Event-Related Potential (ERP) Word Imageability Effects in The Attentional Blink

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Abstract

Highly imageable words (e.g., banana) are easier to process than abstract words that are not readily associated with an image (e.g., justice). This difference has been attributed to the existence of two separate verbal- and image-based semantic codes. The advantage of highly imageable words may result from the fact that they activate information in both semantic systems, whereas non-imageable words only activate verbal codes. Electrophysiological research supports the idea of a separate imageability code by showing cortical activation associated with the processing of highly imageable words. This study examines the imageability effect during the attentional blink, a short period of time after the detection of a stimulus in a rapid visual stream in which subsequent stimuli are missed. Previous research has shown that words are processed for meaning during the attentional blink even though participants seem unaware of the word. This study investigates the activation of image-based information in this state of unawareness by recording event-related potentials (ERPs) to find out whether this activation is dependent upon deep semantic processing or whether it occurs automatically. Significant effects of imageability, as evidenced by the ERP imageability effect, indicate activation of image-based codes in the absence of awareness. This finding lends support to a view of semantic activation in which image-based codes are automatically activated.

Introduction

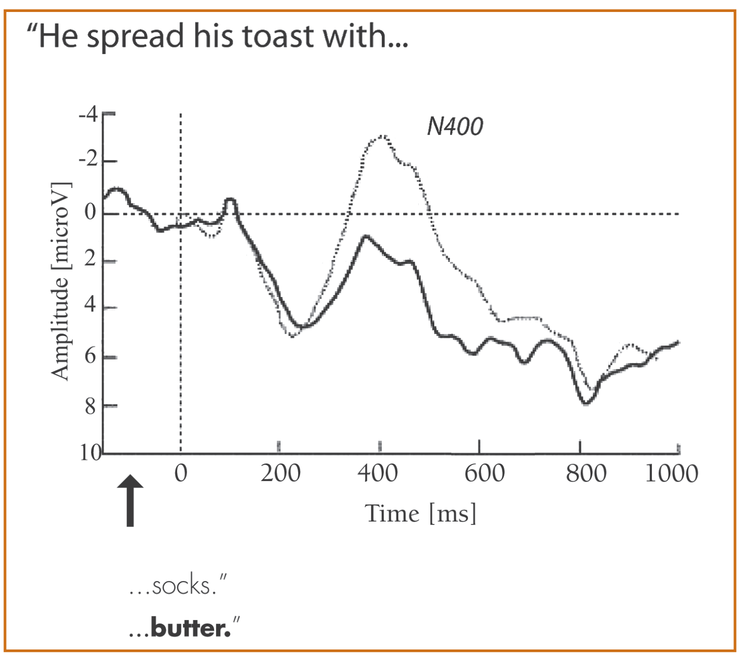
A well-documented feature of highly imageable words (e.g., *banana*) is that they are easier to process than less imageable words (e.g., *justice*). Various theories have been proposed to account for this so-called *imageability effect*. The *dual coding* theory (Paivio 1986, 1991) maintains that there are two separate semantic systems, one containing verbal codes and the other containing image codes. Within this framework, high-imageable words activate both verbal and image codes, while low-imageable words activate only verbal ones. The processing advantage of high-imageable words follows from the richer information content associated with their word representations, which draws on both of the theory's semantic systems.

An alternative account of the imageability effect explains the advantage of high-imageable words in terms of their contextual support in a single semantic system. According to this so-called *context availability* framework, context can be internal to a word, in the form of strong associations to contextual knowledge within a unitary semantic store, or external, in the form of language context. This model predicts an imageability effect (i.e., faster processing) for words not preceded by supporting context (e.g., with an unrelated prime word), but a diminished imageability effect when words are preceded by supporting context. High-imageable words, according to this model, have strong contextual support irrespective of linguistic context. Low-imageable words lack this internal support, but can still be processed quickly if linguistic context is available.

