones are usually ignored and haven't been investigated so far (e.g., typical color in the present study), even both of them share the same type of affordance. The present study has tried a first attempt to investigate the dynamic activation of two types of color simulation (i.e., phrase color and typical color) simultaneously to fill up this gap.

In the past, most of the simulation studies usually just involve comparison between a congruent and an incongruent condition, which is then only able to show that the activation was present. Without a reference time course, it would be difficult to interpret any effects changes as a function of SOA. The time course data can possible make sense as the present design introduces the new variable of typical color in the same context as the phrase color. The relative activation of phrase color directly constrained by the phrase context, and typical color highly associated with the target object, would provide further insights on the embodied cognition by demonstrating a dynamic process of perceptual simulation.

Another major change from the Connell study was that I change from a task to detect whether the pictured object appeared in the previous sentence to a color patch naming task. So I will present the phrase followed a color patch and ask participants to name the color of the patch. Naming latency to the color patch was used to probe activation of perceptual color information when reading the preceding phrase. Simmons et al. (2009) assumed that the linguistic system and the simulation system both become active initially, but that activation in the linguistic system peaks first. The dissociation between the presentation of prime and task could help avoid the involvement of other confounding factors which may have impacts on the processing of the prime phrase. It was expected that if color information is activated in the phrase, it would facilitate naming of the color patch if the patch color was congruent with the color activated than when the patch color was incongruent with the color activated.

2) Apparently, Klein (1964) and Naor-Raz, Tarr, and Kersten (2003) have shed light on the conceptual representation of color in concrete words such as object nouns. In addition, in studies of motor simulation, other than action-related sentences, isolated action verbs have been presented and found to induce motor simulation. The above studies taken together raise the possibility that color simulation may also be demonstrated in linguistic units of words, even those less concrete than object nouns such as verbs and words psychologically related to color. In Study I, activation may be found for the typical color of the object noun in the phrase, it remains unclear whether such activation would only occur in a color directly denoting by object nouns. That is, Study I does not tell whether when the abstract words or those not as concrete as object nouns was presented, they would induce color activation.

Thus, in addition to object nouns which serve as the baseline, I also included two more types of words, verbs and words psychologically associated with colors. Verbs are concepts that have no direct concrete reference to perceptual color information. However, verbs, in denoting actions, are associated with agents and objects. For example, the verb 'plant' implies an action involving hands and trees. As mentioned in the introduction, there have been studies showing that body parts as agent information were simulated in processing action verbs, that is, reading 'lick' activates face area and reading 'kick' activates foot areas in motor cortex. It is possible that objects denoting by verbs may also be mentally simulated. To examine this in the general context of my focus of color information, I examined whether color information associated the object of a verb is simulated when reading a verb.

In addition, it was argued that the brain could simulate not only the perceptual and motor but also the mental states during the interaction with the world's referents (e.g., Barsalou, 1999, 2008; Damasio, 1989; Glenberg, 1997; Martin, 2001, 2007; Thompson-Schill, 2003). For example, the simulation of the word 'cat' involves how a cat looks, sounds and feels, and how one feels emotionally around them. The current study also took these emotional reenactments into consideration. Based on one's life experience, color can be associated frequently and indicate some emotional state. For example, black indicates fear, white indicates sadness, and red indicates danger and happiness. Therefore, abstract words such as fear, festival, and danger are indirectly connected with and imply a specific color. When reading such words, will there be activation for their implied color?

Putting verbs and words psychologically related to color together, they are both abstract concepts in the sense that they do not refer to concrete objects and would imply color as objects do but are just indirectly associated with the perceptual color information. Words psychologically related to color share the same psychological functioning with physical color. For example, red color could exert the feeling of danger (e.g., Elliot et al., 2007; Goldstein, Davidoff, & Roberson, 2009; Hill & Barton, 2005; Mehta & Zhu, 2009). Thus, reversely should color representation be demonstrated for words psychologically associated with color, it would be an interesting and significant extension to our understating of the scope of applicability for the claims of mental situation. Further, it would also be informative to compare their effect size, to see among the three types of words, which will show stronger effect of color simulation, the object nouns with direct connection to color, or the verbs or words indirectly or psychologically associated with color?

3) To repeat, Connell (2007) is the only study which is claimed to show perceptual color simulation. In that study, participants were presented with a sentence first, and then judged whether the following picture was mentioned in the preceding sentence. What he 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 his 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 interpretation 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 (around 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.

Chapter 3 Experimental Studies

Study I -- Color Simulation at Phrase Level

For this study involving three experiments and seventy-one participants, I used color-naming tasks to examine the activation of color information in phrase processing, relying on measurement of naming latency (Bock, 1996). The three experiments were conducted to examine whether one critical word could be strong enough to constrain particular color at phrase level and to provide time course information of the activation for the relevant color and irrelevant color.

In each trial, participants were presented with a phrase indicating a specific color. For example, '夜晚的天空', namely '夜晚的' (night) plus '天空' (sky) means 'sky in night', as a whole indicates the color black. All phrases used were in the form of adjective + noun, referring to particular objects as objects are mostly likely to imply color.

The phrase serves as a prime to a following target color patch whose color may be consistent or inconsistent with the color specified by the phrase. Participants need to name the color of the color patch as quickly and accurately as possible. If color information as denoted by the phrase prime had been activated, one would expect color naming to the target patch to be facilitated if the two colors were consistent with each other.

The type of phrases was manipulated to include phrases in which the adjective is associated with color information, referred as color-adjective phrases, and phrases in which the adjective is not/less associated with color information in itself, referred non-color-adjective phrases. An example for color-adjective phrase would be'夜晚的天空'where the adjective'夜晚的'implying color black. An example for non-color-adjective would be'不健康的', meaning unhealthy indicating no color but'不健康的牙齿'meaning unhealthy teeth indicates the color black as a whole phrase. The manipulation on phrase type could help to specify whether phrase color is based on the color activation of adjective or not.

Each phrase was paired with a patch in three different types of colors: a phrase color which is the color implied by the entire phrase ('夜晚的天空'-black); an object color which is not implied by the phrase but the typical color for the noun ('夜晚的天空'- blue); an incongruent color which is implied neither by the phrase nor the noun ('夜晚的天空'- green). The incongruent color serves as a baseline (although this may appear strange as incongruent typically implies an interference condition but not a neutral control. I will return to this point in the discussion of Exp. 1). Briefly, for the phrase of sky in night, the phrase color would be black, and the typical color would be blue and the incongruent color would be green.

The comparisons were between the average naming latencies to the three types of patch colors, all preceded by the same phrase prime. If there were color information activation during phrase comprehension, one would expect better performance for when the patch was in the phrase color, relative to when the patch was in the incongruent color. There was no specific prediction as to whether similar effects would be found for the typical color condition, relative to the incongruent control condition. However, typical color was included to further investigate whether linguistic context could be empirical impact which is not indicated by the current linguistic context, namely the irrelevant information, would play a role in language processing. To examine the time course of such activation, the prime-target SOA between the phrase onset and the color patch onset was manipulated across the three experiments, as in typical priming studies. If color activation was found for typical color, then strong evidence would be also provided to support the embodied cognition which has a primary focus on the interaction between body and the referent. The typical color is the frequently one experienced by our senses. Thus, its activation in a irrelevant context would be a stronger piece of evidence.

Experiment 1

Method

Participants

Twenty-four right-handed undergraduates (12 males), aged between 20 and 25 years, with a mean age of 22.1 (SD =1.10), were recruited from South

China Normal University, Guangzhou, China. All were native Chinese speakers and all signed informed consent form. All had normal color vision as assessed by the City University Color Vision Test (Fletcher, 1980).

Materials and design

Color stimuli were draw from six Munsell color patches displayed on the monitor, namely, red, green, white, black, blue, and yellow. For the chromatic colors, lightness and saturation dimensions were kept constant at Value 5 and Chroma 6, while the hue set at Hue 10R, 10G, 10B, and 10Y, for red, green, blue, and yellow, respectively. For black and white, their lightness was Value 0 and 10, respectively, with the same saturation at Chroma 0.

Color patches were presented as a square of 120 × 120 pixels (approximately 3 × 3 cm) on a white background with a thin black line (one pixel) as boundary.

There were 40 adjective-noun phrases used and half of them were test items indicating particular colors and half were fillers indicating no color (e.g., '拥挤的交通' means heavy traffic). Each phrase was paired with three different types of colors, as described above, the phrase color, the typical color, and the incongruent color. The fillers were also paired with three different color patches. To ensure participants read the phrase, a two-character word was presented 800 ms after the offset of color patch for half of the filler trials. Participants should judge whether this word was included in the preceding phrase or not by pressing one key for yes and another key for no. There is a 800 ms interval between trials.

Test phrases were pre-tested to ensure they actually implied the intended color. Twenty-one college students who did not participate any of the experiments were instructed to write down the corresponding color implied by the whole phrases and the target object nouns and rate the canonicality of color based on a 7-point Likert scale ranging from 1 (very low canonicality) to 7 (very high canonicality), respectively. Across all subjects, the average reported color matched that of the intended color. For the phrase, mean = 90%, SD = 5%, with the rating of each phrase higher than 5; for object noun: M = 93%, SD = 4%, with the rating of each object noun higher than 5. Another twenty college students were instructed to write down the corresponding color implied by the adjectives and rated their canonicality as well. For half of them, M = 90%, SD = 5%, with the rating of each phrase higher than 4, for the other half, none of them showed a consistent color.

Each of the 40 items was paired with 3 color patches, producing 120 trials in total. These 120 trials were evenly divided in three blocks, each of 40 trials. All 20 different test items appeared in each block and each appeared only once, and the rest trials in each block were filler trials. For the test items, about 1/3 of them would be paired with a patch in the phrase color, 1/3 paired with a patch in the typical color, and 1/3 paired with a patch in the incongruent color. The design was therefore a 2 (Phrase type: color-adjective phrase vs. non-color-adjective phrase) × 3 (Color version: phrase color, typical color, incongruent color) design with two within-subject factors.

Procedure

Stimulus presentation and response acquisition were controlled by the E-Prime software running on an IBM-compatible computer. Response latencies were recorded by computer using a voice-activated key, and accuracy was recorded and scored by the experimenter.

All participants were tested individually in a dimly lit room. Instructions were displayed visually onscreen and explained by the experimenter. Participants completed 10 practice trials before the actual testing. Each trial began with a central fixation cross for 500 ms, followed by a 600-ms presentation of a phrase. At the offset of the phrase, a color patch appeared onscreen. Participants should name the color patch as quickly as possible, while maintaining high accuracy. If participant failed to respond within a 5000 ms time window, the program would regard it as an error. The color patch was turned off after response or at the end of the response window. In some catch trials, there would also be a two-character test word presented after the patch and participants to indicate whether this word was in the phrase or not. The test words were equally likely to be the adjective (without out the last character '的') or the noun. They pressed one key's' for yes response and another 'n' for no response. No feedback on the response accuracy or speed was given to the participants.

The items were pseudo-randomized across participants with no two successive trials requiring the same naming response. The experimental session was made up of three blocks with a 1-minute break between blocks. At the beginning of each block, there were three warm-up trials whose data were removed from the data analyses.

Results

Analyses used repeated-measures ANOVA with either participant (*F*1) or item (*F*2) as the random variable. Both Phrase type and Color version were within-participant and within-item variables. Response accuracies for the color naming task were generally very high with a mean value of 0.97 (*SD*=0.01) for all three conditions combined. The accuracy was also very high for the word judgment for the catch filler trials (mean = 0.94). No significant was revealed from ANOVA for any main effect or interaction. The same pattern was found for Exp. 2 and 3 so I would only focus on the latency results in the following.

Table 1

Mean Response Times (in Milliseconds) per Phrase as a Function of Color Version

Color version / Phrase type	Phrase color		Typical color		Incongruent color	
	M	*SD*	*M*	*SD*	*M*	*SD*
Color-adjective phrase	715	49	741	69	785	70
Non-color-adjective phrase	708	55	736	80	793	81

Trials with RT less than 250 ms and greater than 1750 ms were excluded from all analyses, which accounted for 5.4% of the total number of trials and were approximately equally distributed across conditions. The mean naming times for different conditions are illustrated in Table 1. The results showed a non-significant main effect of Phrase type ($F1$ (1, 23) = 0, MSE =1, p> .5, $F2$ (1, 9) = .11, MSE = 376, p>.1), but a significant effect of Color version ($F1$ (2, 46) = 21.88, MSE = 59551, p< .001, $F2$ (2, 18) = 13.02, MSE = 28628, p< .01). Specifically, significant differences were found between phrase color and incongruent color (715 vs. 785 ms, $F1$ (1, 23) = 42.54, MSE = 116821, $p < .001$, $F2$ (1, 9) = 20.13, MSE = 57041, $p < .01$), between phrase color and typical color (715 vs. 741 ms, $F1$ (1, 23) = 5.74, MSE = 16776, $p < .05$, $F2$ (1, 9) = 7.78, MSE = 11389, $p < .05$), as well as between typical color and incongruent color (741 vs. 785 ms, $F1$ (1, 23) = 18.05, MSE = 45058, $p < .001$, $F2$ (1, 9) = 7.58, MSE = 17454, $p < .05$).

No significant interaction was found between Phrase type and Color version, $F1$ (2, 46) = .88, MSE = 2367, $p > .1$, $F2$ (2, 18) = .76, MSE = 1241, $p > .1$. This indicates in particular that the difference between phrase color and typical color was not different between color-adjective phrases and non-color-adjective phrases.

Discussion

Exp. 1 demonstrated that when a phrase was briefly presented for 600 ms, both the color implied by the whole phrase and the typical color associated with the noun of the phrase were named faster than an incongruent color baseline. And significant difference was also found between phrase color and the typical color, suggesting a stronger activation for the phrase color than for the typical color. The results showed clear color simulation, i.e., a clear effect of color activation in language comprehension for linguistic unit at the phrase level.

