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Separable effects of priming and imageability on word processing: an ERP study

Tamara Y. Swaab[a,*], Kathleen Baynes[b], Robert T. Knight[c]

[a]Department of Psychology, University of California, One Shields Avenue, Davis, CA 95616-8686, USA
[b]Department of Neurology and Center for Neuroscience, University of California, Davis, CA 95616, USA
[c]Department of Psychology and Helen Wills Neuroscience Institute, University of California, Berkeley, CA 94720, USA

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Abstract

Concrete, highly imageable words (e.g. *banana*) are easier to understand than abstract words for which it is difficult to generate an image (e.g. *justice*). This effect of concreteness or imageability has been taken by some as evidence for the existence of separable verbal- and image-based semantic systems. Instead, however, effects of concreteness may result from better associations to relevant contextual representations for concrete than for abstract words within a single semantic system. In this study, target words of high and low imageability were preceded by supportive (related) or non-supportive (unrelated) context words. The influence of contextual support on the imageability effect was measured by recording event-related brain potentials (ERPs) to the high and low imageable target words in both context conditions. The topographic distributions of the ERPs elicited by the high versus low imageable target words were found to be different, and this effect was independent of contextual support. These data are consistent with the idea that distinct verbal- and image-based semantic codes exist for word representations, and that as a result, concrete words that are highly imageable can be understood more easily.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Semantic memory; Imageability; Priming; ERPs

1. Introduction

A major challenge in the study of the human brain and mind is to understand the nature and organization of semantic representations. One way to address this issue is to assess differences in the processing of various categories of words. It has been well-established that concrete words such as '*banana*' are more easily understood than abstract words such as '*justice*'. It is generally accepted that concreteness facilitates comprehension, but the mechanism of the concreteness effect remains a matter of debate (e.g. Refs. [6,8,13,17]).

Two major theories have been proposed to explain the effects of concreteness. The *dual coding theory* assumes two separate semantic systems [12,13]. One of these semantic systems contains verbal-based codes and the other contains nonverbal image-based codes. Within this dual-coding framework, the processing advantage for concrete words occurs because these words activate *both* verbal- and image-based codes, whereas abstract words primarily activate only verbal codes, and therefore, the information content of the activated word representation is less for abstract words.

The *context availability* theory on the other hand, does not propose the existence of separate semantic systems [3,7] (for a review see Ref. [17]). According to this theory, the available contextual information is crucial in language comprehension because it provides the structure to link different concepts to one another. This contextual information is available either from a person's own memory system or from external sources such as the context provided by the preceding word or discourse. This theory

*Corresponding author. Tel.: +1-530-752-4207; fax: +1-530-752-2087.
E-mail address: swaab@ucdavis.edu (T.Y. Swaab).

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explains the concreteness effect by hypothesizing that concrete words (when presented in isolation) are processed more easily than abstract words because the representations for concrete words are assumed to have stronger or better associations to relevant contextual knowledge within a single semantic memory store, and can therefore activate more semantic information.

Evidence in favor of the context availability theory comes from studies by Schwanenflugel and co-workers [18–20]. They found that the concreteness effect on reaction times and accuracy diminished or disappeared when abstract and concrete words were presented in equally supporting sentence contexts. They argued that this diminishing concreteness effect was due to external context availability and its effect on processing for abstract and concrete words: concrete words have strong internal contexts and the processing of these words does therefore not benefit much from external context, but abstract words lack a strong internal context and hence benefit from external context to such a degree that they are processed as efficiently as concrete words. In general the diminishing concreteness effect with external context availability has been taken to indicate that there is a single semantic system that contains representations for both concrete and abstract words; what differs between these types of words is the strength of their contextual associations.

The theory of a single semantic system of knowledge representations was, however, challenged by three recent event-related brain potential (ERP) studies that further tested the idea that concrete words are represented by dual codes in separate verbal- and image-based semantic systems [6,8,22]. Kounios and Holcomb [8] presented subjects with a series of abstract and concrete words, one word at a time. In another study, Holcomb et al. [6] provided their subjects with external contextual information in the form of a sentence that would either bias towards an abstract or a concrete sentence final word. In both studies, the ERPs to concrete words elicited a more negative polarity waveform at anterior scalp sites than the ERPs to abstract words (i.e. the 'ERP concreteness effect'). A distinct topographic distribution for ERPs to concrete versus abstract words is consistent with the idea that these different types of words activate partly or wholly distinct neural populations, which is compatible with theories of more than one semantic system, thereby supporting the dual coding theory of Paivio [13].