There has been a good deal of electrophysiological research dedicated to uncovering the nature of imageable words. The event-related potential (ERP) technique is one experimental method frequently employed in these studies. ERPs are elicited by events in the outside world and/or by cognitive processes in the brain, and, as measured by electroencephalography, make up part of the ongoing electrical activity of the brain

Electroencephalography (EEG) is the recording of electrical activity in the brain by way of electrodes placed on the scalp. It is frequently used to measure *brain waves*, the normal steady fluctuations of electrical activity emanating from the brain. The orchestrated firing of a population of pyramidal neurons in the cerebral cortex can be detected via EEG. Electrical potentials created by these firings can reach the scalp and be detected by electrodes, at which point they can be amplified and recorded. By relating the activity of these "generator" neurons to the perception or cognitive processing of events in the world, such as a word or shape on a computer screen or a spoken sentence or tone heard through headphones, researchers can draw conclusions about how the brain processes sensory information, maintains attention, and understands language, among other things. To accomplish this, a unique code signifying the onset of a relevant stimulus is transmitted to the signal amplifier at the onset of each stimulus and appended to the EEG signal. In this way, the final recording consists of the signal from each electrode *and* time-stamps indicating the presentation of relevant stimuli to the subject. This pairing of EEG recording and specific events is known as the Event Related Potential (ERP) technique. [For a review of this technique and its applications see Picton et al. (1995), Rugg and Coles (1995), Kutas and Dale (1997), and Kutas et al. (1999).]

Fig. 1. A typical N400 effect.



A typical ERP is the so-called "N400" effect, which has been associated with difficult semantic integration (Kutas and Hillyard, 1983). When a word that does not make sense in light of previous context is read or heard (e.g., after reading the final word in "He spread his toast with socks."), a negative potential, peaking at 400 msec after perception of the word, is detectable, and is strongest over the right posterior part of the scalp (Fig. 1). To discern the N400 amidst the large volume of background noise emanating from the brain, EEG signals that are time-locked to many semantically incongruent words (e.g., 'socks' in the previously cited example) are averaged and compared with averages from semantically normal words (in the literature, these words are said to be "primed," while words that do not make sense in light of context are "unprimed"). This procedure of averaging signals from many different instances of a type of stimuli is typical in ERP research.

A simple brain wave reading can be conducted with a single electrode attached to the scalp, but using more electrodes lets researchers obtain a higher-resolution mapping of where on the scalp electrical activity is concentrated. This in turn allows for a better idea of where in the cortex a population of neurons is firing for a given event. For the present study, a cap with 29 electrodes distributed over the area of the scalp was used. Electrode sites are named according to the part of the brain over which they lie: "F" for frontal, "O" for occipital, etc. [See Fig. 2 for a complete map of the scalp-site electrodes used in this study.]

THE IMAGEABILITY EFFECT

ERP studies have been performed to test whether the processing of high imageable words is supported by dual codes (Paivio, 1986; 1991) or by a single semantic code (Schwanenfluger et al., 1983; 1988; 1989). Swaab, Baynes & Knight (2002) presented participants with word pairs, divided twice for a total of four conditions: 1) into high- and low-imageable words, and 2) into related and unrelated word pairs. As had been reported in previous studies (e.g., Kutas and Hillyard, 1983), the second word in the unrelated pairs elicited the N400 effect. At the same time, the high-imageable words consistently elicited an ERP with maximal distribution over frontal electrode sites, which is different than a typical N400 effect. The fact that this imageability effect had a different scalp distribution than the N400 effects is consistent with the idea that these effects are generated by (partially) non-overlapping neural generators. If this is the case, then the effects of context and the effects of imageability may be processed by separate brain structures. This idea was supported in an fMRI study by Giesbrecht, Camblin, and Swaab (2004), which found that non-overlapping areas in temporal and frontal regions of the cortex were involved in the processing of high-imageable words. In addition, the distinct imageability potential found in Swaab et al. (2002) was elicited both in trials in which the target word was supported contextually by a related word and in those in which the word was preceded by an unrelated word (i.e., the effects of imageability and of priming did not interact). These findings are inconsistent with theories that hold that there is a single semantic system and that attribute the imageability effect to the putatively better