The color of the whole phrase and the typical color of the noun object were different. For example, in the phrase of '刚长出的枫叶' (new-born maple), the phrase color is green, while the typical color of maple is red. However, activation of both the phrase color and the typical color were observed, with the priming effect being larger in size for the phrase color than for the typical color.

This pattern of results suggest that the color constructed at the whole phrase level based on the combination of the adjective and the noun enjoys some processing priority, but does not dominate to the extent of totally suppressing the activation of the typical color, which was incongruent with the phrase color. It may also be interpreted to mean that the color information, such as a color typically (i.e., strongly) associated with an object concept due to life experience, was activated highly automatically in processing the concept. The dominant access view of concept's property also provide some support for the current finding by claiming that the most dominant form of the property is retrieved during property verification task, even if that form is incorrect for the concept. For example, in a previous work of Solomon and Barsalou (2001), when verifying nose for airplane, some subjects reported that they initially imagined a human nose that did not match any part of an airplane, often leading to an incorrect false response.

The other interesting finding is that there is no significant interaction between phrase type and color version. That is, activation of the phrase color was the same regardless of whether the adjective in the phrase implies a color (in the color-adjective phrases) or not (in the non-color-adjective phrases). As the adjectives in the color-adjective phrases always referred to the same color as the phrase color, this confirmed that the activation of color information indeed resulted from the phrase color but not from color from the adjective. If it were the adjective color that was important, one would expect to find a priming effect difference between the two types of phrases.

The present results were based on differences between a congruent condition and an incongruent condition. It is well-known that without a suitable neutral condition, it would be difficult to assess whether any congruence effects observed reflect facilitation or priming. Given the present task was color naming, it was impossible to put in a condition neutral, compared to the congruent and incongruent conditions. However, literature studies have tended to show that the effect of automatic color information activation in language processing with modified Stroop paradigm seems more likely to result from facilitation but not inhibition (Klein, 1964; Naor-Raz, Tarr, & Kersten, 2003). I therefore assume for color simulation and tentatively consider the incongruent condition to be a baseline to assess such facilitation in the congruent condition.

Experiment 2 and 3

Method

Exp. 2 and 3 were identical to Exp. 1 except the SOA between the phrase prime and the target color patch was manipulated to further characterize the time course of the color simulation observed in Exp. 1. While the SOA was 600 ms in Exp. 1, it was increased to 800 ms in Exp. 2, and 1000 ms in Exp. 3. All aspects were as in Exp. 1 except where this SOA was relevant. Participants were taken from the same subject populations and formed the same inclusion criteria as in Exp. 1. Two groups of new participants were recruited for Exp. 2 (N=24, 12 males, mean age+/- *SD* = 22.1+/-1.1) and Exp. 3 (N=23, 11 males, mean age+/- *SD* = 22.1+/-1.2).

Results and discussion

The mean naming times across all participants for different conditions are illustrated in Table 2 and 3 for Exp. 2 and 3, respectively.

The two-way interaction of SOA × Color Version was obtained both by participant (*F*1 (4, 136) = 3.3, *MSE* =9870, p< .05) and by item (*F*2 (4, 54) = .8.73, *MSE* = 15742, *p*<.001). See Fig. 2.

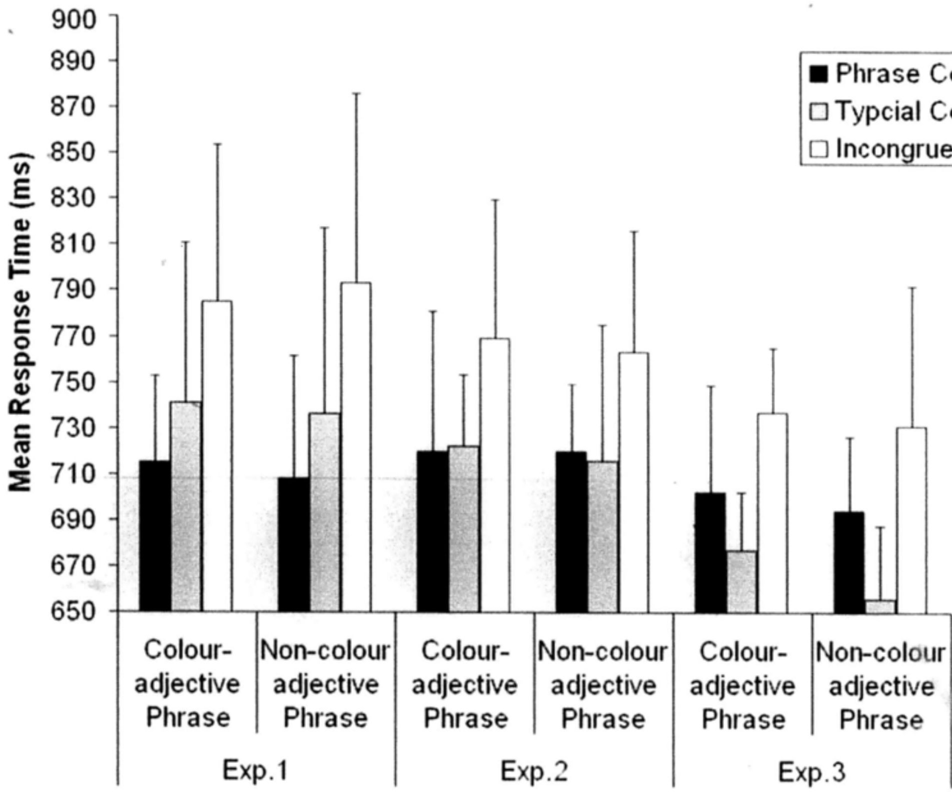


Fig. 2. Mean response times for the three types of colors in the color-adjective phrase and non-color adjective phrase from Experiment 1-3.

As in Exp. 1, for Exp. 2, the main effect of Phrase type was not significant (*F*1 (1, 23) = .22, *MSE* =378, p> .1, *F*2 (1, 9) = .04, *MSE* = 243, *p*>.1), neither was the interaction between Phrase type and Color version (*F*1 (2, 46) = .5, *MSE* = 1069, *p*> .1, *F*2 (2, 18) = .03, *MSE* = 58, *p*> .1). Critically, the main effect of Color version was significant (*F*1 (2, 46) = 8.79, *MSE* = 28938, *p*= .001, *F*2 (2, 18) = 12.38, *MSE* = 14075, *p*< .001). Response time for incongruent color was significantly longer than phrase color (*F*1 (1, 23) = 10.56, *MSE* = 44187, *p*= .004; *F*2 (1, 9) = 32.69, *MSE* = 20752, *p*< .001) and typical color (*F*1 (1, 23) = 11.01, *MSE* = 42613, *p*= .003; *F*2 (1, 9) = 11.92, *MSE* = 21466, *p*< .01), with no difference between phrase color and typical color (*F*1 (1, 23) = .01, *MSE* = 14, *p*> .1, *F*2 (1, 9) = .01, *MSE* = 6, *p*> .1).

Table 2

Mean Response Times (in Milliseconds) per Phrase as a Function of Color Version

Color version / Phrase type	Phrase color		Typical color		Incongruent color	
	M	*SD*	*M*	*SD*	*M*	*SD*
Color-adjective phrase	720	62	722	31	769	60
Non-color-adjective phrase	720	31	716	57	763	50

Table 3

Mean Response Times (in Milliseconds) per Phrase as a Function of Color Version

Color version / Phrase type	Phrase color		Typical color		Incongruent color	
	M	*SD*	*M*	*SD*	*M*	*SD*
Color-adjective phrase	702	49	677	25	737	23
Non-color-adjective phrase	694	43	656	32	731	61

However, in the experiment 3, the main effect of Phrase type was marginally significant only by participant but not by item (*F*1 (1, 22) = 3.77, *MSE* =7910, $p = .06$; $F2\ (1, 9) = .54$, *MSE* = 1887, $p > .1$). The main effect of Color version was significant by both participant and item ($F1\ (2, 44) = 15.33$, *MSE* = 45439, $p < .001$; $F2\ (2, 18) = 21$, *MSE* = 22729, $p < .001$). Response time for incongruent color was significantly longer than phrase color ($F1\ (1, 22) = 8.08$, *MSE* = 26085, $p = .009$; $F2\ (1, 9) = 11.11$, *MSE* = 12984, $p < .01$) and typical color ($F1\ (1, 22) = 23.4$, *MSE* = 90719, $p < .001$; $F2\ (1, 9) = 34.03$, *MSE* = 45384, $p < .001$). However, different from Exp. 1 and 2, response to phrase color was slower than typical color ($F1\ (1, 22) = 10.93$, *MSE* = 19512, $p < .005$; $F2\ (1, 9) = 13.17$, *MSE* = 9818, $p < .01$). Again, the 2-way interaction did not reach significance ($F1\ (2, 44) = .09$, *MSE* = 158, $p > .1$; $F2\ (2, 18) = .2$, MSE = 355, $p > .1$).

The results of Exp. 2 and 3 are discussed together with that from Exp. 1.

Discussion for Study I

Results from Experiments 1 to 3 all showed a clear congruence effect of naming latency difference between the congruent phrase color condition and the incongruent color condition, providing a robust demonstration of the activation of perceptual representation of color information or the presence of color simulation in processing phases. In addition, the typical color associated with object noun in the phrase, being different from that of the phrase color, was also found to be activated. Along with the existing evidence of color simulation, this indicates that simulation of a concept can be influenced by one critical word, namely the adjective used in the current study. Such result is consistent with the recent finding of Wu and Barsalou (2009) that different types of properties were generated to object nouns and their corresponding noun phrase which indicated another state of the noun. Interestingly, not only color information implied by the global context as contained in a simple phrase structure but also color information irrelevant to the global context as implied by a component unit of the phrase were both found activated, which could be elucidated by the dominant access view that the dominant form of the property could be retrieved in the concept understanding. The current study further extend this view by demonstrating that such dominant form of the property could be retrieved and kept strong even in an irrelevant context such as the blue color of sky in the phrase of 'night sky'.

The critical difference across the three experiments was that the effect size of color simulation was larger for phrase color in Exp. 1 at 600 ms SOA, but became comparable between the two at 800 ms SOA, and got reversed to be larger for the typical color than the phrase color at 1000 ms SOA. That is, the relative level of activation between the two color codes seems to vary as a function of the time available to process the phrase. When the time was short, the phrase color seems to have been activated, while as the presentation time was lengthened, the typical color was activated more and eventually became larger than the phrase color.

The color information based on the linguistic construction of the whole phrase seems to be extracted rather quickly, suggesting a faster activation than the typical color. Such more immediate and direct impact from the phrase color may be understood in the sense that the phrase meaning is more relevant in the context of linguistic processing, compared to the typical color which, driving from long-term daily experience, invariant of and hence indirectly associated with specific context, is retrieved more slowly and gradually.

That the effect of typical color becomes stronger as a function of the variation of SOA may shed light on the dissociation between adjective and noun in a phrase as the SOA was lengthened. It is obvious that the noun phrases used in the current study have a salient focus on noun but not adjective. Thus, it is natural that the participants would have a primary focus on processing the noun while ignore the adjective, at least to some extent. Thus, the context effect become relatively weaker and weaker (i.e., phrase color), while the typical color of object become stronger and stronger. This interesting dynamic change of the color activation provides evidence to support the simulation of concept and simultaneously that the construction of this simulation rest on the influences of both the linguistic context and the frequently experienced context. And it is obvious that when these two forces contradicts with each other, the latter one (i.e., the indirect context) could even become more salient than the former one (i.e., the direct context). The more and more salient effect of typical color, thus, provided strong evidence for the embodied cognition that 'embodiment' (experience) is the central tenet of this theory.

<u>Study II -- Color Simulation at Word Level</u>

Exp. 1-3 showed that when reading a simple phrase, the color information implied by the phrase can be activated, so is the typical color of the target object. This leads to that typical color of an object is dominantly represented in its corresponding object noun (Klein, 1964; Naor-Raz, Tarr, &

Kersten, 2003). In the current study, a follow-up question whether such color simulation can be further demonstrated for single less concrete word remains an issue.

So far, in demonstrations of mental simulation, the association between the concept presented in sentences, phrases, action verbs, and the perceptual information implied by the sentence, phrases, action verbs is usually concrete, based on their direct connection in the actual experience of the relevant physical events, e.g., seeing a banana in real life directly entails the concrete connection between the concept of banana and the yellow color in perception.

As an extension to the basic phenomenon of color simulation, I will examine whether color simulation occurs when such association is not so direct or less concrete by including verbs and a special category of words that are psychologically associated with color.

Verbs are abstract concepts in the sense the action the verb connotes does not have any direct connection to perceptual color information. However, verbs are indirectly associated with color via the color of the object involved in the action. The issue under investigation is therefore, when reading a verb, will not only the action but also the object involved in the action be mentally simulated?

Colors are frequently associated with some abstract concepts about emotional state or feeling. For example, black indicates fear, blue indicates depressed, and red indicates danger. Presumably such associations are non-arbitrary and not totally based on just social convention. For example, it is generally more dangerous in the darkness relative to bright lighting conditions. There has also been much documentation of the effects of color on mood (e.g., Cothran & Larsen, 2008; Callejas, Acosta, & Lupianez, 2007; Sakuta & Gyoba, 2006). So while such words are psychologically associated with color, the association is not totally semantic in nature but seems to have some physiological basis linking the perception of a specific color with the particular psychological state the word denotes. This therefore provides a situation where color information is connected with concepts indirectly in a less concrete way.

In summary, in addition to concrete object nouns, I considered verbs and words psychologically related to color, which are both abstract concepts in that they do not refer to concrete objects or imply color as objects do but are indirectly associated with perceptual color information. The primary interest was to see whether color simulation would occur for the three types of words and how it may be affected by the nature of the association between the color and the concept. Towards this goal, Study II would also manipulate SOA to investigate their relative time course and level of activation.

