Imaginal, Semantic, and Surface-Level Processing of Concrete and Abstract Words: An Electrophysiological Investigation

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Abstract

■ Words representing concrete concepts are processed more quickly and efficiently than words representing abstract concepts. Concreteness effects have also been observed in studies using event-related brain potentials (ERPs). The aim of this study was to examine concrete and abstract words using both reaction time (RT) and ERP measurements to determine (1) at what point in the stream of cognitive processing concreteness effects emerge and (2) how different types of cognitive operations influence these concreteness effects. Three groups of subjects performed a sentence verification task in which the final word of each sentence was concrete or abstract. For each group the truthfulness judgment required either (1) image generation, (2) a semantic decision, or (3) evaluation of surface characteristics. Concrete and abstract words produced similar RTs and ERPs in the surface task, suggesting that postlexical semantic processing is necessary to elicit concreteness effects. In both the semantic and imagery tasks, RTs were shorter for concrete than for abstract words. This difference was greatest in the imagery task. Also, in both of these tasks concrete words elicited more negative ERPs than abstract words between 300 and 550 msec (N400). This effect was widespread across the scalp and may reflect activation in a linguistic semantic system common to both concrete and abstract words. ERPs were also more negative for concrete than abstract words between 550 and 800 msec. This effect was more frontally distributed and was most evident in the imagery task. We propose that this later anterior effect represents a distinct ERP component (N700) that is sensitive to the use of mental imagery. The N700 may reflect the access of specific characteristics of the imaged item or activation in a working memory system specific to mental imagery. These results also support the extended dual-coding hypothesis that superior associative connections and the use of mental imagery both contribute to processing advantages for concrete words over abstract words. ■

INTRODUCTION

Concrete words (words that refer to specific objects or events, e.g., *bicycle*) have been found to have many cognitive processing advantages over abstract words (words that refer to more general and/or complex concepts, e.g., *honesty*). In general, subjects both encode and retrieve concrete words faster and more completely than abstract words. This has been demonstrated with recognition, free and cued recall, and paired associate learning (e.g., Paivio, Walsh, & Bons, 1994; Nelson & Schreiber, 1992; Marschark & Paivio, 1977). In addition, the time to comprehend a sentence is generally shorter when the sentence is concrete rather than abstract (Haberlandt & Graesser, 1985; Schwanenflugel & Shoben, 1983). Subjects also respond faster to concrete than to abstract sentences in meaningfulness judgment (Holmes & Langford, 1976; Klee & Eysenck, 1973) and truthfulness judgment (Belmore, Yates, Bellack, Jones, & Rosenquist, 1982) tasks.

The cognitive processing mechanism(s) underlying these "concreteness effects" have been the topic of great debate. The two major competing accounts are the context-availability model and dual-coding theory (see reviews by Paivio, 1991; Schwanenflugel, 1991). The context-availability model (Kieras, 1978; Bransford & McCarrell, 1974), a variation of the single semantic-system view, argues that comprehension relies heavily on available contextual information, provided either intrinsically (in the preceding discourse) or through the subject's own knowledge base (semantic memory). Concrete words are thought to have greater contextual associations in semantic memory than abstract words and are thus processed more efficiently, particularly when little context is provided with the stimulus. This model argues for a difference in the *quantity* of information available to concrete and abstract words in a single system. On the other hand, dual-coding theory (Paivio, 1971, 1986, 1991), a variant of the multiple semantic-systems view, argues that all verbal stimuli initially activate representations in a verbal "linguistic" semantic system. Subsequently, concrete words, but not abstract words, are able to activate information in a nonverbal "imagistic" system through referential connections to that system. According to dual-coding theory, it is the availability of multiple processing resources and forms of representation that give concrete words their distinct advantages. Thus, this model argues for a difference in the *type* of information available to concrete words compared to abstract words.

Recently, Holcomb and colleagues examined concreteness effects using event-related brain potentials (ERPs) and proposed a modified version of the dual-coding theory that can best account for the resulting ERP differences between concrete and abstract words. In one study, Kounios and Holcomb (1994) examined the effect of concreteness on ERPs using both a lexical decision task and a concreteness judgment task in a repetition-priming paradigm. Concrete words elicited a more negative ERP than abstract words between 300 and 500 msec after stimulus onset. Interestingly, this difference was larger in the concreteness judgment task (which requires deeper semantic processing) than in the lexical decision task. This negativity coincided temporally with the classic N400 component (e.g., Kutas & Van Petten, 1988), which has been suggested to reflect the process whereby semantic information is integrated with the preceding context (e.g., Rugg, Doyle, & Holdstock, 1994; Brown & Hagoort, 1993; Holcomb, 1993). The concreteness N400 effect was also largest over the anterior right hemisphere scalp sites. This interaction between concreteness and scalp distribution indicates that concrete words were accessing a nonidentical set of cognitive and neural processing resources than abstract words and *not* simply more of the same resource[1] (although they may access more of this resource as well) and is inconsistent with the single-code context-availability model, which would predict a difference only in the amplitude and not in the scalp-distribution of ERPs for concrete and abstract words.

In a subsequent study utilizing an anomalous sentence task, Holcomb, Kounios, Anderson, and West (1999) found evidence that concreteness and context are separate independent factors that each influence N400 amplitude. As in previous studies (e.g., Kutas & Hillyard, 1984), final words that were incongruous with the sentence context (e.g., "Armed robbery implies that the thief used a *rose*.") produced a more negative ERP (N400), which was most robust over centro-parietal scalp sites, than final words that were congruous with the sentence context (e.g., "Armed robbery implies that the thief used a *weapon*."). Incongruous concrete final words also elicited more negative ERPs than incongruous abstract final words during the temporal region of the N400, but this effect extended to 800 msec or beyond and had a maximum amplitude focused over anterior scalp sites. Clearly, these findings are supportive of a role for contextual factors in the facilitation of semantic processing. However, single-code models cannot account for the prominent differences in spatial distribution found for concrete and abstract words. The extended dual-coding theory proposed by Holcomb et al. (1999) accounts for both the contextual and the concreteness ERP effects. This modified version of Paivio's dual-coding theory states that both contextual factors within the linguistic system as well as referential connections to a separate imagistic system influence semantic processing. Furthermore, contextual factors can, in certain instances (such as when there is adequate contextual information present in the discourse), mask or supercede the added benefit available to concrete words through referential connections to the imagistic system. This may occur, for example, because linguistic contextual information involves a faster or earlier process than does imagistic information.