Holcomb et al. [6] also observed that the ERP concreteness effect was only found in the sentences that ended with an anomalous word, that is, when the semantic specifications of the sentence context did not support the semantic specifications of the sentence final word. Although on the surface this result might seem compatible with the context availability theory, the effect of congruence was larger on the concrete than on the abstract words, which is not consistent with the predictions of the context availability theory. On the basis of these results, Holcomb et al. [6] proposed a modification of Pavio's dual coding theory: the 'context extended dual coding theory'.

This context extended dual coding theory posits similar effects of linguistic context for abstract and concrete words within a verbal-based system, but larger effects of context for concrete than for abstract words within an image-based system (see also Ref. [22]). Holcomb et al. [6] further argued that the effects of a supportive context can override the concreteness effect because context can exert its influence before concreteness. They argued that if a higher order context representation can be made on the basis of context alone, other semantic properties (such as concreteness) are no longer needed and will not become activated. In this line of reasoning, image-based semantic properties of words will only become active if the building of a higher order context representation is difficult, for example when the sentence context is anomalous.

What remains untested, however, is how much supportive context is required to override the concreteness effect. A key question is whether image-based codes would be activated if the supporting context for a target word is limited. Testing this would further establish the existence of image-based codes in semantic memory.

In the present study the question of the role of a single word context on the concreteness effect was addressed by manipulating the context of target words in a two-word priming paradigm. Half of the word pairs were high imageable and half were low imageable. Imageability (the extent to which a word evokes a mental image) was tested instead of concreteness. This was because although concreteness and imageability are highly correlated (high imageable words are always concrete), the concreteness effect has been attributed to an additional link to the image system [16]. The imageability of a word may therefore provide a more direct test of Paivio's dual coding theory than does concreteness per se.

The context was manipulated by varying the relationship between the prime and the target words in each pair. That is, the target word was either related or unrelated to the first word (prime). In this way we were able to investigate the imageability effects on target words when the context was supporting (related condition), and when the context was not supporting (unrelated condition), and in each case limited to a single word prime. ERPs were used as the dependent measure. To establish that our context influenced word processing, we examined the N400 effect of priming [4,5]. An effect of priming would be evidenced by a reduction of the amplitude of the N400 to target words that were preceded by a related prime word relative to target words that were preceded by an unrelated prime word. As observed in the studies by Kounios and Holcomb [8], and Holcomb et al. [6] we expected a frontally distributed ERP effect of imageability. In contrast to the study by Holcomb et al. [6], we predicted that there would be no effect of context on the ERP imageability effect, since the context in our study is less supportive being limited to only one word.

2. Method

2.1. Subjects

Twelve paid volunteers (seven male, five female; mean age = 20.2) participated in the experiment. All subjects were native speakers of English with normal hearing, and were right-handed according to an abridged version of the Oldfield Handedness Inventory [11]. All participants had given informed consent.

2.2. Stimuli

A stimulus list of 320 word pairs was constructed. Half of the word pairs consisted of high imageable words, and half of the pairs consisted of low imageable words. Half of the word pairs in this list were related in meaning, and half were unrelated. The word pairs were presented in random order. An example of the stimuli is presented in Table 1.

Imageability of the words was established from an imageability rating pre-test with 40 paid subjects. This pre-test was designed after Paivio et al. [14], and words were rated from 1 (low imageable) to 7 (high imageable). Low imageable words had an average imageability rating of 4, and the average imageability rating for the high imageable words was 6. Related pairs included words that were semantically, but not associatively related (from the same semantic category, association frequency: 0%), and word pairs that were associatively related. Association frequency did not differ across high and low imageability conditions (24.5% for high imageable word pairs, and 21.2% for low imageable word pairs). Semantically related word pairs were prototypical members that were selected from 46 semantic categories from published norms [1], and from a pre-test with 33 paid subjects. Associated word pairs were selected from published English association norms [2,15]. Unrelated word pairs were not associatively related and did not come from the same semantic category.[1] Importantly, across imageability and priming conditions, primes were matched on average word frequency (low imageable related (LIR) = 38%, low imageable unrelated (LIU) = 32%, high imageable related (HIR) = 31%, high imageable unrelated (HIU) = 33%). Targets also were matched in average word frequency (LIR = 54%, LIU = 54%, HIR = 57%, HIU = 56%). Word frequency norms were obtained from Francis and Kucera [9], and the online MRC psycholinguistic database (http://www.itd.clrc.ac.uk).