Experiment 4

Method

Participants

A new group of twenty-six participants (12 males, mean age+/- *SD* = 23.0+/-1.5) were recruited from the same subject population as in Exp. 1, based on the same inclusion criteria.

Materials and design

The structure of the stimulus set was similar to that in Exp. 1 including 30 test words and 30 filler words. The test items consisted of 10 verbs (e.g., ‘[illegible]

长'- grow), 10 words psychologically-related to color (e.g., '邪恶' - evil), and 10 concrete nouns (e.g., '芒果' - mango). For simplicity, the psychologically-related were short-handed as psych-color words. The ten nouns were taken from the phrases used in Exp. 1 and all referred to objects. These three types of words were matched in stroke number and visual word frequency (Modern Chinese Frequent Words Dictionary, 1990). All of the test items were selected to imply color and none of the 30 filler words imply color (e.g., '步伐'- step). Each word was designated with a color which is supposedly implied by and hence congruent with the word. This was confirmed in a rating study involving 20 participants not in any of the formal experiments.

Participants were given each of the test words and asked to write out a color that they considered most related to that word and rate how strong the color-word association was. Results showed that for each of the test words in the stimulus set, more than 75% participants wrote out the color designated. The color-word association strength rating for every test word and its congruent color was higher than 5 in a 7-point Likert scale. There was no significant differences across the three word groups neither association consistency, nor association strength (*F*s <1), ensuring good materials match across prime word type.

Each test word was paired with two different colors: its congruent color and an incongruent color. For example, '苹果' (apple) would be followed by either a red color patch to make a congruent pair or a white color patch to make an incongruent pair. Thus, the design was a 3 (Prime type: verb, psych-color word, object noun) x 2 (Congruency: congruent, incongruent) design with Prime type and Congruency as two within-subject factors.

Each of the 60 word items was paired with two color patches, producing 120 trials in total. These 120 trials were evenly divided into two blocks, each of 60 trials. All 30 test words appeared in each block and appeared only once. Half of them were paired with congruent color in one block and the incongruent color in the other block. For the other half, it was the opposite. Hence there was equal number of congruent and incongruent trials within each block.

To ensure participants read the word carefully, an italic probe word would be presented at the end in half of the filler trials. Participants were instructed to judge whether the italic words was the same as the previous one by pressing one key for yes and another for no. Half of the times, the probe word would be different from the filler word but the other half, it would be the same. That is, participants would need to make a yes response for half of these catch trials and a no response for the other half.

Procedure

The procedure was the same as in Exp. 1 except the duration of the word presentation was set at 400 ms, when the semantic processing of the word is assumed to achieve its peak or be nearly finished.

Results and Discussion

The mean naming times across all participants for the different conditions are illustrated in Table 4 for Exp. 4. ANOVA showed a significant main effect for Prime type ($F1$ (2, 50) = 29.92, MSE =76741, p<.001; $F2$ (2, 18) = 8.33, MSE = 28900, p<.005) and for Congruency ($F1$ (1, 25) = 10.83, MSE =29714,

p<.005; $F2$ (1, 9) = 3.88, MSE = 14997, p=.08), although for Congruency the item analysis significance was marginal. The psych-color words elicited faster patch color naming than verbs ($F1$ (1, 25) = 50.05, MSE = 109121, p< .001; $F2$ (1, 9) = 9.56, MSE = 42851, p< .05) and object nouns ($F1$ (1, 25) = 31.74, MSE =120805, p<.001; $F2$ (1, 9) = 17.27, MSE = 43842, p<.005), but there the verbs and object nouns did not differ from each other ($F1$ (1, 25) = .17, MSE =297, p>.1; $F2$ (1, 9) < .005, MSE = 6, p>.1). The interaction between Prime type and Congruency was only significant by participant (F(2,50) = 4.72, MSE=8799, p<.05), but not by item (p>.1).

As expected, response time for incongruent color was significantly longer than congruent color ($F1$ (1, 25) = 10.83, MSE = 19809, p< .005; $F2$ (1, 9) = 3.88, MSE = 9998, p= .08). Planned comparisons showed that, however, the congruence effect was present only for the psych-color words ($F1$ (1, 25) = 15.7, MSE = 82790, p=.001; $F2$ (1, 9) = 11.04, MSE = 20658, p< .01) but not the verbs and object nouns (Fs>.1).

Table 4

Mean Response Times (in Milliseconds) per Word type as a Function of Color Version

Word type / Color version	Verbs		Psych-color words		Object nouns	
	M	*SD*	*M*	*SD*	*M*	*SD*
Congruent color	762	91	672	81	758	92
Incongruent color	768	97	728	89	779	114

Not relevant to our main interest, the absolute performance differences across the three types of prime words may reflect some special attributes of the words psychologically associated with color. For example, such words as fear, danger may enhance emotional arousal speeding up response non-specifically (hence, independent of whether the following patch was incongruent or incongruent in color), relative to verbs and nouns that lack emotional content.

Critically, Exp. 4 showed that when a word was briefly presented for 400 ms, the color it implied was named faster than an irrelevant color. The results showed color simulation, or a clear effect of color activation in language comprehension for linguistic units such as abstract words.

It is surprising that such effects were only obtained for words psychologically associated with color, but not for verbs and object nouns. For example, given the direct connection between an object noun and the object's color, the noun words were expected to produce the clearest evidence of color simulation. However, this was not the case in our results where the congruence effect for nouns was 21 ms, though in the right direction (faster congruent than incongruent conditions) but non-significant. Noted that in Study I, effects of the typical color of an object were significant and increased with longer SOA and the 400 ms SOA in the present study was shorter than the shortest 600 ms in Study I, I increased SOA to 800, and 1000 ms in the next two experiments to see whether this effect would become significant when more processing time on the prime was available. Results from Exp. 4 would be further discussed together with that from Exp. 5 and 6.

Experiment 5 and 6

Method

Exp. 5 and 6 were identical to Exp. 4 except the SOA between the word prime and the target color patch was manipulated to further characterize the time course of the color simulation observed in Exp. 4. While the SOA was 400 ms in Exp. 4, it was increased to 600 ms in Exp. 5, and 800 ms in Exp. 6.

All aspects were as in Exp. 4 except where this SOA was relevant. Participants were taken from the same subject populations and formed the same inclusion criteria as in Exp. 4. Two groups of new participants were recruited for Exp. 5 (N=27, 13 males, mean age+/- *SD* = 23.1+/-1.2) and Exp. 6 (N=24, 12 males, mean age+/- *SD* = 22.1+/-1.0).

Results and discussion

The mean naming times across all participants for different conditions are illustrated in Table 5 and 6 for Exp. 5 and 6, respectively.

The three-way interaction of SOA × Word Type × Congruency was obtained neither by participant ($p>.1$), nor by item ($p>.1$). See Fig. 3.

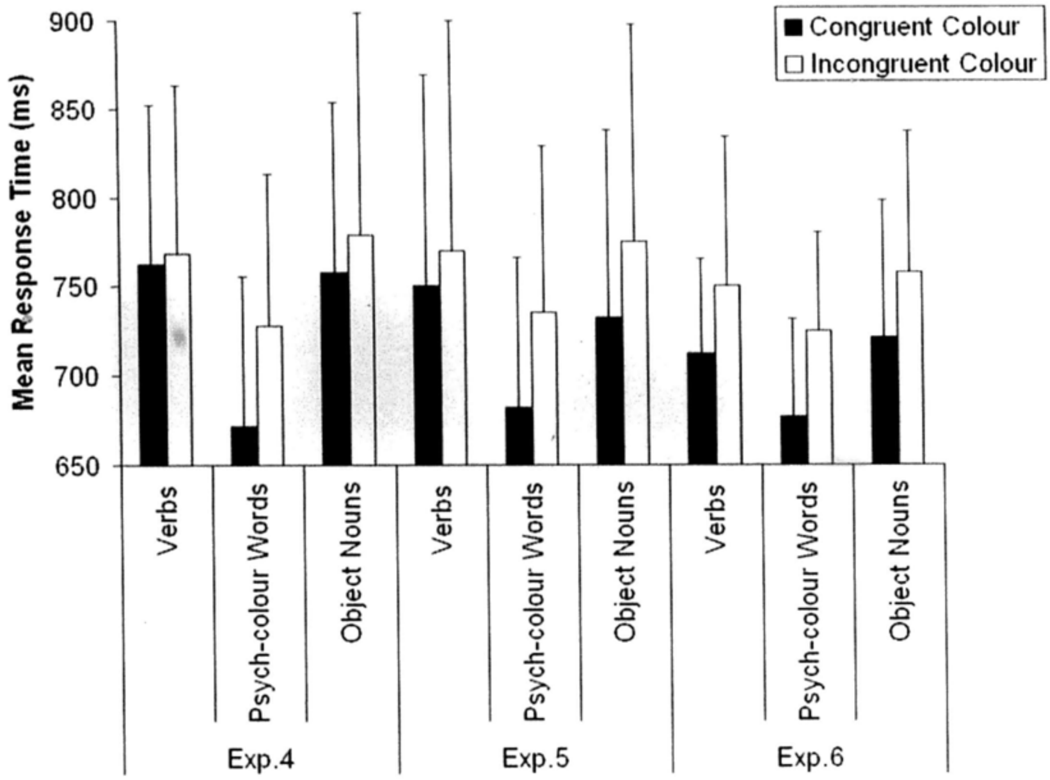


Fig. 3. Mean response times for the three types of words followed by congruent color and incongruent color from Experiment 4-6.

For Exp. 5, ANOVA revealed significant main effects of Prime type ($F1$ (1, 52) = 14.51, MSE =42395, $p< .001$; $F2$ (2, 18) = 8.96, MSE = 16258, $p<.005$) and Congruency ($F1$ (1, 26) = 33.38, MSE = 60812, $p< .001$; $F2$ (1, 9) = 13.77, MSE = 21185, $p= .005$). Specifically, response time was faster for color patches following the psych-color words, compared to verbs ($F1$ (1, 26) = 18.06, MSE =71815, $p< .001$; $F2$ (1, 9) = 10.05, MSE = 28034, $p<.05$) and nouns ($F1$ (1, 26) = 18.24, MSE =54119, $p< .001$; $F2$ (1, 9) = 11.01, MSE = 20077, $p<.1$) but was not significantly different between verbs and nouns ($F1$ (1, 26) = .69, MSE =1249, $p> .05$; $F2$ (1, 9) = .8, MSE = 662, $p>.1$). As expected, color naming was faster for the congruent word-color pairs than for the incongruent pairs ($F1$ (1, 26) = 33.39, MSE =40541, $p< .001$; $F2$ (1, 9) = 13.77, MSE = 14123, $p=.005$). The interaction between Word type and Congruence was non-significant ($F<1$).

Planed comparisons showed congruence effects for both the psych-color words ($F1$ (1, 26) = 33.39, MSE =40541, p< .001; $F2$ (1, 9) = 17.59, MSE = 13910, p<.005) and nouns ($F1$ (1, 26) = 33.39, MSE =40541, p< .001; $F2$ (1, 9) = 13.13, MSE = 9462, p<.01), but still not for verbs ($F1$ (1, 26) = 2.0, MSE =11168, p> .1; $F2$ (1, 9) = 1.38, MSE = 1360, p>.1).

For Exp. 6, the main effects of Prime type were significant ($F1$ (2, 46) = 3.96, MSE =19583, p< .05; $F2$ (2, 18) = 4.23, MSE = 10792, p<.05) and Congruency ($F1$ (1, 23) = 25.4, MSE = 58084, p< .001; $F2$ (1, 9) = 31.64, MSE = 22216, p< .001). Specifically, color naming was significantly faster when following the psych-color words than verbs ($F1$ (1, 23) = 7.47, MSE =21528, p< .05; $F2$ (1, 9) = 7.93, MSE = 11041, p<.05) and nouns ($F1$ (1, 23) = 9.65, MSE =35486, p= .005; $F2$ (1, 9) = 9.91, MSE = 20439, p<.05), but no significantly different between verbs and nouns ($F1$ (1, 23) = .21, MSE =1735, p> .1; $F2$ (1, 9) = .33, MSE = 1435, p>.1). The interaction between Word type and Congruence was no significant (F<1). As expected, color naming was faster for the congruent word-color pairs than for the incongruent pairs ($F1$ (1, 26) = 33.39, MSE =40541, p< .001; $F2$ (1, 9) = 25.4, MSE = 38722, p<.001). Planed comparisons showed a congruence effect for all three types of words: psych-color words ($F1$ (1, 23) = 12.54, MSE =26609, p< .005; $F2$ (1, 9) = 11.04, MSE = 21518, p<.01), nouns ($F1$ (1, 23) = 6.67, MSE =31390, p< .05; $F2$ (1, 9) = 8.92, MSE = 17917, p<.05), and verbs ($F1$ (1, 23) = 8.56, MSE =33297, p<.01; $F2$ (1, 9) = 9.61, MSE = 7149, p<.05).

Table 5

Mean Response Times (in Milliseconds) per Word type as a Function of Color Version

Word type / Color version	Verbs		Psych-color words		Object nouns	
	M	*SD*	*M*	*SD*	*M*	*SD*
Congruent color	750	110	682	83	732	103
Incongruent color	770	119	735	94	775	115

Table 6

Mean Response Times (in Milliseconds) per Word type as a Function of Color Version

Word type / Color version	Verbs		Psych-color words		Object nouns	
	M	*SD*	*M*	*SD*	*M*	*SD*
Congruent color	712	55	677	55	721	80
Incongruent color	750	83	725	56	758	75

The pattern of results in Exp. 5 and 6 were the same as that in Exp. 4 in that all revealed a main effect of Prime type but no Prime type by Congruency interaction. As in Exp. 4, this absolute performance difference across the three types of prime words was interpreted to reflect enhanced emotional arousal for the words psychologically associated with color producing non-specific response speed-up independent of the congruency manipulation, relative to verbs and nouns.