The aim of the present set of experiments was to more carefully examine the two processes implicated in the Holcomb et al. (1999) study by determining if they could be differentially affected by changes in task demands. A "levels of processing" approach (Craik & Lockhart, 1972) was used to determine (1) at what point in the stream of cognitive processing ERP concreteness effects emerge and (2) how different types of cognitive operations influence the resulting ERP concreteness effects.[2] Subjects in this study were assigned to one of three groups: imagery, semantic, and surface. Each group performed a variation of a sentence verification task in which subjects were required to judge the truthfulness of sentences with either concrete or abstract final words. Sentences for each task were constructed such that a specific type of cognitive processing was required to make the judgment. In the imagery task the sentences required subjects to try to generate an image of the final word (e.g., "It is easy to create a mental image of *shoes/bravery*."). This task may also elicit some abstract semantic processing, since according to dual-coding theory, words are first processed by the verbal semantic system before accessing the imagistic system. In the semantic task the sentences required subjects to retrieve verbal knowledge (e.g., "It is common for people to have an *elephant/aptitude*."). While these sentences were constructed so as not to encourage subjects to use imagery, there may be some inadvertent or "implicit" image generation in this condition. The materials were generated such that this implicit imagery would not, in any case, provide information useful for making the required judgment since the decisions involved abstract general knowledge. Finally, in the surface task the sentences required subjects to decide if a probe letter was present in the final word

("The letter 'x' appears in the word *aluminum/dexterity*"). These sentences do not encourage the use of imagery[3] or the extraction of semantic information.

Based on previous findings (e.g., Belmore et al., 1982; Holmes & Langford, 1976; Klee & Eysenck, 1973), it was expected that verification decisions in both the imagery and the semantic tasks would be faster for concrete sentences than for abstract sentences. No behavioral differences were expected within the surface task since concreteness effects generally are not found in tasks that do not require postlexical semantic processing (Schwanenflugel, 1991). Finally, decision latencies were expected to be faster in the surface task than in either the imagery or semantic tasks, since decisions that require only shallow levels of processing are generally faster than those that require deeper semantic levels (Posner, 1969).

As mentioned earlier, the previous ERP studies by Holcomb and colleagues generally found a more negative N400-like ERP component for concrete words than for abstract words. Also, concreteness effects had the greatest magnitudes in tasks requiring deeper "semantic" processing (e.g., larger effects with categorization than lexical decision). From these data the authors argued that the ERP concreteness effect is most likely semantic in nature. However, all of the tasks they employed have been shown to engage this type of processing and therefore leave open the question as to whether a task that does not require semantic processing would produce similar effects. Accordingly, in the current study it was predicted that a large ERP concreteness effect would be obtained in the semantic task because it explicitly requires linguistic semantic processing. A somewhat smaller or qualitatively different ERP concreteness effect was predicted in the imagery task, because although it does not depend on, it might nevertheless elicit, some linguistic semantic processing and it almost certainly requires imagistic semantic processing (but see below). Finally, a small or absent ERP concreteness effect was predicted in the surface task because it does not require or encourage any type of semantic processing. Further, if as stated in dual-coding theory, activation of the imagistic system by words only occurs after activation of the verbal semantic system, then image-generation ERP effects should have a longer latency than linguistic semantic effects. The prolonged ERP effects (those extending beyond the typical N400 window) in the Holcomb et al. (1999) study are consistent with this prediction. In the current study, it was anticipated that an ERP concreteness effect with a longer onset latency than the N400 concreteness effect would also be observed. This image-based concreteness effect was expected to have the greatest magnitude in the imagery task that requires explicit image generation, be reduced in the semantic task that may elicit some implicit imagery but that does not require image generation, and be absent in the surface task that does not encourage image generation.

Another possible outcome is that the semantic task might produce only *quantitative* differences (single code) between concrete and abstract words, while image generation might produce *qualitative* differences (dual code). A change in amplitude but similar scalp topography in the ERPs for concrete and abstract words (main effect of concreteness) would indicate a quantitative difference (i.e., activation of the same source but to different degrees). This could occur in the semantic task if, as anticipated, participants only process final words for their verbal semantic attributes without explicitly using imagistic information. Conversely, a change in amplitude combined with distinct topographical patterns (an interaction between concreteness and electrode site) would indicate a qualitative difference (i.e., activation of different sources). This pattern is expected to occur in the imagery task, if in fact concrete words activate an image-based representation in a separate semantic system that is not available to abstract words.

RESULTS

Behavioral Data

The time to respond to all sentence final words (see Table 1) was shorter for subjects in the surface group than for those in the imagery or semantic groups [main effect of group: $F(2,33) = 32.72$, $p < .0001$]. Response time was generally shorter for concrete than abstract words [main effect of word type: $F(1,33) = 48.43$, $p < .0001$]. However, the magnitude of this concreteness effect varied for the three groups [group by word type interaction: $F(2,33) = 16.01$, $p < .0001$]. Follow up analyses revealed that this effect was significant for

Table 1. Response Times (msec) for Sentence Verification

	Final word type	
Sentence type	*Concrete*	*Abstract*
Imagery		
M	1371.28	1921.90
SD	79.91	284.76
Semantic		
M	1720.05	1944.64
SD	449.69	514.76
Surface		
M	877.56	902.15
SD	186.99	195.05

subjects in the imagery and semantic groups but not the surface group. Furthermore, response times to concrete words were shorter for subjects in the imagery group than for subjects in the semantic group, while response times to abstract words were equivalent for the two groups.

ERP Data

Overview of ERPs

The grand-mean ERPs time-locked to the onset of concrete and abstract target words are plotted in Figure 1 (imagery task), Figure 2 (semantic task), and Figure 3 (surface task). Several early (less than 400 msec) components were elicited by both word types. These components were similar for all three tasks. They included a broadly distributed early negativity (N1) that peaked around 125 msec at all but the occipital sites. At these sites, there was an early positivity peaking at about 125 msec (P1) followed by a later N1 with a peak between 175 and 200 msec. At most sites, the N1 component was followed by a positivity peaking between 200 and 250 msec (P2). None of these early components differed by word type.