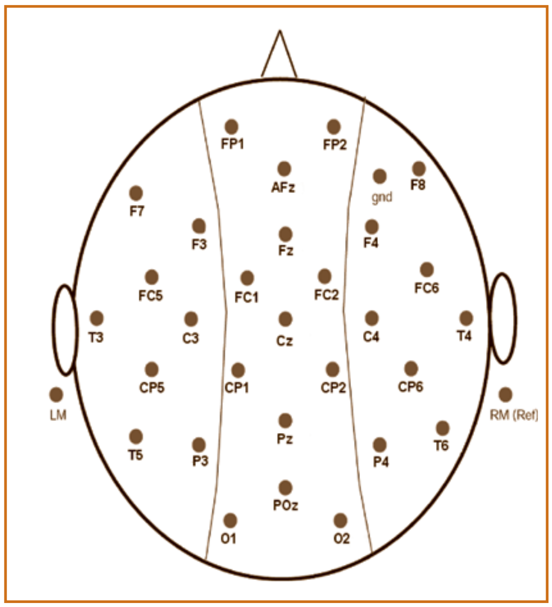


Fig.2. Electrode sites in the configuration used in this study. Electrical activity detected at each site is amplified and recorded.

internal contextual support received by high-imageable words. A single-code model would predict a diminished imageability effect for high-imageable words compared with low-imageable words even when contextual support is available (e.g., in a prime word). Swaab et al. (2002) showed that there is no interaction between contextual support and imageability; a distinct, frontal ERP was found for high-imageable words presented in conditions of both related and unrelated contexts.

The results of these studies are consistent with Paivio's dual coding theory (1986, 1991) and have shown that highly imageable words may activate information that is coded in a second, image-based semantic system or store residing in a separate area of the cortex. However, another important question concerns the nature of the image-based semantic system: do imageable words activate representations in this system automatically, or is the image-based system only accessed with deep semantic processing of words?

The question is not a trivial one. Studies have shown more robust effects of imageability for tasks that require deep semantic processing (Jessen et al., 2000; Kounios & Holcomb, 1994; Fiebach & Friederici, 2003; Martin-Loeches et al., 2001). Kounios and Holcomb (1994) found that the lateral asymmetries associated with the imageability effect were more pronounced for tasks that required a decision about concreteness than for those that required a lexical decision. The latter does not necessarily involve accessing the word's meaning, while the former most certainly does. Martin-Loeches et al. (2001) found significantly less activation than is normally associated with the imageability effect for a task that did not demand deep semantic processing.

THE ATTENTIONAL BLINK

When strings are presented in a rapid serial visual stream, there is a period of 300-600 ms after the detection of a stimulus in which a second stimulus is not reported accurately, even when the first stimulus has been reported accurately (Shapiro et al. 1997). Research indicates that, although words presented in this so-called "attentional blink" are not processed to the level necessary for a subject to accurately report the word, some aspects of the word are processed (Shapiro et al., 1997a; Luck et al., 1996; Vogel et al., 1998; Maki et al., 1997; Shapiro et al., 1997b; Rolke et al., 2001). The attentional blink is different than a normal eye blink–i.e., it is not a perceptual impairment, but rather a momentary lapse in attention that impairs recollection of a target word.

Research by Luck, Vogel & Shapiro (1996) compared behavioral and electrophysiological measures to identify whether or not words are processed at semantic levels of representation during the attentional blink. In their study, participants saw a prime word (establishing context) followed by a stream of strings presented in rapid serial visual presentation (RSVP). Most of the strings were distractors consisting of random consonants. Also appearing in the stream were two targets, first a numeral string and later a word. The interval between the numeral string and the target word was manipulated so that in some trials the target word was presented within the AB (Lag 3) and in other trials it was presented outside this window of attentional impairment (Lag 7). A control condition was included in which participants ignored the numeral target. The significant finding of this study was that words were seen and processed for meaning, though there was behavioral evidence of an attentional blink (66% accuracy on a decision task involving word relatedness). The researchers interpreted this finding as evidence in support of the proposal that the attentional blink is not a form of perceptual suppression, like an eye blink, but a postperceptual impairment. Furthermore, the study establishes that words are processed at least as far as meaning even when reporting of the word is inhibited by the attentional blink.

Later work by Vogel, Luck & Shapiro (1998) seems to confirm this interpretation of the attentional blink. The researchers showed ERP components related to perceptual processing (the P1 and N1) and N400 effects for semantic mismatch to words in the attentional blink, but they found complete suppression of an ERP component related to the updating of working memory (the P3) to the same words. The picture of the attentional blink that emerges from these findings suggests that it is a momentary impairment of the ability to consolidate perceived stimuli into working memory.