Regarding Congruence, both experiments showed a similar main effect as in Exp. 4 but the planned comparisons reveal some different results so that color simulation was observed for verbs in Exp. 6 and for object nouns in both Exp. 5 and 6.

Discussion for Study II

Following Study I, Study II shows that color simulation can be demonstrated in less concrete words and indicates that effects of color simulation occurs at several different levels of language processing from phrases to the present level of individual nouns representing concrete objects, as long as the concept expressed implied color information. This result also suggests that the activation observed for the typical color associated with the noun in the phrases of Study I was not a contingent on the fact that the noun was embedded in a larger linguistic units carrying color.

Further, color simulation was also found for two other kinds of abstract words, including verbs and words with a psychologically-related color. This finding indicates that color simulation is not limited to situations where there is a concrete, direct connection between the concept and the color information but can be extended to situations where the concept is indirectly linked to color via another mental representation or when the two are psychologically associated based on some common physiological state.

Results from manipulating the SOA between the onset of the concept presentation and the onset of the patch probing the color activation indicate that at short SOA, words psychologically related to color lead to color activation as short as 400 ms and stayed around the same level of activation when SOA increased to 600 ms, and 800 ms (Exp. 4-6: 56: 53: 48 ms). For object nouns, the color activation was present but not significant until after 600 ms (Exp. 4-6: 21, 43, 37 ms). The verbs were the latest in activation, showing a trend of gradually increasing in effect size as SOA was increased but only achieved significance at the final SOA of 800 ms (Exp. 4-6: 6:20:38 ms). At the end, the level of activation was comparable for the nouns and verbs (noun: verb – 37:38 ms).

These results do not seem to be confounded by the strength of association between words and colors which has been matched as shown in the pilot rating study. Nor do they seem to be confounded by stimulus differences across word types, such as stroke number and word frequency, two of the most important factors indexing word visual complexity and difficulty in lexical processing. It therefore seems that the extent to which color information is activated may not be solely dependent on the color-word association as subjectively rated but also on some other factors. One possible factor, for example, may be the number of alternative colors that can be associated with a word. Words psychologically associated to color typically only have one single color association but objects can quite often have more than its typical color (e.g., apple can be red, green, and yellow).

Or it could be that the psych-color words are special in that they tend to increase arousal level as would be produced in perceiving their associated color and such shared physiological state may function at a subconscious level and not reflected in the conscious subjective rating of their connection. So essentially the overall connection between the two, pooling both the conscious and the subconscious is stronger, which produced the larger color simulation effects observed for the words psychologically-related to color.

Moreover, the strong relation between color and psychological functioning has been demonstrated in some recent studies (Elliot et al., 2007; Hill & Barton, 2005; Mehta & Zhu, 2009). For example, Elliot et al. (2007) focused on the relation between red and performance attainment. Red is hypothesized to impair performance on achievement tasks, because red is associated with the danger of failure in achievement contexts and evokes avoidance motivation. Their first four experiments demonstrated that the brief perception of red prior to an important test (e.g., an IQ test) impairs performance. Moreover, such influence seems to be an unconscious one. Obviously, their findings provide support to the possibility that reversely psychological-feeling words such as danger could involve color as part of the representation. Our results fit with these previous studies.

The results that color activation was the slowest for verbs, particularly slower than the color activation for object nouns, is relatively easy to interpret if we assume that for verbs, the retrieval of associated color information depends on or is mediated by the first activation of the objects involved in the action the word refers to.

The different time courses of the activation of verbs, nouns, and words psychologically-related to color seem to fit with the proposal of Simmons et al. (2008) that the contributions of perceptual simulation in conceptual processing are assumed to vary (Fig. 4). In response to different types of words, the height, width, shape, and offset of the distribution of linguistic system (L) and simulation system (SS) are likely to change. In regard to the current study, our results showed that the latency of word psychologically-related to color comes first, which in turn was followed by object noun and verbs.

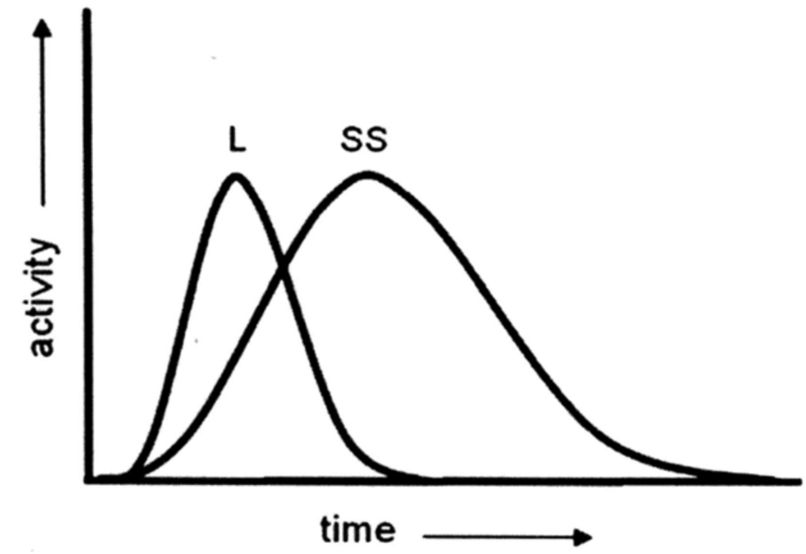


Fig. 4. Hypothesized contributions from the language system (L) and the situated simulation system (SS) during conceptual processing proposed by Simmons et al. (2008).

Study III -- Electrophysiological Evidence for Color Simulation

In most studies demonstrating perceptual simulation, including the one by Connell (2007) for color simulation, participants were presented with a sentence to read followed by a picture to make judgment of the object depicted in the picture. The central argument for the occurrence of perceptual simulation is based on a kind of congruence effect, i.e., task performance was affected by whether or not the color expressed by the linguistic expression matches the color perceptually given.

Although a correct and also the most straightforward interpretation for such congruence effect is that perceptual information was activated during sentence reading and affected later perceptual processing. Logically, however, it is possible that at least part of this congruence effect reflects a congruence effect at other levels beyond perceptual representations.

Although not directly addressing color simulation, Naor-Raz and colleagues (2003) made a convincing argument for the case in point when they discussed the effect of color in object recognition. In light of their argument, color information may affect object recognition in several different levels, including visual, semantic, and lexical levels. Consider the very often-used example of a yellow banana. At the visual perceptual level, the object `banana' drives neural responses from shape-selective neurons in inferior temporal cortex, from color-sensitive neurons in extra-striate cortex. At the conceptual level, knowledge about bananas may include modality-independent set of semantic features including descriptions of shape, e.g. 'bent, elongated axis, tapered ends', descriptions of surface, e.g., 'yellowish-green, brown speckles, flat, and smooth', and descriptions of function, e.g. 'edible, sweet, eaten by monkeys'. At the lexical level, the entry 'banana' might be associated with other entries in the mental lexicon such as 'yellow' for high probability of co-occurrence, compared with 'yellow spinach' or 'purple banana'. When participants are asked to identify or recognize a banana, information from any and all of these levels is likely to get involved. For example, when one names the object 'banana' in response to a colored picture of a banana, shape and color information, associated semantic features appropriate lexical representations may all be access for best performance.

Following this logic, one possibility to be entertained for the Connell (2007) study is that sentence reading may only activate semantic memory of color information based on the common mechanism of inference making in text processing. However, color information in the following perceptual task may be verbalized to produce semantic activation of associated color information. These two types of codes would interfere at the semantic and produced the observed congruence effect.

Briefly, along with Naor-Raz and colleagues (2003), I argue here that pure behavior measures are unable to distinguish the congruence effect occurring at the perceptual level favoring color simulation from the congruence effect occurring at other levels, such as the semantic level or the lexical level, disfavoring color simulation. It is also possible that both accounts are right and not mutually exclusive so that there are both perceptual congruence effects and semantic/lexical congruence effects. The key reason is the well-known fact that behavioral results reflect the final product summated over all preceding processing stages all the way till response and do not provide the temporal profiles of activations to locate them as early perceptual or late semantic in the processing sequence. Therefore, one needs to go beyond behavioral measures to look for more definite evidence to support the 'pure' perceptual simulation of color interpretation in language comprehension.

Recently, the co-existence of linguistic representation and perceptual simulation has been demonstrated by Simmons et al. (2008). By using fMRI, they found that the early activation in conceptual processing overlapped with those for word association, while the late activation in conceptual processing overlapped with those for situated generation, which suggested the conceptual processing involves multiple representations at least involving linguistic and perceptual representations. However, the property generation task used to elicit perceptual simulation seemingly relies on conscious imagery retrieval, at least to some extent. The current study tried to investigate the co-existence of perceptual simulation and linguistic representation during conceptual processing in a more implicit or less conscious task. Positive results would provide direct and stronger evidence to support the unconscious part of perceptual simulation claimed by theory of embodied cognition (Barsalou, 1999).

To this end, in Study III, two event-related-potential (ERP) experiments involving 26 participants were conducted to examine the dissociation between perceptual simulation and linguistic representation of color. ERPs 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 are linked with perceptual processing and later ERP components with longer latencies such as N400 are associated with semantic processing. By examining whether the linguistic context affects early or later components in the ERP waveform, one would expect to discriminate activation of color information in the perceptual representation and semantic representation.

The key task in this study involves presenting an object noun word implying a typical color, followed by a picture of an object and asking participants to judge whether they matched in identity. The major concern was on the match trials where the word and the picture referred to the same object. For these critical trials, the relevant manipulation was the color of the object in the picture was made to be either congruent, incongruent, or neutral. That is, for a word 'banana' followed a picture of banana, the object banana could be in its typical yellow color to make congruent trial, in blue color to make an incongruent color, or in gray color to make a reference no-color neutral condition.

If reading of the word leads to color simulation, such activated color information would affect perceptual processing of the color information contained in the picture. That is, early processing of the object picture should be affected by whether or not the two color match and consequently, the ERP components reflecting such early processing should show differential waveforms in the congruent and the incongruent conditions. The gray color condition was added to provide a situation where no color information was available for supplementary information to facilitate interpretation of the results. To avoid artifacts in ERP waveforms due to motor responses, as in many ERP studies, over responses were not needed in the above critical trials but only in the mismatch trials. The mismatch trials were generally considered filler trials that did not offer much information for our main interest. This is because the noun word and the picture referred to different objects the colors of which were not related to each other. As filler trials in fact involved two unrelated objects that are known to reliably induce processing related to mismatch or semantic violation in the ERP literature, a subset of the filler trials were still analyzed to form a mismatch/violation condition. This condition was included only for a validity check to confirm that the basic data collection and data analysis were reliable to replicate typical findings in the literature.

One problem with the above design is that previous studies have found that ERP waveforms were different when picture objects were presented in their different colors. That is, the ERP responses a picture banana in its congruent yellow color, or a blue incongruent color would be different when participants were simply passively viewing them. Such evidence has been interpreted to indicate that color information is attracted intrinsically to the perceptual representation of a picture object critical to its recognition, a research issue that is not relevant to our main interest. This is because we used picture objects mainly as a probe to tap into the consequences of the preceding word reading process. However, this baseline difference must be considered in our experimental design. Towards this purpose, we conducted Exp. 7a as a control experiment where the same set of picture objects used in Exp. 7b, each in their three different colors (congruent, congruent, gray color), were presented for passive viewing in another group of participants with their ERP responses recorded. Results from Exp. 7a would serve as the baseline for any effects in the results of Exp. 7b.

In summary, in the trials critical to our main interest, participants in Exp. 7a passively viewed an object picture in its three color versions and participants in Exp. 7b also saw the same object picture except preceded by the noun word referring to this object and they judged whether the word and the picture referred to the same object. As the ERP components were expected to differ across the three conditions in Exp. 7a, what we were most interested in was in which components the cross-condition differences observed in Exp. 7a would be altered when there was a preceding noun word. That is, we looked for trial condition (congruent, incongruent, and gray) by Experiment (Exp. 7a vs. 7b) interaction effects in the ERP components.

We would focus on the following ERP components to distinguish between early perceptual processing and later semantic processing.

For visual processing, these components are N1, P2, and N2 that have been widely demonstrated to reflect early perceptual processes. N1 is the first negative component elicited 80 – 130 ms post visual stimulus onset (Näätänen, 1992). It involves multiple multi-generators in temporal, frontal, cingluate, and parietal regions (Näätänen & Picton, 1987; Hari et al., 1980; Knight et al., 1980; Tzourio et al., 1997). N1 is also shown to index an early face-sensitive response at the occipito-temporal cortex (Bentin et al., 1996; Thorpe et al., 1996; Johnson & Olshausen, 2003; Rossion et al., 2000). Wang and Kameda (2005) found that the posterior N1 was significantly influenced by view-invariant object discrimination learning. N2 is a widespread negative potential with maximum peak between 200 and 350 ms after stimulus onset. Traditional research on the N2 component mostly focuses on its role in stimulus classification (e.g., Nittono, Shibuya, & Hori, 2007; Sibylle & Rudolf, 2005) and stimulus deviance detection (e.g., Daffner, et al., 2000). P2 is the peak waveform evoked about 200 ms after the presentation of visual stimuli. The amplitude of P2 changes as the subject pays attention to the visual stimuli (e.g., Maeno et al., 2004), although there is also evidence for its role in working memory (e.g., Missonier et al., 2007; Rader, Homes, & Golob, 2008). N2 has been found mainly in priming tasks and interpreted as a correlation of repetition suppression (e.g., Heil et al., 2000).

For semantic processing, these components are N3 (or N300) and N4 (or N400). N3 is a negative-going component peaking around 300 ms, reported in previous studies comparing brain activity elicited by the related and unrelated picture pairs. N3 has been generally recognized to be sensitive to semantic, rather than physical properties in processing of picture stimuli (e.g., Federmeier & Kutas, 2002). N4 is a component particularly relevant to semantic processing (Kutas & Hillyard, 1980), peaking around 400 ms after the onset of the stimulus. It was found that N4 components are commonly generated when stimulus events involve semantic or conceptual processing.