There were also several later ERP components visible in the waveforms. Following the P2, there was a widespread negative-going wave that peaked around 400 msec (N400). Following the N400, there was a positive wave (P3) that peaked between 600 and 800 msec over the central and posterior sites. Beginning at about 250 to 300 msec after stimulus onset, ERPs elicited to concrete words were more negative than to abstract words in the imagery and semantic conditions. This divergence continued until 900 msec or beyond.

Comparison of concreteness effects between the groups is made easier by examining the difference waves produced when the ERPs to abstract words are subtracted from those to concrete words (Figure 4). These difference waves suggested the presence of two contiguous negativities. The first emerged at about 250 to 300

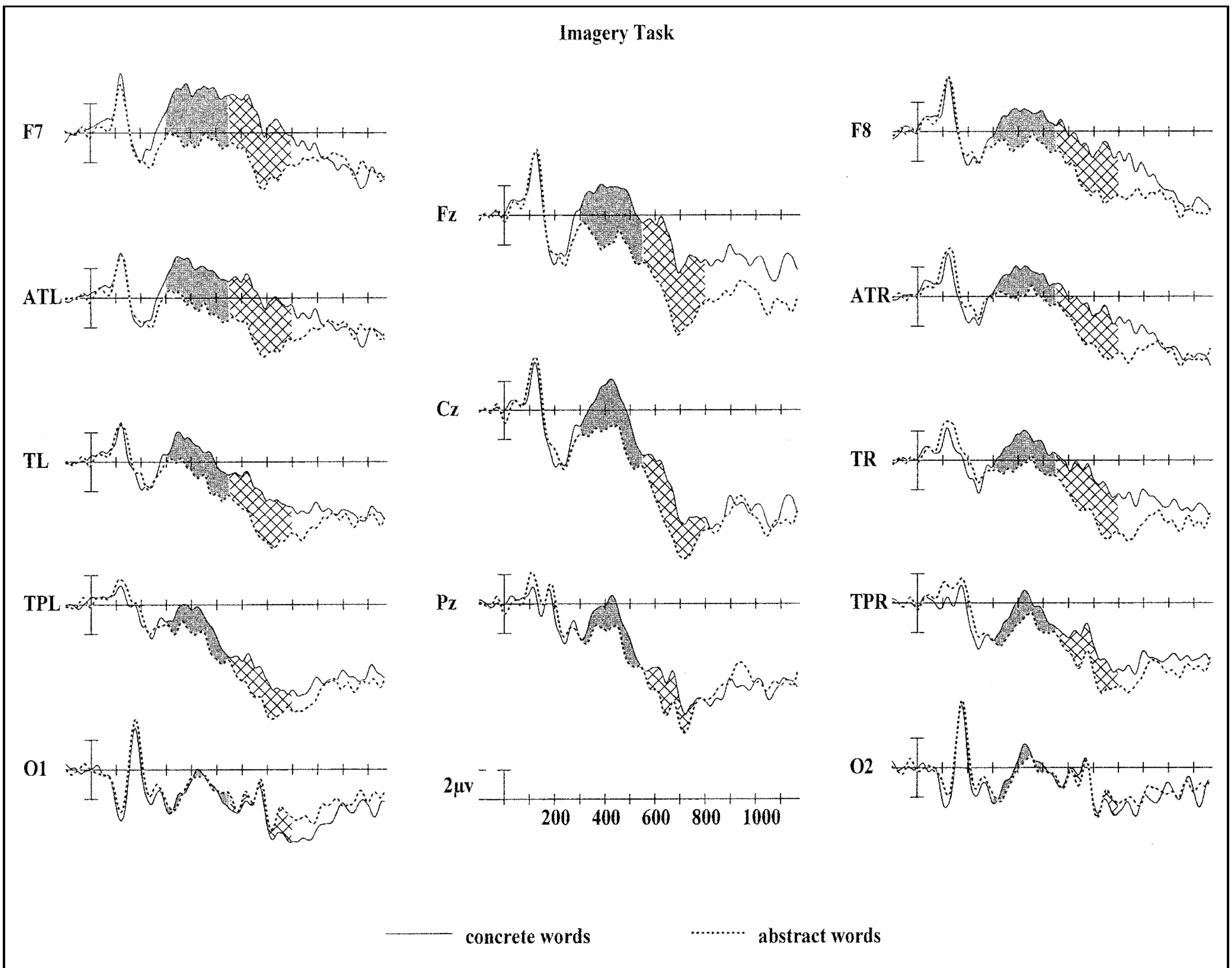

Figure 1. Grand average ERPs elicited to concrete and abstract sentence final words for subjects in the imagery task group. In this and all subsequent figures the shaded areas correspond to the 300–550 msec epoch and the hatched areas correspond to the 550–800 msec epoch.

msec and ended at about 550 msec; the second began at 550 msec and continued until 800 msec or beyond (see especially midline sites in Figure 4). These two negativities appeared to differ between tasks. For the semantic task the amplitude of the effects peaked during the first negativity and slowly declined thereafter, while for the imagery task the amplitude slowly increased, reaching a peak during the second negativity. These observations motivated the choice of the two temporal windows used in the following analyses.

300–550 msec

An omnibus ANOVA of the mean amplitudes for this epoch revealed that overall concrete words were associated with a more negative-going wave than were abstract words [main effect of word type, midline: $F(1, 33) = 49.94$, $p < .0001$; lateral: $F(1,33) = 44.28$, $p < .0001$]. The magnitude of this effect varied by group [task by word type interaction, midline: $F(2,33) = 13.86$, $p < .0001$; lateral: $F(2,33) = 11.68$, $p < .001$; see analyses below]. Across groups, the voltage difference between concrete and abstract words became increasingly larger toward more anterior scalp locations [word type by electrode-site interaction, midline: $F(2,66) = 4.94$, $p < .05$; lateral: $F(4,132) = 7.90$, $p < .01$]. This difference was also more pronounced at left anterior sites than at right anterior sites [word type by electrode-site by hemisphere interaction: $F(4,132) = 3.51$, $p < .05$].