PRESENT STUDY

In the present study, ERPs were recorded during the presentation of words in the attentional blink to determine whether the imageability effect was dependent upon deep semantic processing. During the attentional blink, the processing of a stimulus inhibits the consolidation of a stable representation of a subsequent stimulus in working memory. In the attentional blink, word processing takes place without awareness. Words are processed as far as meaning, as evidenced by Luck et al.'s (1996) finding of N400 effects to words in the attentional blink, but deeper semantic processing is limited by the lack of a stable representation of the word in working memory.

In the terms of the dual code theory, the presence of an ERP imageability effect for high-imageable words presented in the attentional blink would indicate that the activation of representations in the image-based semantic system is not dependent on deep semantic processing. On the other hand, if the effect were observed in response to words outside the attentional blink but not to those inside the attentional blink, it would support the idea that activation of image-based semantic codes is made possible by deep semantic processing.

Methods

PARTICIPANTS

Twenty-two students from the University of California, Davis (14 females, 8 males, average age 21.23) participated in the study. All were right-handed (as determined by an abridged version of the Oldfield Handedness Inventory) and native speakers of English. All participants had normal to corrected-to-normal eyesight. Participants gave informed consent before taking part in the study. Data from two participants was not included because of extensive artifacts in their EEG signal.

STIMULI

A list of 320 word pairs was used. Half of the word pairs were related in meaning, and the other half were not. Half of the list consisted of high-imageable words, and the other half consisted of low-imageable words. Importantly, for the related word pairs, the strength of the relatedness of word pairs in the high- and low-imageable conditions did not differ. This assured that both the high- and low-imageable conditions consisted of word pairs with the same average contextual support. The critical words in all conditions were also matched for word frequency and length. Further details about the construction of the word list used in the present study can be found in Swaab et al. (2002).

In half of the trials the second word of the pair was presented within the "attentional blink," while in the other half of trials it was not. The in- (Lag 3) and out-blink (Lag 11) conditions contained the same number of related and imageable words. The details of how the attentional blink was engendered are provided in the following section. With relatedness, imageability, and attentional blink as the experimental conditions (2 x 2 x 2), the word pairs fell into eight condition-groups with 40 stimuli in each condition.

PROCEDURE

A word pair from the list was presented in each trial. The first word served as a prime word. The second was the target word. This terminology will be followed in the description of the presentation of stimuli that follows.

Participants were tested in a dimly-lit, sound-attenuated booth, seated in a comfortable padded chair. They were instructed to remain as still as possible and to blink only during established times in the trial. Before beginning the experiment, subjects were told that their task consisted of reading a word presented at the beginning of each trial, then searching for a numeral and a second word in a series of quickly-presented nonsense strings. They were told that at the end of each trial they would answer whether the number was even or odd and whether the word was related or not to the word they saw at the beginning of the trial.

Each trial began with the presentation for 1 sec of a prime word in the center of the screen, followed by a fixation cross presented for 1 sec. Twelve-character strings were then presented in rapid serial visual presentation (RSVP). All stimuli appeared in the center of the screen for 83 msec, with no interstimulus interval (ISI). The seventh or tenth string presented was a repeated numeral (e.g., "777777777777"). This alternation was random and intended to ensure that participants attended each string and did not learn when to expect the numeral. A target word appeared a certain number of strings after the numeral. The length of time between the presentation of the numeral and the second word was manipulated, presented either three (Lag 3, 249 msec) or eleven (Lag 11, 913 msec) strings after the numeral. The target word was presented in red all-caps letters and had an "X" on either side to make the string a total of twelve characters long. Ten more random consonant strings were presented after the target word.

Following the last random consonant string presented in RSVP, subjects were presented a fixation cross for 1sec. The question, "Even or odd?", was then asked. Subjects made a push button response which triggered the presentation of the second question: "Related or unrelated?" Subjects made their response and the experiment advanced to the next trial.

All items were presented in the Lucida Console font (each letter subtending 2.5º of the visual angle) on a black background. Except for the aforementioned target words, all items were presented in blue.