Although both N3 and N4 show larger amplitude (more negative-going) in response to semantically unrelated object pictures compared to related pictures (e.g., Barrett & Rugg, 1990; Eddy, Schmid, & Holcomb, 2006; Gunter & Bach, 2004; Lebib et al., 2004; Wu & Coulson, 2007), they are regarded to reveal different aspects of visual object perception. N3 has only been found in response to pictures and thus considered to reflect picture-specific semantic processes. In contrast, N4 has been observed in a wide range of studies concerning a variety of meaningful representations, including words (Coulson & Van Petten, 2002), ASL hand signs (Neville et al., 1997), and gestures (e.g., Bernardis, Salillas, & Caramelli, 2008; Cornejo et al., 2009; Holle & Gunter, 2007; Sheehan, Namy, & Mills, 2007; Wu & Coulson, 2005; Wurm & Seaman, 2008), and hence considered to reflect more general semantic processes.

Experiment 7

<u>Methods</u>

Participants

Twenty-six new participants (13 males, mean age +/- 1.5*SD* = 23.4 +/- 1.5years) were recruited (13 for Exp. 7a and 13 for 7b) from the same subject population as in Exp. 1 with the same inclusion criteria.

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 6.2x6.2 cm) in the center of the screen while maintaining their aspect ratios. The two versions of each test picture 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.

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), the materials also included 96 object noun words (48 test words corresponding to the test pictures and 48 filler words corresponding to the filler pictures).

Procedure and design

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.

In Exp. 7a, 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 Exp. 7a was the three levels of object-color relationship (congruent, incongruent, gray neutral).

In Exp. 7b, 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, gray neutral). 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 reliably.

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 countering balancing for different conditions. Each participant was given 20 practice trials before completing all 6 blocks. Same as Exp. 7a, Exp. 7b also paid attention to the three levels of object-color relationship (congruent, incongruent, gray neutral), except an additional semantic violation condition was also examined for validity check.

ERP recording

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 (plus the semantic violation condition in Exp. 7b) across all participants.

Results

Exp. 7a

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.

In Exp. 7a, 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). In Exp. 7b, trial type involved one validity check condition, namely, semantic violation condition. Thus, similar three-way (3x3x4) repeated measure ANOVAs were conducted.

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 condition 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 ($F<1$).

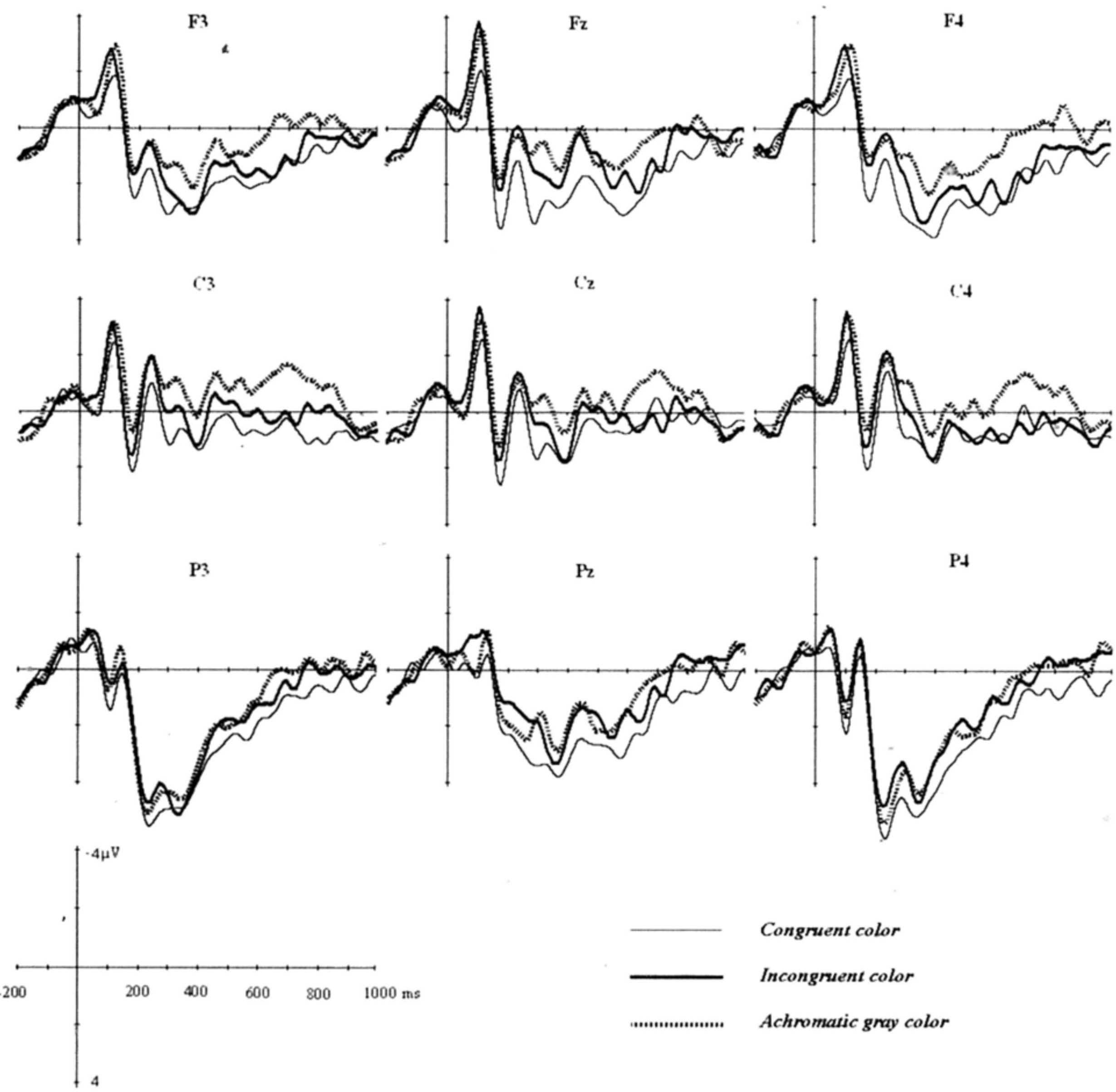


Fig. 5. Grand average ERP waveforms, at 9 representative electrodes, for object pictures

with congruent color, incongruent color, and achromatic gray color. 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.

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-wire $ps<.01$).

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 ($ps>.1$).

Exp. 7b

As Exp. 7b was planed to use Exp. 7a as a reference baseline, analysis was conducted in exactly the same way as in Exp. 7a on the same set of components during the same time windows (see Fig. 6).

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 (Fs<1).

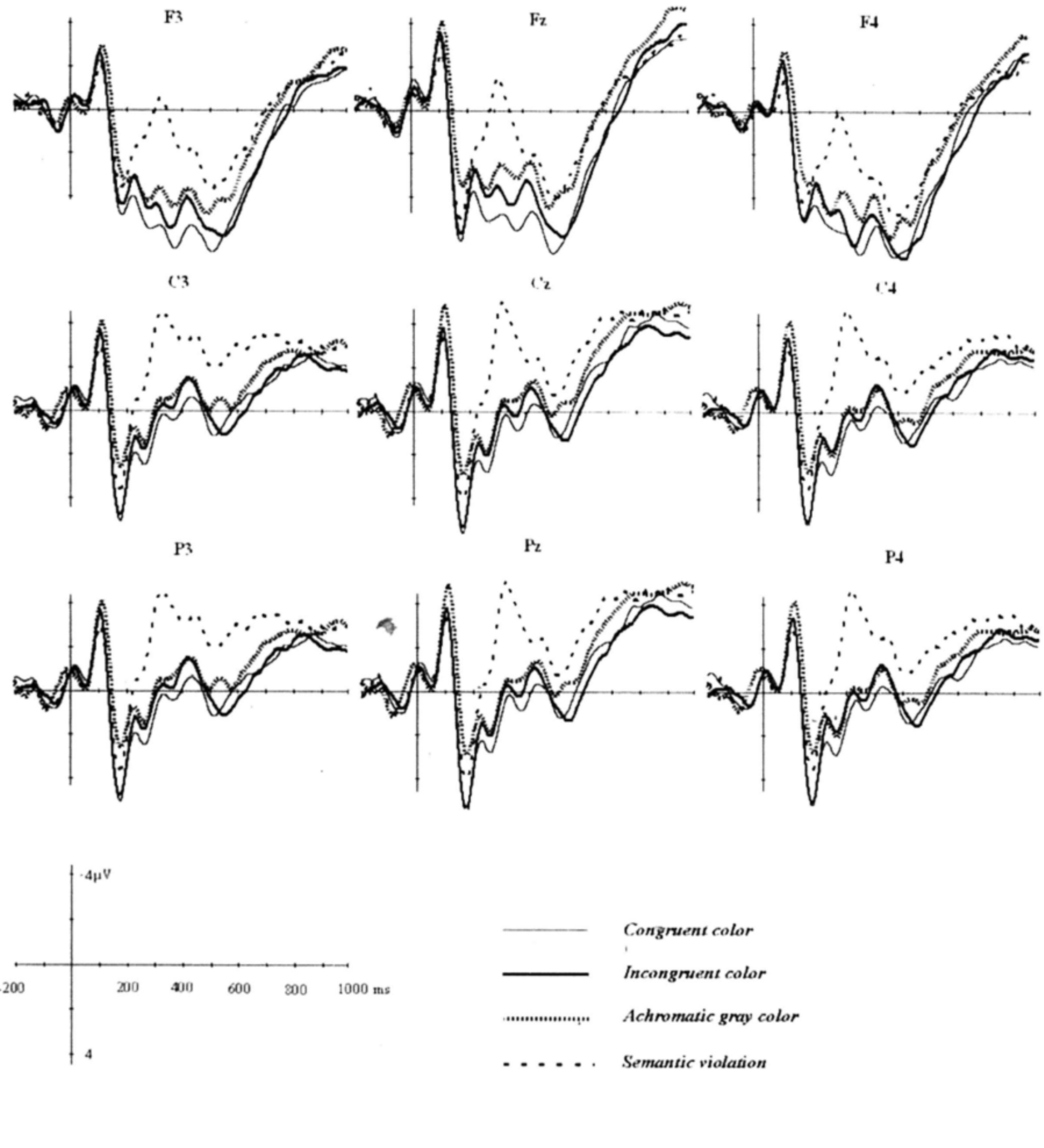


Fig. 6. Grand average ERP waveforms, at 9 representative electrodes, for object pictures with congruent color, incongruent color, and achromatic gray color as well as semantic violating pictures. The thin line represents the congruent color condition, the solid line

represents the incongruent color condition, the broken line represents the achromatic gray color condition, and the dotted line represents the semantic violation condition.

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 incongruent, congruent 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 (ps>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 (ps>.05).

The mean amplitude of N3 was significantly different (ps<.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), ps<.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 Exp. 7.

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 Exp. 7a, participants viewed a set of object pictures presented either in their typical or congruent color, an incongruent color, or in an 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 two color conditions, possibly reflecting a processing distinction between color and non-color objects. The same pattern was also present in the N4 period. 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 indicate 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 its 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 Exp. 7a represents an extension of the Proverbio et al. results for more ecological validity. Therefore, Exp. 7a, 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 Exp. 7a 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 Exp. 7b 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.

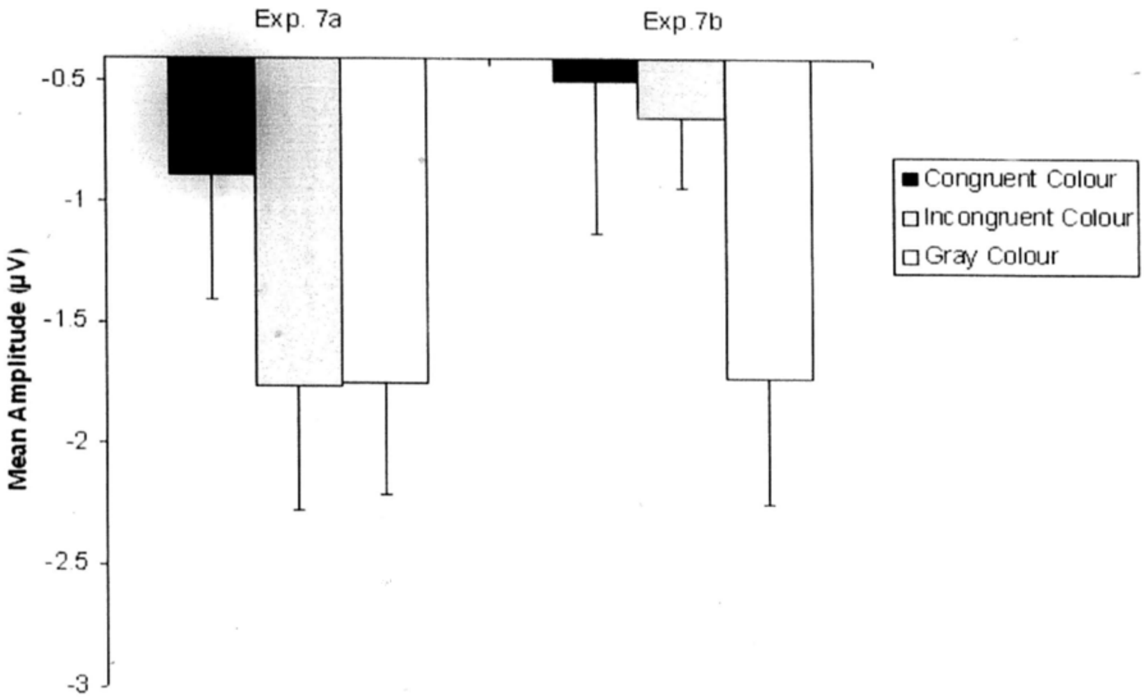


Fig. 7. Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in N1 (80-150 ms interval) between Experiment 7a and 7b.