In order to better understand the task by word type interaction, data for subjects in each of the three groups were also analyzed in separate ANOVAs. In the imagery task during this epoch (Figure 1), concrete words elicited more negative-going waves than abstract words [main effect of word type, midline: $F(1,11) = 22.43$, $p < .001$; lateral: $F(1,11) = 12.65$, $p < .01$]. The difference in amplitude between concrete and abstract words appeared to increase toward more anterior locations although this effect only approached conventional significance levels [word type by electrode-site interaction, midline: $F(2,22) = 4.01$, $p = .072$; lateral: $F(4,44) = 3.95$, $p = .056$]. Follow-up analyses revealed that the differ-

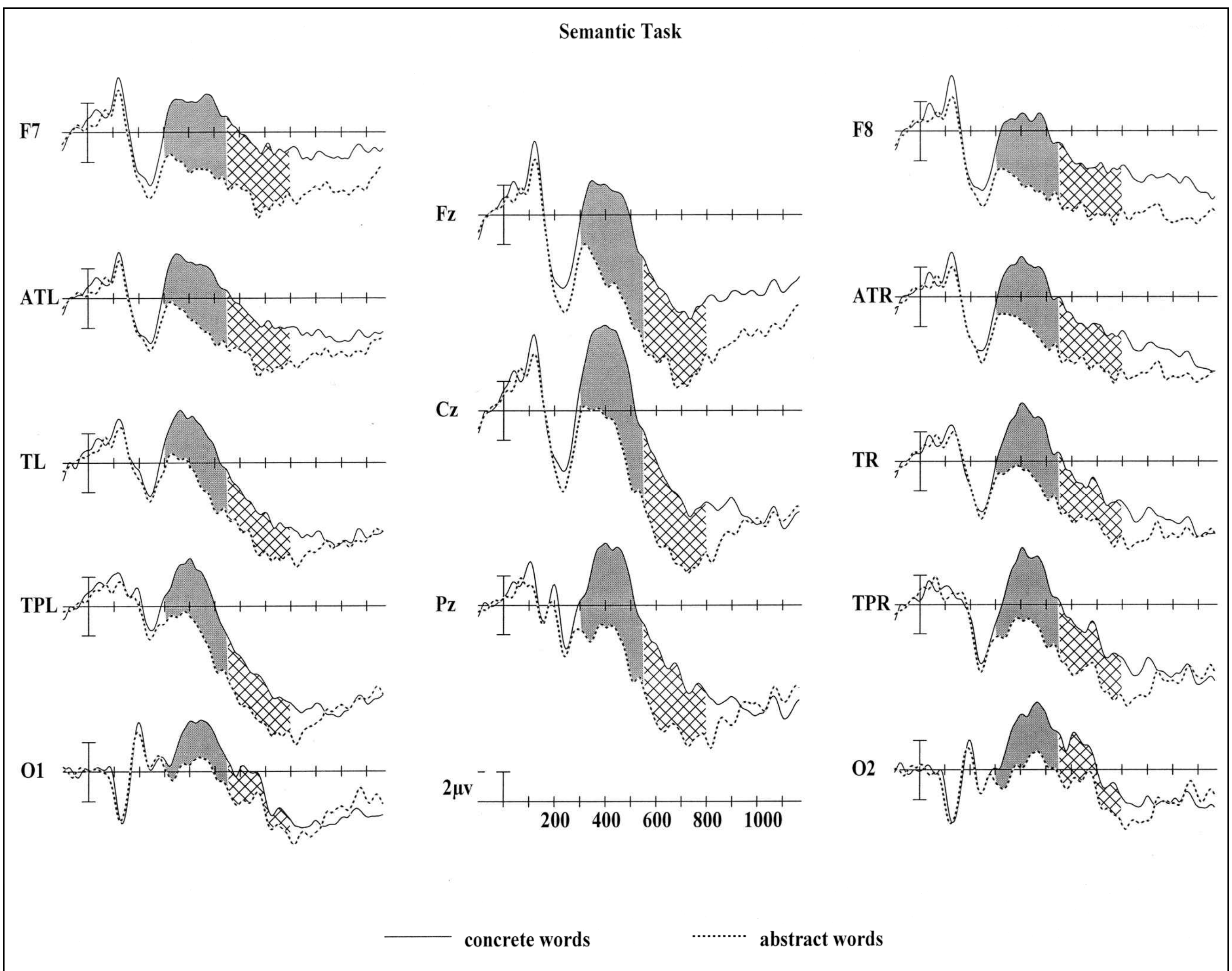

Figure 2. Grand average ERPs elicited to concrete and abstract sentence final words for subjects in the semantic task group.

ences between concrete and abstract words were significant at all but the most posterior locations (Pz, O1, O2). In the semantic task (Figure 2), concrete words also elicited more negative waveforms than abstract words [main effect of word type, midline: $F(1,11) = 60.82$, $p < .0001$; lateral: $F(1,11) = 46.74$, $p < .0001$]. Like the effect in the imagery task, this difference tended to become larger toward anterior locations, but again the effect only approached significance and only at the lateral sites [$F(4,44) = 3.64$, $p = .066$]. Also, at occipital sites the difference was larger over the right hemisphere than over the left hemisphere [word type by hemisphere interaction: $F(1,11) = 5.31$, $p < .05$]. In the surface task (Figure 3), there was not a significant main effect of word type ($p > .4$). However, there was a small concreteness effect over the left hemisphere evident in a significant word type by hemisphere interaction [$F(1, 11) = 6.02$, $p < .05$].

An ANOVA comparing ERPs in the semantic and imagery tasks was also conducted to test the hypothesis that the semantic task would elicit a larger concreteness effect than the imagery task during the early time window. In fact, the concreteness effect in the semantic task had a larger magnitude than in the imagery task [task by word type interaction, midline: $F(1,22) = 13.52$, $p < .01$; lateral: $F(1,22) = 8.76$, $p < .01$; see Figure 4]. Furthermore, in this analysis there was no interaction with electrode site, indicating that the spatial distribution of the concreteness effect did not vary for the two tasks.