Table 1
Examples of related and unrelated word pairs in the low and the high imageability conditions. Related word pairs were either associates or from the same semantic category

	Low imageable	High imageable
Related	Atom–molecule	Bread–butter
	Month–minute	Pig–leopard
Unrelated	Pace–dispute	Wheat–slipper
	Bile–sentence	Yacht–balloon

2.3. Procedure

The word pairs were presented auditorily with a constant SOA of 1200 ms. The ISI varied between 300 and 800 ms, and the inter-trial interval was 2.5 s. All the subjects were tested individually in a session of about 2.5 h duration. They were tested in a dimly illuminated sound-attenuating booth, seated in a comfortable reclining chair. Subjects were instructed to move as little as possible and to keep their eyes fixated on a fixation cross at eye level on a computer monitor. They were told that they would hear pairs of words and were instructed to judge whether the words in a pair were associatively or semantically related or unrelated (semantic judgement). This semantic judgment task was included so that subjects would pay attention to the relationship between words, and to divert their attention from the imageability manipulation. When subjects were debriefed, none of them reported having noticed differences in the degree to which words were imageable. An instruction replaced the fixation cross 1500 ms after the offset of the target word (‘press yes or no now’). Subjects were told that this was their sign to press the *no*-button with the index finger of their right hand when the words in a pair were unrelated and the *yes*-button with the middle finger of their right hand when the words in a pair were related. The experimental session was preceded by a practice session of 2 min to familiarize the subjects with the procedure.

2.4. EEG procedure

The EEG was recorded from 27 tin electrodes mounted in an electrode cap. All electrodes were referred to the left mastoid. Vertical and horizontal eye movements were monitored via sub- and supra-orbital electrodes, and left and right external canthus montages, respectively.

The EEG and EOG recordings were amplified by Grass Model 12 amplifiers. A low-pass filter cut-off of 30 Hz was used, with a time constant of 10 s. The impedances were kept below 3 kΩ. The signal was digitized on-line

[1] The relationship between the words was varied such that half of the related word pairs came from the same semantic category but were not associated and the other half were strong associates. However, this manipulation yielded no interactions with any of the effects of interest in this paper, and hence will not be discussed further.

with a sampling frequency of 256 Hz, and recorded continuously with a Neuroscan acquisition system, together with condition codes at the onset of each stimulus. ERP averages over the different conditions were made for all trials that were free of eye and muscle artifacts.

3. Results

Repeated-measures analysis of variance (ANOVA) was performed using the within-subject factors of: imageability (low, high) and relatedness (related, unrelated). Separate ANOVAs were conducted for the ERPs to lateral and midline electrode sites. The lateral ANOVA included the additional factors of: electrode site and hemisphere (left vs. right). The midline ANOVA included the factor electrode. A Greenhouse–Geisser correction was applied for all the repeated-measures that had more than one degree of freedom in the numerator. Unless indicated differently, the Greenhouse–Geisser corrected P values will be reported. Mean amplitude ERPs were calculated for the 350–650 ms latency window after the onset of the target words.

There was a significant main effect of *imageability* in the lateral analysis ($F(1,11)=7.83$, $P<0.02$). This effect was maximal over frontal electrode sites as was evident from a significant interaction between imageability and electrode site for the lateral analysis ($F(10,110)=3.56$, $P<0.05$), and a marginally significant interaction in the midline analysis ($F(2,22)=3.83$, $P=0.07$). The top part of Fig. 1 shows this frontal maximum for the ERP imageability effect. Importantly, as is shown in Figs. 2 and 3, there was no interaction between imageability and relatedness (imageability×relatedness: midline: $F<1$; lateral: $F<1$). This indicates that the effect of imageability was independent of contextual support, and that the effect of priming was comparable for the low and the high imageable words.

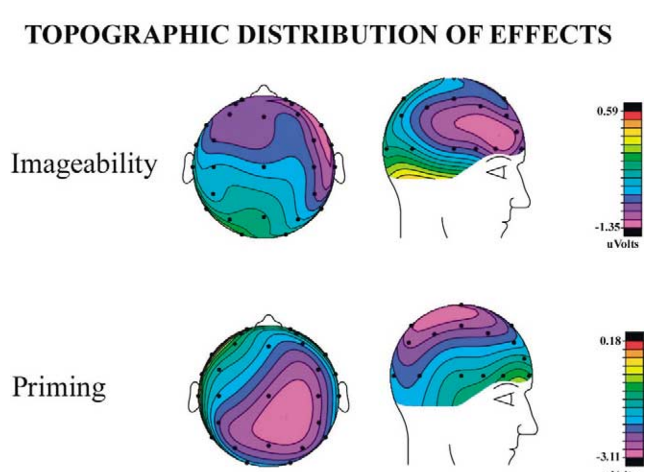

Fig. 1. Topographic distribution of the ERP effects. Pink colors indicate the negative maximum of the effects. The top part of this picture shows a frontal maximum for the ERP imageability effect (high imageable–low imageable). The bottom part shows the posterior maximum for the ERP priming effect (unrelated–related; i.e. the N400).