Stimuli were presented in blocks of 40 stimuli each, for a total of 8 blocks. Block presentation order was counterbalanced across subjects. Within each block, items from each condition were presented in random order.

EEG was recorded from 29 tin electrodes fitted in an elastic cap (see Figure 2), referenced to the right mastoid. Vertical eye movements were monitored by a sub-orbital electrode, and horizontal eye movements via left and right external canthus montages. Impedance was kept below 5 kOhm. Prior to off-line averaging, and starting 200 msec before the onset of the critical words, all single-trial waveforms were automatically screened for amplifier blocking, muscle artifacts, horizontal eye movements and blinks over epochs of 1200 msec. For each participant, average ERPs were computed over artifact-free trials for critical words in all four conditions. Off-line the waveforms were re-referenced to the algebraic average of both mastoids. The bandpass was 0.01 to 30 Hz at a sampling rate of 250 Hz.

Results

BEHAVIOR

Participants responded correctly (even/odd question and related/unrelated question) to 60% of trials in the Lag 3 condition and 66% in the Lag 11 condition.

ERPs

Repeat analysis of variance (ANOVA) was performed on the mean amplitude of ERPs over the 29 electrode sites in two epochs, 300-500 msec and 500-800 msec. In each epoch, an omnibus analysis was conducted over the following within-subject factors: 1) relatedness (related, unrelated), 2) imageability (low/high), and 3) Lag (3/11). For evaluating effects with more than one degree of freedom in the numerator, the Greenhouse-Geyser correction was used to compensate for inhomogeneous variances and covariances across treatment levels (Greenhouse & Geisser, 1959). The adjusted *P*-values are reported. Averages are plotted in Fig. 3.

THE 300-500 msec EPOCH

In the 300-500 msec time window there was a main effect of priming ($F(1,19)=9.94$, $P<.0052$), but no significant effects of imageability ($F<1$) or lag ($F=1.11$). Significant interactions of priming and lag ($F(1,19)=5.41$, $P<0.0312$) and priming and electrode ($F(1,28)=3.91$, $P<0.0063$) were found. The latter can be attributed to the distribution of the N400.