550–800 msec

The omnibus ANOVA for this epoch revealed that voltages to concrete words were again more negative than those to abstract words [main effect of word type, midline: $F(1,33) = 12.38$, $p < .01$; lateral: $F(1,33) = 14.51$, $p < .001$]. As in the previous epoch, the magnitude of this effect varied by group [task by word type interaction, midline: $F(2,33) = 10.41$, $p < .001$; lateral: $F(2,33) = 9.42$, $p < .001$]. Across groups, the voltage difference between concrete and abstract words was

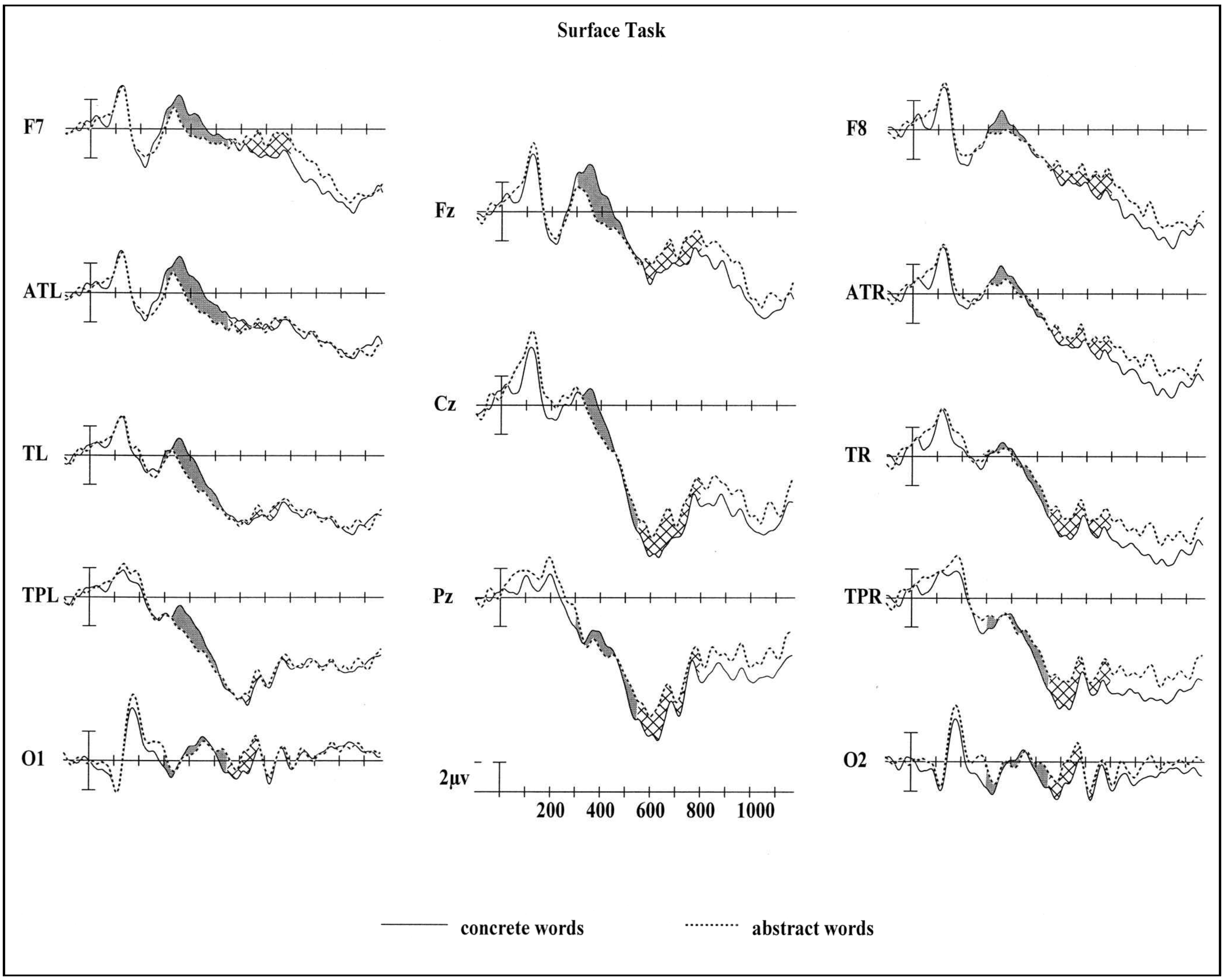

Figure 3. Grand average ERPs elicited to concrete and abstract sentence final words for subjects in the surface task group.