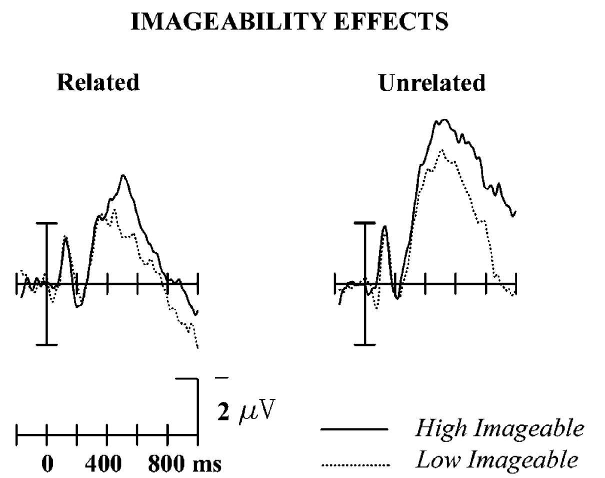

Fig. 2. Imageability effects (high imageable vs. low imageable) for the related and unrelated context conditions for electrode F4 (right frontal).

The absence of context effects on the ERP effect of imageability was not due to an absence of context effects on word processing. A significant main N400 effect of *relatedness* was found (midline: $F(1,11)=25.11$; $P<0.0005$; lateral: $F(1,11)=18.50$, $P<0.002$). In contrast to the ERP imageability effect, the N400 effect showed a posterior distribution (relatedness×electrode site: midline: $F(2,22)=10.99$, $P<0.0006$; lateral: $F(10,110)=19.28$, $P<0.00000$), and was maximal over the right hemisphere (relatedness×hemisphere: lateral: $F(1,11)=15.07$, $P<0.003$). Finally, a three-way interaction of relatedness, electrode and hemisphere indicates that the N400 effect was maximal over the right posterior electrode sites (lateral: $F(10,110)=8.51$, $P<0.0001$) (see bottom part of Fig. 1). This topographic distribution is typical for the N400 (e.g. Ref. [10]).

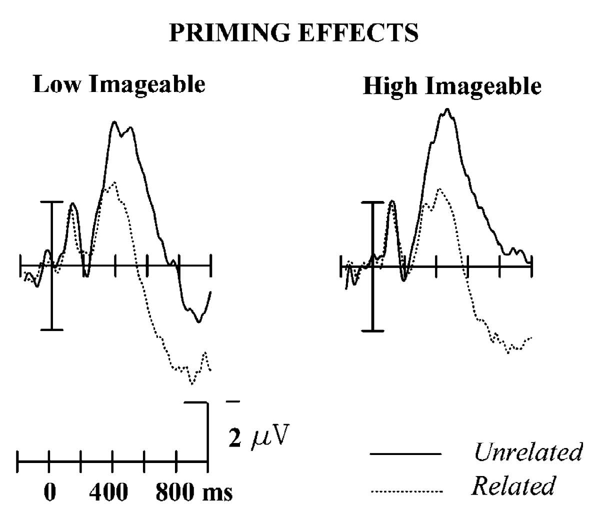

Fig. 3. N400 priming effect (unrelated vs. related) for the high and the low imageable target words for electrode Pz (midline posterior).

4. Discussion

The central finding of this experiment provides support for the idea that there are at least two separable semantic stores, one containing verbal- and the other containing image-based information on words (e.g. Ref. [13]). In contrast to low imageable words, high imageable words elicited ERPs that were maximal over frontal electrode sites. Distinct topographic distributions of the ERPs to low versus high imageable words is compatible with the idea that low and high imageable words had activated distinct neural populations, which is consistent with the idea that these properties are represented by more than one semantic system.

Importantly, the size and topographic distribution of this ERP imageability effect was not influenced by the contextual support that was provided by the preceding context in this word processing priming paradigm.[2] This result argues against the idea that effects of concreteness or imageability can be explained in terms of the context availability theory (e.g. Ref. [17]), because this theory predicts that effects of context should be larger for low than for high imageable words.

The current findings contrast with the findings of the study by Holcomb et al. [6]. Whereas Holcomb et al. [6] showed that concrete words were influenced more by a supportive context than abstract words, the present study found an effect of imageability both when the context was not supportive (unrelated condition) and when the context was supportive (related condition). The major difference between the present study and the study by Holcomb et al. [6] was that these authors provided their subjects with a sentential context, whereas in the present study the context was limited to one word. This indicates that a supportive context can only override the effects of imageability when the contextual support is relatively strong, as in a sentence context.

In conclusion, the results of the present study provide support for the idea that separable semantic stores represent verbal- and image-based information. Importantly, our study has provided evidence that image-based codes can become activated during normal word processing even when contextual support is present as long as that contextual support is limited.

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[2]We replicated these results in a study that used the same paradigm but without a semantic judgment task [21].

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