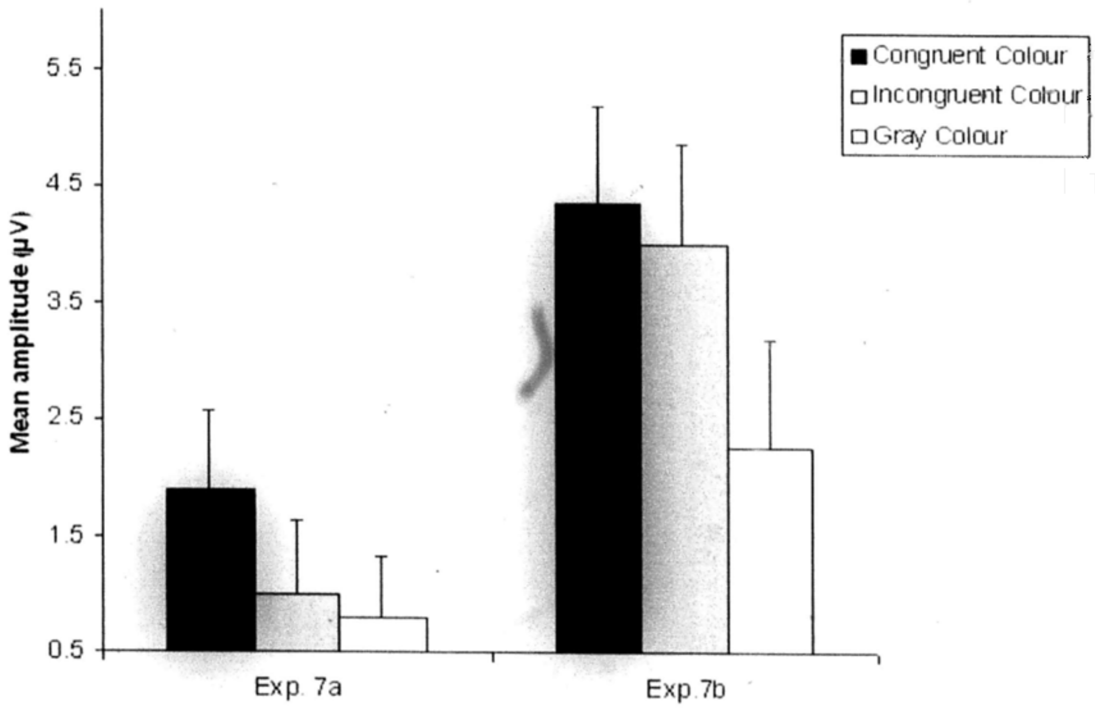


Fig. 8. Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in P2 (150-200 ms interval) between Experiment 7a and 7b.

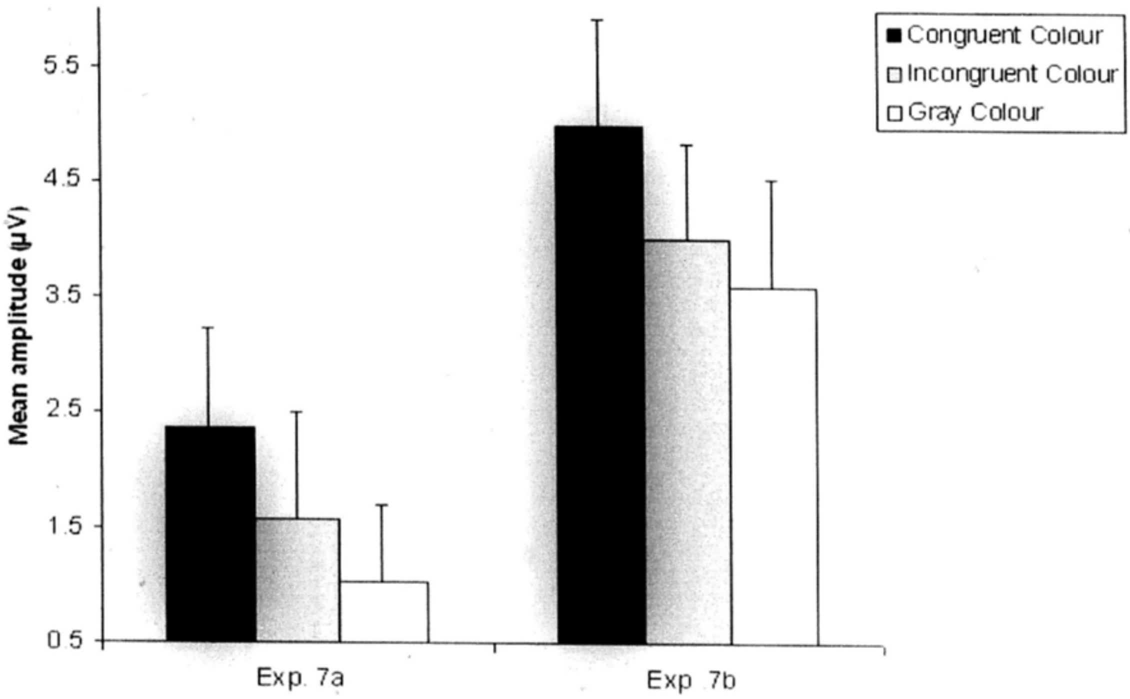


Fig. 9. Mean amplitudes elicited by congruent color, incongruent color, and achromatic gray color in N4 (375-475 ms interval) between Experiment 7a and 7b.

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, Exp. 7b shows no congruence effect in N1 and P2, as illustrated in Fig. 7 and 8. Note however that there was congruence effect in Exp. 7a for the same two ERP components, the present results then indicate that word reading in Exp. 7b 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 Exp. 7b 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 Exp. 7a and 7b. This finding implies that results differences caused by changes from Exp. 7a to 7b, 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 Exp. 7a and 7b 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 Exp. 7b, relative to their salient differences demonstrated in Exp.7a, may be attributed to the perceptual simulation formed in the processing of the priming words in Exp. 7b. 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 Exp. 7a, 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 Exp. 7a as a baseline situation, results in Exp. 7b 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, as we described in the introduction section of Study III.

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 Exp. 7a, N2 was more negative-going in the incongruent condition than in the congruent condition in Exp. 7b.

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 Exp. 7a 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 Exp. 7a 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 Exp. 7a 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 Exp. 7a, 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., Franklin et al., 2007; Hamm, Johnson, & Kirk, 2002). The finding that N4 but not N3 was modified by experiment indicates that word reading in Exp. 7b, 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 Fig. 9.

The experimental tasks were different between Exp. 7a and 7b so that participants were asked to detect occasional catch trials involving shape repetition in Exp. 7a 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 Exp. 7a may not serve as a good reference baseline for Exp. 7b. 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.

Chapter 4 General Discussion

Summary and main conclusions

Recent research on embodied cognition has primarily focused on motor simulation to demonstrate activation of motor-related representations when processing sentences and verbs depicting actions with limited attention paid to perceptual simulation, particularly to color simulation. With three studies, the present research investigated color simulation systematically to enrich understanding of perceptual simulation.

In the first study involving three experiments and seventy-one participants, I used color-naming tasks to examine the activation of color information and associated time course in phrase processing. Participants were presented with an adjective + noun phrase indicating one color for the whole phrase, followed by a color patch for color naming. Results from all three experiments showed a clear congruence effect for faster naming response when the phrase color was consistent with the patch color than when the two were inconsistent, providing a robust demonstration of the activation of perceptual color representation of color information in phrase processing. The typical color of the object noun, different from the phrase color, also produced a congruence effect, depending whether or not it was consistent with the patch color, suggesting the automatic activation of color information irrelevant to the present linguistic context. Results from prime-target stimulus-onset-asynchrony (SOA) manipulation indicated that the phrase color was activated earlier while the typical color was activated later.

The second study involving three experiments and seventy-two participants and using further demonstrates the presence of color simulation to an even smaller linguistic unit of single words. The task was the same as in Study I except the phrase was replaced with a concrete object noun. Naming latencies were significantly shorter when the patch color was consistent with the object's typical color relative to when they were inconsistent. Such color simulation was also found for verbs involving an object with color and words psychologically-related to color, indicating that color simulation is not limited to situations where there is a concrete, direct connection between the concept and the color information.

Results from SOA manipulation indicates a more rapid activation of color information for the words psychologically-related to color, followed by activation of color for object nouns, and slowest color activation for verbs, providing the first clear demonstration that the nature of the concept-color connection affects the time course of color simulation.

Study III addressed a critical and general problem in literature studies of perceptual simulation, including the present Study I and II, which mostly inferred occurrence of perceptual simulation based on some congruence effect, i.e., task performance was affected by whether or not the color expressed by the linguistic expression matches the color in a later perceptual task. Logically, in addition to perceptual simulation, it is possible that at least part of this congruence effect reflects a congruence effect at the semantic level, i.e., color information in the perceptual task may be verbalized to produce semantic activation of associated color information that interferes with semantic activation due to inference made during sentence reading.

This implies that pure behavior measures are unlikely to distinguish these two types of congruence effects and therefore cannot be taken as strong evidence for perceptual simulation. I, therefore, in Study III, turned to the ERP techniques offering time course information for activation of mental representations to find the temporal locus of the congruence effect. Participants read an object noun first, followed by a picture of this object, either in a congruent color, i.e., its typical color or in an incongruent color. Results from two ERP experiments involving 26 participants show that congruence clearly modulated early ERP components that are known to be associated with perceptual processes. This provides stronger evidence that semantic processing cannot account fully for the congruence effects observed in studies demonstrating perceptual color simulations.

In summary, along with existing evidence of color simulation, with a series of three studies of eight experiments, the present study documents clear color simulation in several levels of language processing from phrase to words. Color simulation is found to be present not only for color information implied by global context but also for color information irrelevant to the global context, not only for words with direct and concrete associations with color but also for words where such associations are indirect and less concrete. The nature of the concept-color association was found to affect the time course of color simulation so that surprisingly concrete connections may not necessarily produce the largest color activation. The ERP results provide the first electrophysiological evidence to strongly support that spontaneous color simulation does occur at the perceptual level as argued by embodied cognition theorists and cannot be attributed totally to semantic processing. Briefly, this present research systematically investigates color simulation and provides a rich dataset and valuable insights deepening understanding to color simulation in particular and mental stimulation in general.

Implications

1) The demonstration that color simulation can be shown not only for sentences but also for phrases and individual words indicates that not all aspect of a sentence, or a complete scenario are necessary for simulation. That is, even only one critical word could be strong enough to create a context for perceptual simulation. This opens up new research possibilities into color simulation. Future studies, for example, can avoid the complexity in deigning sentence stimuli. SOA manipulations can also be made more effective for word stimuli relative to sentence stimuli in precisely control the temporal separation between the linguistic prime the target.

However, one should be cautious as the mechanism underlying color simulation at the level of sentences involving more complicated processes (e.g., Just & Carpenter, 1977; Myers & O'Bren, 1994) may differ from that the phrase or word level. For example, although both are taken to support color simulation, the congruence effect observed in Connell (2007) was an inhibition while in Study I and II here was a facilitation. That is, in Connell (2007), the congruent condition was responded to slower than the incongruent condition while the pattern was the opposite here. Studies on motor simulation and other perceptual simulation, both at the sentence and the word level, typically found facilitative effect, as in the present study.

However, given there is no other study on color simulation at the sentence level, it remains to be seen whether the Connell results truly reflect a unique characteristic of color simulation or are due to some factors specific to his study. Participants in his study were instructed to read a sentence and then determine whether a following object was mentioned in the sentence. Connell argues that this creates a situation where color was task irrelevant and participants may possibly be distracted by the automatic activation of color information interfering with their paying full attention to the shape of the object. In comparison, participants in the present task did color naming explicitly paying attention to the color dimension. Further, instead of object picture in Connell, the probe stimulus we used was a color patch which lacks any shape information and tends to highlight the color dimension. Consequently, color activation from simulation would also be processed as relevant information and facilitated performance. That is, although color simulation occurs as a type of activation suggesting whether the task focuses on color as here or not as in Connell, it may not necessarily facilitate task performance depending on the specific situation.

Relative to shape, color may be special in that it is a secondary feature and so far other demonstration of perceptual simulation has been focused on shape, direction, size that are all related to shape representation critical to identification. So it might be possible that color simulation may differ from shape simulation so that while for shape, facilitation is observed for both sentences and words, for color, inhibition is observed for sentences but facilitation observed for phrases and words. This issue remains to be explored in future.

2) Stanfield and Zwaan (2001) argue that not all the actions and properties associated with a concept are activated during a simulation but rather that only those relevant to comprehension are activated. For example, in understanding novel denominal verbs (i.e., verbs formed from nouns, as in "He hammered the nail"), Kaschak and Glenberg (2000) found that the properties most relevant to the comprehension of a given passage was verified faster than that not relevant to comprehension and further that one property can be more relevant than another in one condition and verified faster but the pattern was reversed in another situation.

Following this proposal, one would expect to find that only the contextual relevant phrase color should be activated in Study I, but not the irrelevant typical color of the object, although the actual results were that both were activated, while the phrase color was activated earlier, the typical color became even larger in effect size than the phrase color with longer SOA. While this supports the notion that the context relevant activation may be more dominant and have more immediate effects, it also indicates that color information inconsistent with the context is also activated.

One possible reason for this discrepancy may be that what Stanfield and Zwaan emphasizes is properties from different dimensions, for example, when the sentence context is about the spatial properties of an object, the irrelevant motion properties would not be activated. Different properties from the same relevant dimension may both be activated, even though the property that not directly related to the context. Similar situations are also present in studies on text processing. Information pertaining to the local construction of a situation not coherent with the global construction can still be activated (e.g., Albrecht & Myers, 1998; O'Brien, Rizzella, Albrecht, & Halleran, 1998).