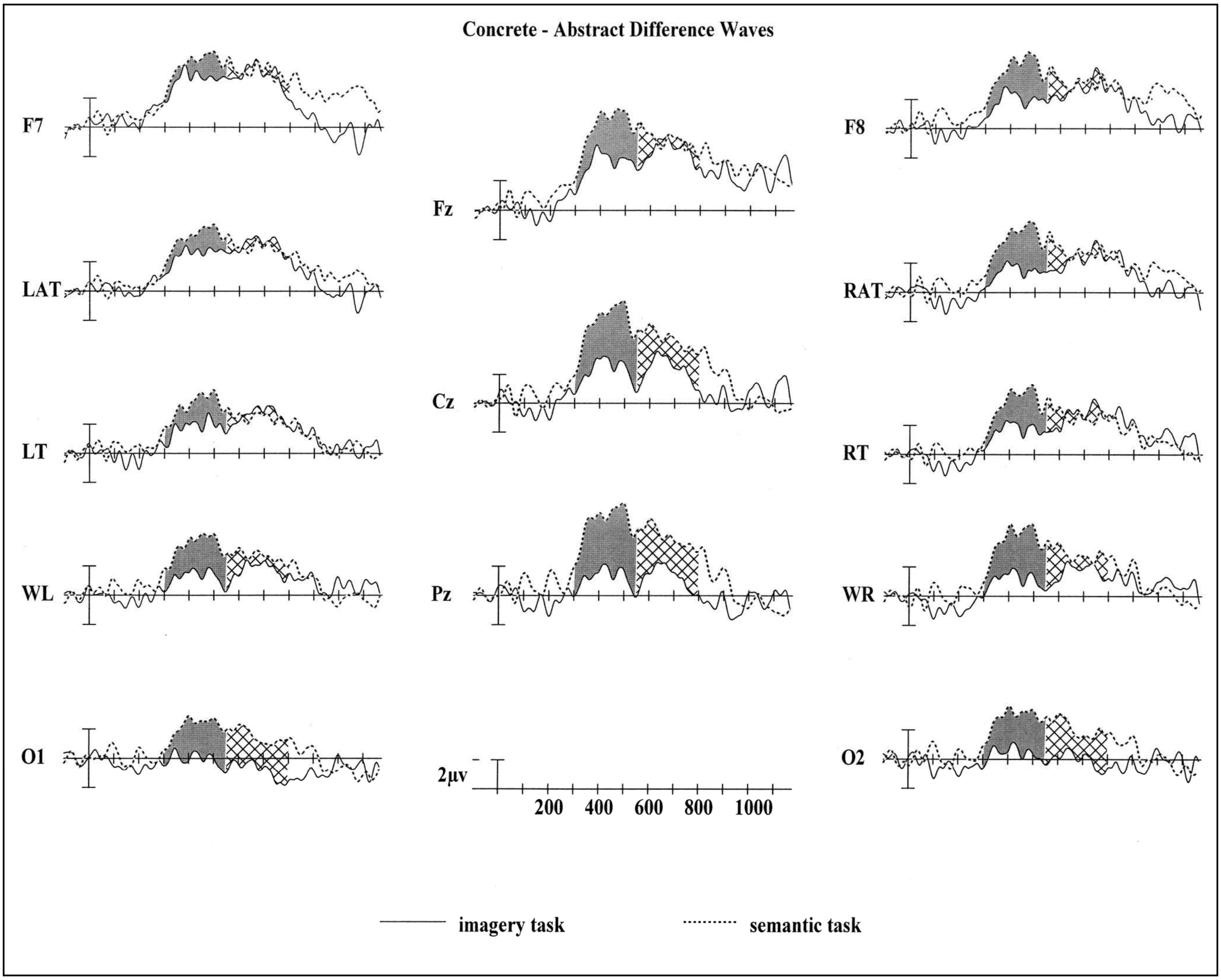

Figure 4. Difference waves, produced by subtracting ERPs to abstract words from the ERPs to concrete words, plotted for the imagery, semantic, and surface task groups.

found to increase from posterior to anterior scalp locations [word type by electrode-site interaction, midline: $F(2,66) = 4.51$, $p < .05$; lateral: $F(4,132) = 7.78$, $p < .01$]. Further analyses revealed that these differences were significant at all locations except the occipital sites.

Individual ANOVAs for the three groups revealed that the voltage differences observed between concrete and abstract words were significant only for the imagery [main effect of word type, midline: $F(1,11) = 12.80$, $p < .01$; lateral: $F(1,11) = 16.53$, $p < .01$] and semantic [midline: $F(1,11) = 33.20$, $p < .001$; lateral: $F(1,11) = 25.90$, $p < .001$] tasks but not for the surface task (midline: $p > .2$; lateral: $p > .3$). Individual analyses also revealed that the trend for larger effects at anterior locations was statistically significant only in the imagery task [word type by electrode-site interaction, midline: $F(2,22) = 10.83$, $p < .01$; lateral: $F(4,44) = 13.88$, $p < .001$]. The trend approached significance at lateral sites in the semantic task [$F(4,44) = 1.91$, $p = .188$] and was not significant in the surface task (p's $> .6$). As in the previous epoch, the voltage differences between concrete and abstract words for the imagery task were found to be significant at all but the most posterior locations (Pz, O1, O2). However, at the occipital sites concrete words were more positive than abstract words and the difference between them was larger over the left than the right hemisphere [word type by hemisphere interaction: $F(1,11) = 11.65$, $p < .01$]. For the semantic task, on the other hand, at occipital sites concrete words were more negative than abstract words and the difference was larger over the right hemisphere than over the left hemisphere [word type by hemisphere interaction: $F(1,11) = 8.27$, $p < .05$].

The analysis comparing the imagery and semantic tasks revealed that in the later time window there was no difference in the overall magnitudes of the concreteness effects for the semantic and imagery tasks. However, during this epoch the effect size was smaller in the imagery task than the semantic task at the posterior midline site [task by word type by electrode site interaction: $F(2,44) = 3.47$, $p < .05$]. This interaction approached significance at lateral sites [$F(4,88) = 2.71$, $p = .095$].

DISCUSSION

Three groups of subjects performed sentence verification tasks in which the final word of each sentence was either concrete or abstract. For each group the truthfulness judgment involved either (1) image generation, (2) a semantic decision, or (3) evaluation of surface characteristics. Event-related potentials time-locked to the onset of the final word in each sentence, as well as response times, were compared for concrete and abstract words in the three tasks. ERPs were analyzed in two time windows (300–550 and 550–800 msec after stimulus onset).

In the surface task, subjects were comparatively faster to verify sentences as true or false than subjects in the semantic and imagery groups. Furthermore, subjects in the surface group responded equally quickly to sentences with concrete and abstract final words, while subjects in the semantic and imagery groups consistently responded faster to concrete words. Finally, subjects showed no overall difference in their ERPs to concrete and abstract words in the surface task, although concrete words were slightly more negative than abstract words over the left but not the right hemisphere. Moreover, there was no evidence of anterior/posterior concreteness differences in this task. These results are consistent with the hypothesis that the subjects performing the surface task were, for the most part, processing only the surface characteristics of the final words and were doing very little processing of the meanings of the words. This pattern of effects is also consistent with previous studies (e.g., Chwilla, Brown, & Hagoort, 1995) that have reported little or no ERP priming effect when subjects were not required to processes words for meaning, and is the strongest evidence to date that the occurrence of ERP concreteness effects depends upon semantic processing.