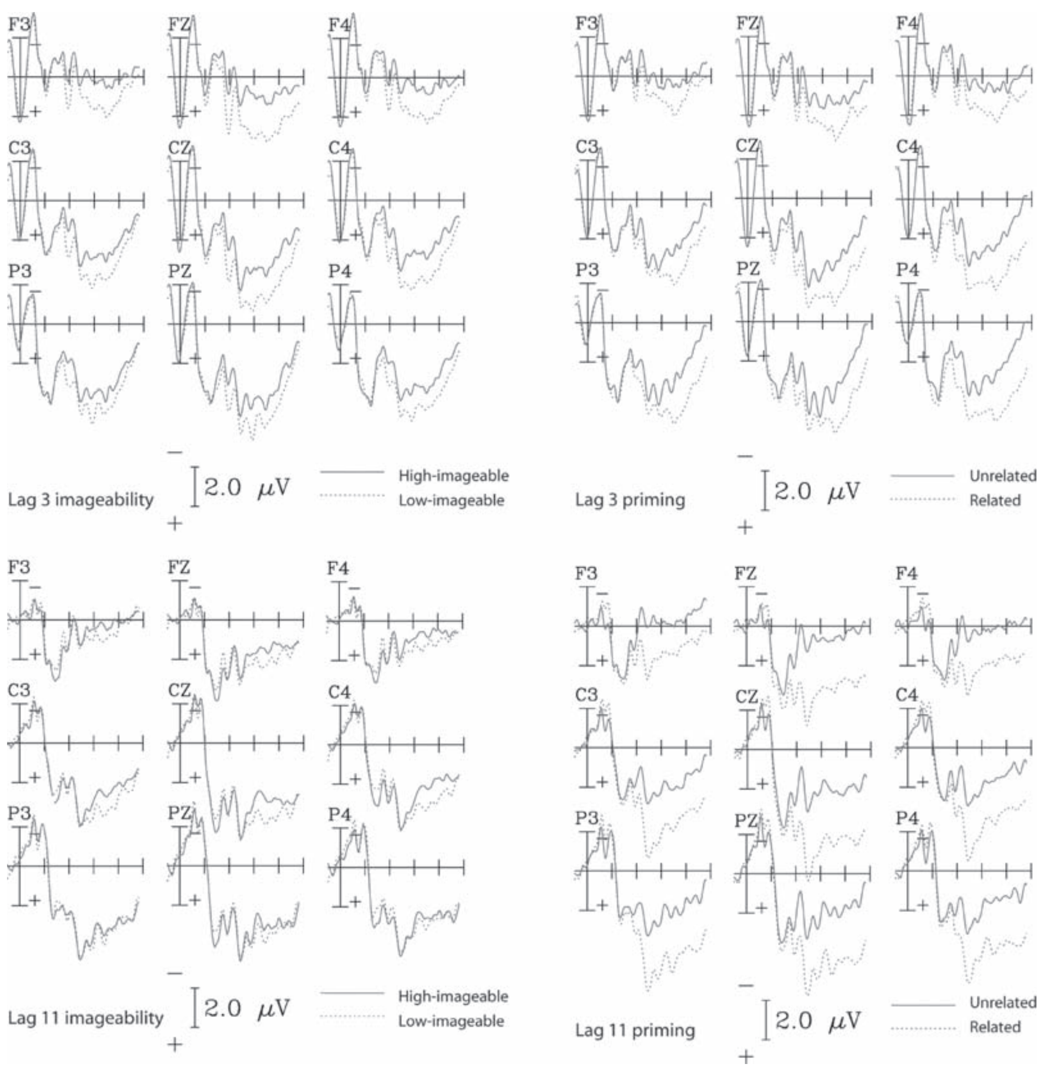


Fig. 3. Signal averages comparing ERPs in high- and low-imageable words (left column), and in unrelated and related word pairs (right column). The effect of imageability can be observed as the difference between the solid 'High-imageable' waves and the dotted 'Low-imageable' waves (left column). Priming can be observed as the difference between the solid 'Unrelated' wave and the dotted 'Related' wave (right column).

To investigate the interaction of priming and lag in the 300-500 msec epoch, pairwise comparisons of Lag 3 and Lag 11 trials were conducted. A significant main effect of priming was found in Lag 11 ($F(1,19)=14.38$, $P<0.0012$) but not in Lag 3 ($F(1,19)=2.20$, $P<0.1542$). In Lag 11, a significant interaction between priming and electrode was found ($F(28,532)=3.77$, $P<0.0149$). Analyses in Lag 3 showed no significant interactions.

THE 500-800 msec EPOCH

In the 500-800 msec epoch significant main effects of priming ($F(1,19)=23.27$, $P<0.0001$) and imageability ($F(1,19)=6.28$, $P=0.0215$) were found. No main effect of lag ($F(1,19)=0.5$, $P<0.4878$) was found. There were significant interactions between priming and lag ($F(1,19)=8.96$, $P<0.0075$), and between priming and electrode ($F(28,532)=5.76$, $P=0.0004$). The latter can be attributed to the distribution of the N400. To investigate the interaction between priming and lag in the 500-800 msec epoch, a pair-wise comparison of Lag 3 and Lag 11 trials was conducted. In Lag 11, a main effect of priming ($F(1,19)=53.33$, $P=0.00$) was found but no significant priming effect was found in Lag 3 ($F(1,19)=3.17$, $P<0.0911$). Lag 11 showed a significant interaction between priming and electrode ($F(28,532)=4.83$, $P<0.0017$). There were no significant interactions in Lag 3.

Discussion

The goal of this study was to determine whether or not the ERP imageability effect operates in the attentional blink. It has been established that words are processed for meaning without awareness during the attentional blink (Luck et al., 1996; Vogel et al., 1998). The nature and extent of this processing is not entirely understood. It was expected that Luck et al.'s (1996) finding of an N400 priming effect would be replicated in this study, as would their pattern of poor performance on a word-relatedness task in the Lag 3 condition alongside good performance outside the attentional blink (their Lag 7, or the current study's Lag 11). Furthermore, it was anticipated that any imageability effect found would resemble the 400 msec-peaking anterior ERP of Swaab et al. (2002). Testing for an interaction between priming and imageability also affords an opportunity to test the context availability theory, which predicts this interaction.