Note that we were able to reveal two types of color activations in the same study was due to a different design feature between our study and Connell (2007). In his study, congruence was defined in terms of whether the color of the picture object was consistent with the color implied by sentence, but in both the congruence and the incongruent condition, the color was a possible color of the object (i.e., a steak could be either brown and red). So while the difference between the two color conditions were clear, without a proper reference condition, it was unable to know whether the color information associated with the object but inconsistent with the sentence context was activated. In the present study, as we added a truly incongruent condition where the color was never possible for the object (e.g., blue for banana), we were able to show that such color information was also activated.

3) The finding that action verbs that are not directly linked to color can imply color via the object involved in the action illustrates a new aspect of mental simulation. As long as the connections are strong enough, color simulation is not constrained by the factor that color information has to be directly linked to the concept. In addition, sufficient time must be allowed as reactivation via an mediating concept seems to be slow, as shown in the results that color simulation effect was only present at the longest SOA of 1000 ms.

For the other type of abstract words producing the fastest activation of color information in Study II, it seems that the connection between these words psychologically-related to color may be stronger, relative to object nouns and verbs. Frequent use of expressions such as 'He feels blue' to mean 'He feels depressed' may underlie such strong connections. Although a counter argument is that, if perceptual color information is activated via the mediation of the color word (i.e., depression activates blue which then activates associated perceptual representation of blue), its time course should not be so fast as suggested by the slow time course in the results for verbs.

More likely is that the connection between color presentation and the words psychologically-related to colors is special. That is, these words tend to increase arousal level as would be produced in perceiving their associated color and such shared physiological state may function at a subconscious level to produce a rapid color activation once these words are processed.

4) There is another study that is closely related to the present research.

Naor-Raz, Tarr, and Kersten (2003) used a modified Stroop paradigm requiring participants to name the color in which a picture object was printed. For example, a picture of an apple may be presented in red color (requiring a correct red naming response) or a blue color (requiring a correct blue naming response). The red apple would be a congruent condition as the object was in its typical color while a blue apple would be an incongruent condition as the object was in a color it can not have. Naming latency was found to be longer for the incongruent condition than for the congruent condition, demonstrating a Stroop-like inference between the inherent color associated with an object well-established in experience with the color it was perceptually presented in the present context.

Given that the shape of the object was task irrelevant, Naor-Raz et al. argued that the fact that the color associated with the object shape had an impact on color naming reflected automatic processing of the shape information and automatic activation of its associated color information, suggesting that the shape-color association is coded in early perceptual representations offering immediate access. This leads to their central conclusion that color information, along with shape information, is an intrinsic part of an object's perceptual representation.

Side to their interest but more relevant to the present research is that they also included a condition where objects nouns were presented in different colors for the same naming task. That is, a word 'apple' may be presented in red to make a congruent condition or in blue to make an incongruent condition. A reversed standard Stroop effect was observed for such word stimuli, indicating that color information is also represented at the semantic level but in a way different way from the perceptual representation they demonstrated for the picture objects. Although the authors did not mention color simulation, their results in the word stimuli can be interpreted as reflecting automatic activation of color information associated with the word concepts and serve as a piece of evidence for color simulation. The fact that the same results can be interpreted as effects occurring at either the perceptual level or the semantic level (or both of the two levels) further calls for the need to go beyond behavioral measure to use ERP techniques to separate different levels of processing, as we did in Stud III.

5) As pointed in the pioneering work of Stanfield and Zwaan (2001), the critical theoretical distinction between the amodal proposition representation and the embodied perceptual representations is not that there are some empirical results that cannot be explained by amodal theories but only by the embodied theories. Rather, given amodal theories possess essentially unlimited explanatory power, they can explain any results by adding a few more propositions ad hoc. Therefore, one should not expect to be able to produce some empirical findings to falsify the proposition theories but rather has to be satisfied that for some findings the embodied cognition can predict and can explain more elegantly or parsimoniously.

This is a reasonable argument, however, also a pessimistic one, implying that researchers will never be able to empirically falsify the proposition theories. Any cognitive models may indeed be able to renovate themselves to accommodate new findings to keep from being rejected, if they are always tested with behavioral performance data that are output information from a cognitive system. However, once the internal neural mechanisms are considered, eventually there will be only model that can stand to the test. Therefore, with more and more research employing cognitive neuroscience methods to look into the inside of the brain, as did for the first time in the area of color simulation, a definite decision between the propositional representations and embodied representations is to be expected.

Future directions

As one interesting future direction, I plan to put together different dimensions of perceptual simulation in the same experiment so that I would be able to compare the time course of the color activation and shape activation. ERP recording will be performed to corroborate or help constrain interpretations of the behavioral data.

The other interesting direction is to understand more about the association between the words psychologically-associated with color to understand they would lead to such a fast activation of color information, even faster than object nouns that directly imply color.

Limitations

1) Although the color/non-color adjectives are rated well, but some examples may sound strange and counterintuitive, it should be examined further.

2) Item analysis did not come out significant for study 1, so it is possible that some items are not well-chosen. And future work can refine the stimuli to get better results.

3) There is no 3 way SOA ×color version × congruence interaction. In terms of the non-significant 3 way interaction, it is really so important. So the manipulation of SOA shows interesting trend, but more data is needed to make a statistically sound conclusion.

References

Bailey, D. R. (1997) .When Push Comes to Shove: A Computational Model of the Role of Motor Control in the Acquisition of Action Verbs. Ph.D. thesis, University of California at Berkeley, Berkeley, CA. from http://citeseer.ist.psu.edu/bailey97when.html.

Barrett, S. E, & Rugg, M. D. (1990). Event-related potentials and the phonological matching of picture names. *Brain and Language, 38*, 424-437.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22,* 577-609; discussion 610-60.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617-645.

Barsalou, L. W., Simmons, W. K., Barbey, A. K., & Wilson, C. D. (2003).Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, *7,* 84-91.

Bentin, S., Allison, T., Puce, A., Perez, A., McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience,* 8, 551-565.

Bernardis, P., Salillas, E. & Caramelli, N. (2008). Behavioural and neurophysiological evidence of semantic interaction between iconic gestures and words. *Cognitive Neuropsychology, 25,* 1114-1128.

Bub, D. N., Masson, M. E., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*, 27-58.

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: a combined TMS and behavioral study. *Brain research. Cognitive brain research, 24*, 355-63.

Callejas, A., Acosta, A., & Lupianez, J. (2007). Green love is ugly: emotions elicited by synesthetic grapheme-color perceptions. *Brain Research, 1127*, 99-107.

Connell, L. (2007). Representing object color in language comprehension. *Cognition 102*, 476-485.

Cothran, D. L., & Larsen, R. (2008). Comparison of inhibition in two timed reaction tasks: the color and emotion Stroop tasks. *The Journal of Psychology, 142*, 373-385.

Coulson, S., & Van Petten, C. (2002). Conceptual integration and metaphor: an event -related brain potential study. *Memory and Cognition, 30*, 958-968.

Daffner, K. R., Scinto, L.F., Calvo, V., Faust, R., Mesulam, M. M., West, W. C., & Holcomb, P. J. (2000). The influence of stimulus deviance on electrophysiologic and behavioral responses to novel events. *Journal of Cognitive Neuroscience, 12*, 393-406.

Damasio, A.R. (1989). Time-locked multiregional retroactivation: A systems- level proposal for the neural substrates of recall and recognition. *Cognition, 33*, 25-62.

Diane, P., Kiki, Z., & Rene, Z. (2007). Verifying visual properties in sentence verification facilitates picture recognition memory. *Experimental Psychology, 54*, 173-179.

Eddy, M., Schmid, A., & Holcomb, P. J. (2006). A new approach to tracking the time-course of object perception: Masked repetition priming and event-related brain potentials. *Psychophysiology, 43*, 564-568.

Elliot, A. J., Maier, M. A., Moller, A. C.,Friedman, R., & Meinhardt, J. (2007). Color and psychological functioning: the effect of red on performance attainment. *Journal of Experimental Psychology: General, 136*, 154-168.

Federmeier, K. D., & Kutas, M. (2002). Picture the Difference: Electrophysiological Investigations of Picture Processing in the Cerebral Hemispheres. *Neuropsychologia, 40*, 730-747.

Fletcher, R. (1980). The City University Color Vision Test (2nd edition ed.), Keeler, London.

Gallese, V., & Lakoff, M. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology, 22,* 455-479.

Glenberg, A.M. (1997). What memory is for? *Behavioral and Brain Sciences, 20*, 1-55.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9,* 558-565.

Glover, S. (2004). Separate visual representations in the planning and control of action. *Behavioral and Brain Sciences*, *27,* 3-78.

Goldstein, J., Davidoff, J., & Roberson, D. (2009). Knowing color terms enhances recognition: further evidence from English and Himba. *Journal of Experimental Child Psychology, 102,* 219-38.

Grabowski, T. J., Damasio, H., & Damasio, A. R. (1998). Premotor and prefrontal correlates of category-related lexical retrieval. *NeuroImage, 7,* 232-243.

Gunter, T. C., & Bach, P. (2004). Communicating hands: ERPs elicited by meaningful symbolic hand postures. *Neuroscience Letters, 372*, 52-56.

Hamm, J. P., Johnson, B. W., & Kirk, I. J. (2002). Comparison of the N300 and

N400 ERPs to picture stimuli in congruent and incongruent contexts. *Clinical Neurophysiology, 113*, 1339-1350.

Hari, R., Aittoniemi, K., Järvinen, M. L., Katila, T., & Varpula, T. (1980). Auditory evoked and sustained magnetic sustained fields of the human brain. Localization of neural generators. *Experimental Brain Research, 40*, 237-240.

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41*, 301-307.

Heil, M., Osman, A., Wiegelmann, J., Rolke, B., & Hennighausen, E. (2000). N300 in the Eriksen-task: Inhibitory executive processes? *Journal of Psycholophysiology, 14*, 218-225.

Hill, R. A., & Barton, R. A. (2005). Psychology: red enhances human performance in contests. *Nature, 435*, 293.

Holle, H., & Gunter, T. C. (2007). The role of iconic gestures in speech disambiguation: ERP evidence. *Journal of Cognitive Neuroscience, 19*, 1175-1192.

Johnson, J. S., & Olshausen, B. A. (2003). Time course of neural signatures of object recognition. *Journal of Vision, 3*, 499-512.

Johnson-Laird, P. N. (1983). Mental models: Towards a cognitive science of language, inference, and consciousness. Cambridge, MA: Harvard University Press.

Just, M. A., & Carpenter, P. A. (1977). Cognitive processes in comprehension. Hillsdale, NJ: Erlbaum.

Kaschak, M. P., & Glenberg, A. M. (2000). Constructing meaning: The role of affordances and grammatical constructions in language comprehension.

Journal of Memory and Language, 43, 508-529.

Kemmerer, D., Castillo, J.G., Thomas, T. Stephanie, P., & Cynthia, W. (2008). Neuroanatomical distribution of five semantic components of verbs: Evidence from fMRI. *Brain and Language, 107*, 16-43.

Klein, G. S. (1964). Semantic power measured through the interference of words with color-naming. *American Journal of Psychology, 77*, 576-588.

Knight, R. T., Hillyard, S. A., Woods, D. L., & Neville, H. J. (1980). The effects of frontal and temporal-parietal lesions on the auditory evoked potential in man. *Electroencephalogr Clinical Neurophysiol, 50*, 112-124.

Kutas, M., & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207,* 203-205.

Lebib, R., Papo, D., Douiri, A., de Bode, S., Gillon Dowens, M., & Baudonniere, P. M. (2004). Modulations of 'late' event-related brain potentials in humans by dynamic audiovisual speech stimuli. *Neuroscience Letters, 372*, 74-79.

Liu Y. (1990). Modern Chinese Frequent Words Dictionary: Yu Hang Press.

Maeno, T., Gjini, K., Iramina, K., Eto, F., & Ueno, S. (2004). Event-related potential P2 derived from visual attention to the hemi-space. Source localization with LORETA. *International Congress Series, 1270*, 262-265.

Martin, A. (2001). Functional neuroimaging of semantic memory. In: Cabeza, R., Kingstone, A. (Eds.), *Handbook of Functional Neuroimaging of Cognition*. MIT Press, Cambridge, MA, pp. 153-186.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25-45.

Martin, D.L., Cheyer, A., & Lee, G.-L. (1996). Agent development tools for the open agent architecture. In Proceedings of the First International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology, pages 387-404, Blackpool, Lancashire, UK, April. The Practical Application Company Ltd.

Mehta, R., & Zhu, R. J. (2009). Blue or red? Exploring the effect of color on cognitive task performances. *Science, 323*, 1226-1229.

Missonnier, P., Deiber, M. P., Gold, G., Herrmann, F. R., Millet, P., Michon, A., Fazio-Costa, L., Ibanez, V., & Giannakopoulos, P. (2007). Working memory load-related electroencephalographic parameters can differentiate progressive from stable mild cognitive impairment. *Neuroscience, 150*, 346-356.

Moore, C. I., Stern, C. E., Corkin, S., Fischl, B., Gray, A. C., Rosen, B. R., & Dale, A. M. (2000). Segregation of somatosensory activation in the human rolandic cortex using fMRI. *Journal of Neurophysiology, 84,* 558-69.

Masson, M. E. J., Bub, D. N., & Warren, C. M. (2008). Kicking calculators: Contribution of embodied representations to sentence comprehension. *Journal of Memory and Language, 59*, 256-265.

Myers, J. L., O'Bren, E. J., Albrecht, J. E., & Mason, R. A. (1994). Maintaining global coherence during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 876-886.

Näätänen, R., 1992. Attention and Brain Function. Erlbaum, Hillsdale, NJ.

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24,* 375-425.

Naor- Raz, G., Tarr, M. J., & Kersten, D. (2003). Is color an intrinsic property of object representation? *Perception, 32,* 667-80.

Neville, H.J., Coffey, S. A., Lawson, D. S., Fischer, A., Emmorey, K., & Bellugi, U. (1997). Neural systems mediating ASL: effects of sensory experience and age of acquisition. *Brain Language, 57*, 285-308.