Subjects who were engaged in deeper modes of processing (the imagery and semantic tasks) exhibited the classic concreteness effect; they responded faster to concrete final words than abstract final words. In addition, subjects in the imagery task responded to concrete words faster than subjects in the semantic task, while response times to abstract words were equivalent for the two groups. In the semantic task, ERPs for concrete and abstract words diverged at about 250–300 msec with those for concrete words becoming more negative than those for abstract words. This negativity peaked at about 400 msec, coinciding temporally with the classic N400 component, and then continued through about 800–1200 msec. During the earlier time window, this concreteness effect tended to increase in magnitude toward anterior sites, although the word type by electrode site interaction only approached conventional significance levels. This trend was less evident in the later time widow. Also, despite the anterior trend the concreteness effect was still quite prominent and significant at even the most posterior sites during both time windows. This pattern of effects was consistent with previous findings of ERP concreteness effects; most notably the pattern here was very similar to that found by Holcomb et al. (1999) in their neutral sentence condition (e.g., "They said it was because of the *rose*."). In both studies, concrete words elicited a larger N400 than abstract words and the effect tended to increase in magnitude toward anterior sites. However, the trend for a larger effect at anterior sites was rather weak in both studies and was accompanied by a clear concreteness effect at the most posterior sites.

In the imagery task, concrete words also elicited more negative ERPs than abstract words. This effect followed a similar time course to that in the semantic task. Also, as in the semantic task, the magnitude of the effect tended to increase toward anterior sites. And as in the semantic task, this trend only approached significance during the earlier time window. However, during the later time widow, the anterior trend was even more prominent than in the earlier window, reaching conventional levels of significance even after normalization (McCarthy & Wood, 1985). Furthermore, there was no significant concreteness effect at the most posterior sites during either epoch. This contrasts with the finding in the semantic task in which there was a prominent effect at the most posterior sites. The pattern of results in the imagery task in the current study is remarkably similar to the effects found by Holcomb et al. (1999) with an anomalous sentence context (e.g., "Armed robbery implies that the thief used a *rose*."). In this condition there was a significant trend for the concreteness effect to increase toward anterior sites and the effect at the most posterior sites was very small.

The similarities between the ERPs elicited by the sentences in the semantic task within the current study and the sentences in the neutral condition in the Holcomb study suggest that these two situations may have activated a similar set of cognitive processing mechanisms. Likewise, the sentences in the imagery task and the sentences in the anomalous condition may have activated another set of processing mechanisms. So, the question at hand is, what do the two groups of experiments have in common? First, the semantic task used here was designed to require a purely verbal semantic judgment that does not encourage image generation. The meaningfulness judgment in the neutral condition in the Holcomb study, while not intended to preclude imagistic processing, may have done so. This is because, like the current semantic task, the sentence stems occurring before the final concrete and abstract words in the Holcomb study contained neutral words that arguably are not conducive to image generation.

Second, the sentence stems in the imagery task also provided no useful contextual information, but the task, by definition, required subjects to try to form a mental image of the final word. In the anomalous condition in the Holcomb study, subjects were not explicitly instructed to generate images. However, the sentence stems in this condition contained many content words that provided a richly informative context that was essential in making the meaningfulness judgment. Such a scenario would very likely encourage the use of mental imagery even though it was not explicitly required. Furthermore, the concreteness effect in the anomalous sentence condition cannot be attributed simply to enhanced context for concrete words. In that experiment, a contextual variable (i.e., congruency) was explicitly manipulated to distinguish effects of context from effects of concreteness. When anomalous sentence final words were compared with congruous sentence final words, an ERP effect with a posterior maximum resulted. The spatial distribution of this effect was similar to the typical N400 distribution and was distinct from the more anterior concreteness effect. Thus, it can be concluded that the imagery task and the anomalous sentence condition in the meaningfulness judgment task may both have encouraged image generation and the use of mental imagery may have produced the similar patterns of ERP effects at the scalp in the two situations.

Another interesting finding was that the overall concreteness effect in the earlier time window was larger in the semantic task than in the imagery task. In addition, there was no interaction with electrode site during this epoch, indicating that there was no difference in the spatial distribution of the effect for the two tasks. Conversely, during the later time window there was no difference between the imagery and semantic tasks in the overall size of the effect. However, at posterior sites the effect size was smaller in the imagery group than in the semantic group. These effects can be seen clearly in the difference waves for the two groups (Figure 4). Examination of these difference waves also reveals that the peak effect for the semantic task occurred during the earlier window, at about 400 to 500 msec after stimulus onset (N400). The effect for the imagery task peaked during the later window, at about 650 to 750 msec (N700).

Taken together, these findings suggest the involvement of at least two distinct cognitive processes, which were differentially activated by the two tasks. One process seemed to be manifested during the earlier recording epoch and shared the temporal characteristics of the N400. These N400 potentials varied in amplitude but had similar scalp distributions for concrete and abstract words. This pattern of results is consistent with activation of a single representational system common to the two word types, with concrete and abstract words producing different degrees of activation in this system. Interestingly, the largest N400 amplitude difference occurred in the semantic task, which would be the task most dependent on the type of verbal semantic information stored in a linguistic semantic system. A similar but smaller effect was also produced in the imagery task. This could be explained by the fact that the imagery task might also activate this process, but to a lesser degree. A second process seemed to be manifested more strongly in the later recording epoch and was associated with what we shall refer to as the N700 component. This N700 component had both different amplitudes and different scalp distributions for concrete and abstract words. This pattern of results is more consistent with a dual coding interpretation in which the two word types activated different sets of processing resources. Since the N700 interaction effect was observed most clearly during the imagery task, we propose that it reflects activation of an imagery process that was relatively more available to concrete than to abstract words. The small increase in effect size toward anterior sites in the earlier window may reflect overlap in the time course of the N400 and N700 components. In addition, the small increase in effect size toward anterior sites in the semantic task may reflect some activation of this process due to some implicit imagery in that task.