EFFECT OF PRIMING

A main effect of priming was found, but the effect occurred later than the typical N400 (see Fig. 3 for ERPs). The lack of interaction between priming and imageability replicates findings by Swaab et al. (2002) and lends support to a model of two semantic systems, one based on verbal information and the other on image information. This observed effect of priming only partially replicates Luck et al. (1996). The interaction between priming and lag indicates that the effect was not evenly distributed across Lag 3 and 11. Crosswise comparison of priming in Lags 3 and 11 indicates that the effect was larger in the later lag. Luck et al. (1996) did not find this interaction. The difference in findings may be the result of a number of features of the experimental design of the present study that differ from Luck et al (1996).

The strings presented in RSVP were seven characters long in Luck et al. (1996), whereas the present study used twelve-character strings. These longer strings were used because the word list contained target words that were maximally twelve characters long. It may be the case that words of this size are significantly harder to process than seven-character words in the scant 83 msec afforded by the paradigm. Under this explanation, attention is likened to a "spotlight" that illuminates a limited range of the visual field in a given attentional episode. If this were the case, it might account for the smaller and later imageability effect we observed. That both imageability and priming are affected suggests that there might be an earlier attentional limitation associated with the longer string size.

Masking is partially responsible for the attentional blink because it makes the processing of a target more difficult, which is partly why attention is still in a precarious state at Lag 3 (Shapiro et al., 1997a). The larger size of the strings, which included the masking consonant distractors, could have impeded processing of the target word more than anticipated.

If it was the case that the twelve-character strings either fell outside the bounds of a typical attentional spotlight or were masked, we would expect poorer behavior in both the Lag 3 and Lag 11 conditions. Performance on the word-relatedness task in both conditions was in fact poorer than in Luck et al.'s study, and the difference between performance in the attentional blink and non-blinked condition was small.

Another important difference in experimental design may have influenced this study's findings. In the present study, the word pairs of the "related" condition were such that half were associative pairs and half were pairs of words belonging to the same semantic category but without association. Swaab et al. (2002) showed no significant difference in the ERP between associatively and semantically related words, nor significant differences in accuracy on a word-relatedness task. In their study, subjects saw words for 1200 msec without masking. It may be the case that words in the attentional blink are processed lexically, but not to the semantic level necessary to relate fellow members of a category. If these two relations were processed differently in the attentional blink, it could have contributed to the weakening of our priming effect.

A further difference between this study and Luck et al.'s (1996) is that target words in the "non-attentional blink" condition were presented at Lag 11 in the rapid visual stream. Luck and colleagues placed non-blink targets at Lag 7. In behavioral testing for the attentional blink, words presented in Lag 3 and in Lag 7 were equally difficult for subjects to judge for relatedness. To see if our longer stimuli were producing an attentional blink of longer duration than that in Luck et al's (1996) study, target words were moved incrementally further from the target numeral until larger differences in behavior were observed. It may be the case that this change in the paradigm had the unintended effect of distancing the second word enough to disrupt the dual-task nature of the paradigm, allowing for a different type of processing of the target word from that found in Luck et al (1996).

To respond to these unanswered questions, a new study is underway. The current paradigm features 7-character strings to reduce the likelihood of exceeding the bounds of the attentional "spotlight" or causing excessive masking. Associative- and semantic-related pairs form their own conditions, to allow comparison of how they are processed in the attentional blink. Also, Lag 11 is replaced by Lag 7 (as in Luck et al. (1996)).

EFFECT OF IMAGEABILITY

The observed imageability effect appears in a later time window than found by Swaab et al. (2002). It does, however, appear to have a frontal distribution, which is consistent with their findings. The variety of already mentioned factors that might have contributed to the unexpected late priming effect could be the cause of this unusual imageability effect.

The main effect of imageability provides the first evidence in support of the idea that imageability effects are attainable in the attentional blink. That awareness is suspended during the attentional blink may indicate that the semantic store associated with image information is activated automatically during word processing. Though the observed imageability effect differs from previously observed ERPs related to imageable words, the presence of a negative potential to imageable words nevertheless seems to indicate processing of word imageability in the absence of awareness.

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