Nittono, H., Shibuya, Y., & Hori, T. (2007). Anterior N2 predicts subsequent viewing time and interest rating for novel drawing. *Psychopysiology, 44,* 687-696.

Pecher, D., & Zwaan, R.A. (2005). Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking: Cambridge University Press.

Proverbio, A. M., Burco, F., del Zotto, M., & Zani, A. (2004). Blue piglets? Electrophysiological evidence for the primacy of shape over color in object recognition. *Cognitive Brain Research, 18,* 288-300.

Pulvermüller, F., Hauk, O., Nikulin, V., & Ilmoniemi, R. J. (2005). Functional links between motor and language systems. *European Journal of Neuroscience, 21*, 793-797.

Pulvermüller, F., Lutzenberger, W., & Preissl, H. (1999). Nouns and verbs in the intact brain: evidence from event-related potentials and high-frequency cortical responses. *Cereb Cortex, 9*, 497-506.

Pulvermüller, F., Shtyrov, Y., & Ilmoniemi R.J. (2005). Brain signatures of meaning access in action word recognition. *Journal of Cognitive Neuroscience, 17*, 884-892.

Rader, S. K., Holmes, J. L., & Golob, E. J. (2008). Auditory event-related potentials during a spatial working memory task. *Clinical neurophysiology, 119,* 1176-1189.

Raposo, A., Moss, H. E., Stamataks, E. A., & Tyler, L. K. (2009). Modulation of motor and premotor cortices by actions, action words and action sentences. *Neuropsychologia, 47*, 388-396.

Rohrer, T. (2001). Understanding through the body: fMRI and of ERP studies of metaphoric and literal language. Paper presented at the *7th International Cognitive Linguistics Association* conference, July 2001.

Rohrer, T. (2005). Image schemata in the brain. In B. Hampe & J. Grady (Eds.), *From perception to meaning: Image schemas in cognitive linguistics* (pp. 165-196). Berlin, Germany: Mouton de Gruyter.

Rohrer, T. (in press). The body in space: Embodiment, experientialism and linguistic conceptualization. In J. Zlatev, T. Ziemke, R. Frank, & R. Dirven (Eds.), *Body, language, and mind* (Vol. 1). Berlin, Germany: Mouton de Gruyter.

Rossion, B., Gauthier, I., Tarr, M.J., Despland, P.A., Bruyer, R., Linotte, S., & Crommelinck, M. (2000). The N170 occipito-temporal component is enhanced and delayed to inverted faces but not to inverted objects: An electrophysiological account of face-specific processes in the human brain. *NeuroReport, 11*, 69-74.

Sakuta, Y., & Gyoba, J. (2006). Affective impressions and memorability of color-form combinations. *Journal of General Psychology, 133*, 191-207.

Sheehan, L., Namy, L., & Mills, D. L. (2007). Developmental changes in neural activity to familiar words and gestures. *Brain and Language, 101*, 246-259.

Siakaluk, P. D., Pexman, P. M., Aguilera, L., Owen, W. J., & Sears, C. R. (2008). Evidence for the activation of sensorimotor information during visual word recognition: the body-object interaction effect. *Cognition, 106*, 433-43.

Sibylle, B., & Rudolf, P. (2005). Lack of standard N2 in elderly participants indicates inhibitory processing deficit [auditory and vestibular systems]. *NeuroReport, 16*, 1933-1937.

Simmons, W.K., Hamann, S. B., Harenski, C.L., Hu, X. P., & Barsalou, L. W. (2008). fMRI evidence for word association and situated simulation in conceptual processing. *Journal of Physiology-Paris, 102*, 106-119.

Solomon, K. O., & Barsalou, L. W. (2001). Representing properties locally. *Cognitive Psychology, 43*, 129-69.

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science, 12*, 153-156.

Tanaka, J., Weiskopf, D., & Williams, P. (2001). The role of color in high-level vision. *Trends in Cognitive Science,s 5*, 211-215..

Tettamanti, M., Buccino, G., Saccuman, M.C., Gallese, V., Danna, M., Scifo, P., Fazio, F., Rizzolatti, G., Cappa, S. F., Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273-281.

Thompson-Schill, S.L. (2003). Neuroimaging studies of semantic memory: inferring 'how' from 'where'. *Neuropsychologia, 41*, 280-292.

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature, 381*, 520-522.

Tzourio, N., Massioui, F. E., Crivello, F., Joliot, M., Renault, B., & Mazoyer, B. (1997). Functional anatomy of human auditory attention studied with PET. *NeuroImage, 5*, 63-77.

Wang, G., & Kameda, S. (2005). Event-related potential component associated with the recognition of three-dimensional objects. *Neuroreport, 16,* 767-771.

Wichmann, F. A., Sharpe, L. T., & Gegenfurtner, K. R. (2002). The contribution of color to recognition memory for natural scenes. *Journal of Experimental Psychology: Learning, Memory and Cognition, 28,* 509-520.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9,* 625-636.

Wu, L. L., & Barsalou, L. W. (2009). Perceptual simulation in conceptual combination: Evidence from property generation. *Acta Psychologica*, online.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22,* 577-660.

Wu, Y. C., & Coulson, S. (2005). Meaningful gestures: Electrophysiological indices of iconic gesture comprehension. *Psychophysiology, 42,* 654-667.

Wu, Y. C., & Coulson, S. (2007). How iconic gestures enhance communication: An ERP study. *Brain and language, 101*, 234-45.

Wurm, L. H., & Seaman, S. R. (2008). Semantic effects in naming and perceptual identification, but not in delayed naming: Implications for models and tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 381-398.

Yaxley, R. H., & Zwaan, R. A. (2007). Simulating visibility during language comprehension. *Cognition, 105*, 229-36.

Zwaan, R. A. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B. H Ross, *Psychology of Learning and Motivation* (Vol. 44) (pp. 35-62). San Diego, CA: Academic Press.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shape of objects. *Psychological Science, 13,* 168-171.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135,* 1-11.

Appendix A Test stimuli used in Experiments 1-3

Test stimuli in Experiment 1-3 (A)			
Color-adjective Phrases	Color version		
	Phrase color	Typical color	Incongruent color
枯死的禾苗	黄色	绿色	蓝色
(died rice seedling)	(yellow)	(green)	(blue)
不成熟的柠檬	绿色	黄色	白色
(immature lemon)	(green)	(yellow)	(white)
秋天的草地	黄色	绿色	红色
(lawn in autumn)	(yellow)	(green)	(red)
北极的熊	白色	黑色	绿色
(polar bear)	(white)	(black)	(green)
夜晚的天空	黑色	蓝色	绿色
(sky in night)	(black)	(blue)	(green)
刚长出的番茄	绿色	红色	蓝色
(new-born tomato)	(green)	(red)	(blue)
苦涩的苹果	绿色	红色	黑色
(bitter apple)	(green)	(red)	(black)
刚长出的枫叶	绿色	红色	蓝色
(new-born maple)	(green)	(red)	(blue)
凋零的叶子	黄色	绿色	红色
(withered leaf)	(yellow)	(green)	(red)
菠菜制的面条	绿色	黄色	红色

(Noodles made with spinach)	(green)	(yellow)	(red)

Test stimuli in Experiment 1-3 (B)			
Non-color- adjective Phrases	Color version		
	Phrase color	Typical color	Incongruent color
不健康的牙齿	黑色	白色	绿色
(unhealthy teeth)	(black)	(white)	(green)
老人的胡须	白色	黑色	黄色
(old man's bear)	(white)	(black)	(yellow)
掉下来的树叶	黄色	绿色	蓝色
(fallen-down leaf)	(yellow)	(green)	(blue)
生的香蕉	绿色	黄色	红色
(immature banana)	(green)	(yellow)	(red)
西式的嫁衣	白色	红色	绿色
(bottom drawer of western style)	(white)	(red)	(green)
加州产的提子	红色	绿色	黑色
(Californian Grape)	(red)	(green)	(black)
炸过的馒头	黄色	白色	绿色
(fried bun)	(yellow)	(white)	(green)
地上的叶子	黄色	绿色	白色
(leaves on the ground)	(yellow)	(green)	(white)
没营养的头发	黄色	黑色	绿色
(malnourished hair)	(yellow)	(black)	(green)

生的芒果 (immature mango)	绿色 (green)	黄色 (yellow)	黑色 (black)

Appendix B Test stimuli used in Experiments 4-6

Test stimuli in Experiments 4-6

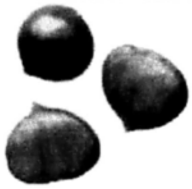
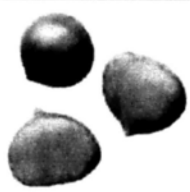
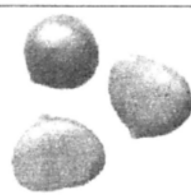
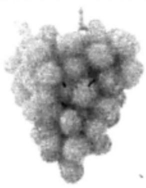
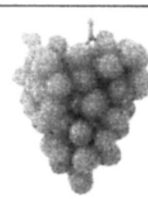
Verbs	Congruent	Incongruent	Psych-color words	Congruent	Incongruent	Object nouns	Congruent	Incongruent
耀眼 (dazzle)	白色 (white)	红色 (red)	纯洁 (immaculacy)	白色 (white)	红色 (red)	牙齿 (teeth)	白色 (white)	绿色 (green)
投降 (surrender)	白色 (white)	黄色 (yellow)	肮脏 (dirtiness)	黑色 (black)	红色 (red)	馒头 (bun)	白色 (white)	红色 (red)
牺牲 (sacrifice)	红色 (red)	黄色 (yellow)	邪恶 (evil)	黑色 (black)	白色 (white)	番茄 (tomato)	红色 (red)	蓝色 (blue)
喝醉 (be in drink)	红色 (red)	黄色 (yellow)	害怕 (scared)	黑色 (black)	绿色 (green)	苹果 (apple)	红色 (red)	白色 (white)
收割 (reap)	黄色 (yellow)	绿色 (green)	恶毒 (malicious)	黑色 (black)	红色 (red)	枫叶 (maple)	红色 (red)	蓝色 (blue)
枯死 (exsiccate)	黄色 (yellow)	绿色 (green)	热爱 (love)	红色 (red)	黑色 (black)	禾苗 (rice seedling)	绿色 (green)	红色 (red)
凋零 (wither)	黄色 (yellow)	绿色 (green)	发怒 (angry)	红色 (red)	黄色 (yellow)	柠檬 (lemon)	黄色 (yellow)	红色 (red)
插种 (plant)	绿色 (green)	红色 (red)	喜庆 (festivity)	红色 (red)	黑色 (black)	草地 (lawn)	绿色 (green)	蓝色 (blue)
长出 (grow)	绿色 (green)	白色 (white)	色情 (eroticism)	黄色 (yellow)	黑色 (black)	香蕉 (banana)	黄色 (yellow)	白色 (white)

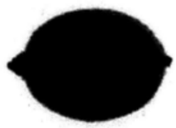
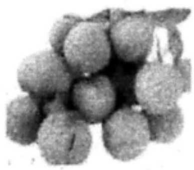
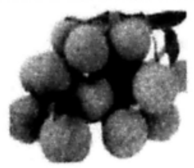
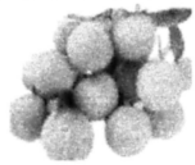
生长 (vegetate)	绿色 (green)	白色 (white)	害羞 (shy)	红色 (red)	黑色 (black)	芒果 (mango)	黄色 (yellow)	蓝色 (blue)

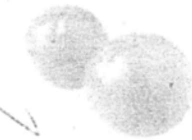
Appendix C Test stimuli used in Experiments 7-8

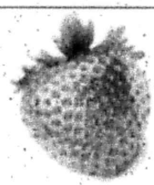
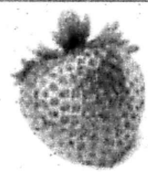
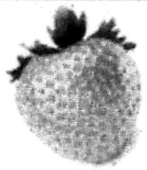
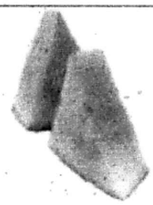
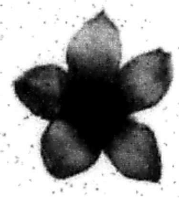
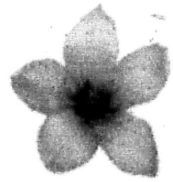
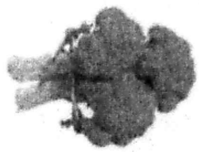
Test stimuli in Experiment 7 and 8			
Nouns	Pictures		
	Congruent color	Incongruent color	Achromatic gray color
苹果 (apple)			
香蕉 (banana)			
葱 (shallot)			
包菜 (brocoli)			
樱桃 (cherry)			
辣椒 (capsicum)			

胡萝卜 (carrot)			
仙人掌 (cactus)			
芹菜 (celery)			
玉米 (corn)			
青瓜 (cucumber)			
灯笼椒 (bell pepper)			
海豚 (dolphin)			
茄子 (eggplant)			

螃蟹 (crab)			
青蛙 (frog)			
栗子 (chestnut)			
姜 (ginger)			
提子 (grape)			
草地 (lawn)			
头发 (hair)			
拳头 (fist)			

核桃 (walnut)			
火龙果 (dragon fruit)			
叶子 (leave)			
柠檬 (lemon)			
荔枝 (lichee)			
龙虾 (lobster)			
芒果 (mango)			
枫叶 (maple)			

橙子 (orange)			
木瓜 (pawpaw)			
水蜜桃 (juicy peach)			
花生壳 (peanut shell)			
豌豆 (pea)			
雪梨 (pear)			
菠萝 (pineapple)			
马铃薯 (potato)			

南瓜 (pumpkin)			
草莓 (strawberry)			
西瓜 (watermelon)			
木棉花 (kapok)			
骆驼 (camel)			
杨桃 (star fruit)			
番茄 (tomato)			
西兰花 (cauliflower)			

玫瑰 (rose)			
小鸭 (little duck)