The earlier negativity observed in the imagery and semantic conditions displayed temporal and morphological characteristics similar to the well-studied N400 component. The spatial distribution of the present component, however, differed somewhat from that of the typical N400. The scalp-recorded N400 component has generally been found to have a maximum amplitude at centro-parietal sites, particularly in tasks using sentences. However, some studies have shown more anterior negativities, particularly in experiments using single words (e.g., Nobre & McCarthy, 1994; Boddy, 1986; Neville, Kutas, Chesney, & Schmidt, 1986) or pictures (e.g., Ganis, Kutas, & Sereno, 1996; Holcomb & McPherson, 1994; Barrett & Rugg, 1990). In studies using intracranial electrodes, a field potential peaking at 400 msec, with response characteristics similar to the scalp-recorded N400, has been recorded and demonstrated to arise in the anterior-medial temporal lobe (McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1995; Smith, Stapleton, & Halgren, 1986). This potential may have, at least partially, contributed to the widespread N400 observed here. It has been proposed that, in fact, multiple neural generators contribute to the scalp-recorded N400 (e.g., Elger et al., 1997). The relative contributions of these sources may vary depending on the requirements of the task and possibly the nature of the stimuli and thus would produce different spatial patterns at the scalp in different situations.

The later negativity, or N700, most evident in the imagery task had an even more prominent anterior distribution than the N400. To our knowledge, there have been no ERP effects comparable to the N700 reported in the literature. We have proposed that this component reflects the activation of an image-based processing mechanism. According to Kosslyn (1994), mental imagery involves several subsystems at varying levels of complexity. Kosslyn's model is based on the long-held belief that the same processing mechanisms underlie both high-level visual perception and visual mental imagery. Processing in this model includes the representation of perceptual and mental images in a visual buffer and activation in an attentional window (located in occipital cortex), activation in the ventral visual system (in the inferior temporal lobes) for pattern activation and image generation and in the dorsal system (in the posterior parietal lobes) for computing spatial properties, and activation in an information lookup system (in dorsolateral prefrontal cortex) for access to information about specific parts or characteristics.

One possibility is that the anterior distribution of the N700 is produced by a posterior positivity (that may reflect activation of the visual buffer) that temporally overlaps with the later portion of the N400 and has the consequence of reducing the N700 effect at posterior sites. This explanation is somewhat consistent with ERP findings by Farah, Peronnet, Weisberg, and Monheit (1989). In their study, subjects read concrete words with or without imagery instructions and abstract words without imagery instructions. They reported that imagery was associated with a slow positivity (beginning 250–300 msec and maximal 800 msec after stimulus onset) over occipital and posterior temporal regions and was larger over the left than the right hemisphere. This finding was consistent with functional neuroimaging studies (D'Esposito et al., 1997; Goldenberg, Podreka, Steiner, & Willmes, 1987) using similar paradigms that found increased regional cerebral blood flow in left inferior temporo-occipital brain regions during image generation. It could be that in the current study there was a similar posterior positivity, which overlapped with the extended N400 and which had a posterior cerebral generator.

However, this explanation seems unlikely. First, some of the differences in scalp distribution between the current study and the Farah study are likely due to the fact that they used a different site for the reference electrode.[4] Second, in the current imagery task and in Holcomb's anomalous sentence condition there were little or no effects of concreteness at the most posterior sites. It seems highly unlikely that a posterior positivity modulated by image generation or concreteness would produce no effect, even if it were overlapping with another component (the N400) of opposite polarity. Finally, the task demands in the two experiments were quite different. In Farah's task, subjects were instructed in one condition to simply read the words (concrete and abstract) and in another condition to read the words and form a mental image of their referents (concrete words only). In the current task, subjects were required to read and try to form a mental image of words in both conditions (concrete vs. abstract). They were also required to make a judgment of the ease or difficulty of forming an image for each word. Consequently, the current task would require higher-level processes such as working memory and decision making, as well as image generation, for both concrete and abstract words. This interpretation is even more plausible given the time course of the effect. In Farah's study, the posterior positivity was evident as early as 250 msec, suggesting an earlier lower-level process. In the current study, the N700 was not evident until 550 msec, suggesting a later higher-level process.

Therefore, a more compelling possibility is that the anterior distributional pattern of the N700 is the result of activation in a higher-level and more frontal brain region. Localization of the neural generator underlying the N700 is not possible with the current data. This will be addressed in future studies using higher-density array electromagnetic recordings combined with structural and functional MRI. However, the neuroimaging literature presents several potential hypotheses. One possibility is that the N700 reflects activation in an information lookup subsystem, such as that proposed by Kosslyn (1994). Using PET, Kosslyn, Thompson, and Alpert (1997) have observed activation in dorsolateral prefrontal cortex when subjects visualized letters in a grid and made a decision as to whether each letter would have covered an *X* present in the grid. Kosslyn proposed that this activation was related to the process of accessing specific individual features of each imaged item in order to make the required decision. The N700 in the current study may reflect a similar mechanism. This process would be more elaborate and involved for highly imageable words than for nonimageable words. Therefore, it would be expected that concrete words should produce more activation in this system than abstract words and thus would elicit a larger N700.

However, the prefrontal cortex has been implicated in a number of higher cognitive functions that may be involved in the imagery task in this study. One framework for the role of the prefrontal cortex suggests that it may be involved in the organization and manipulation of information that is stored elsewhere in the brain (Shimamura, 1995). These processes include working memory (Goldman-Rakic, 1987), inhibitory modulation of activity in other areas (Knight, Staines, Swick, & Chao, 1999), and other executive functions (see Jonides & Smith, 1997). Of particular interest, activity has been observed in the left inferior prefrontal cortex during several semantic processing tasks with words (e.g., Binder et al., 1997; Demb et al., 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1988) as well as with pictures (Vandenberghe, Price, Wise, Josephs, & Frakowiak, 1996). Decreased activation (i.e., priming) of this area has also been reported during repeated semantic processing of the same words (Demb et al., 1995) or pictures (Wagner, Desmond, Demb, Glover, & Gabrieli, 1997). It has been hypothesized that activation of the left inferior prefrontal cortex reflects activity in a system involved in semantic working memory. Specifically, this area may be activated when information must be held in working memory during the selection of semantic items from among competing alternatives to answer a particular question (Gabrieli, Poldrack, & Desmond, 1998; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). The anterior N700 concreteness effect observed in the imagery task may reflect a similar working memory phenomenon. In this case, mental images would be held in working memory in order to make the imageability judgment. Words that are highly imageable would require more of this working memory resource than words that are nonimageable. Therefore, concrete words should activate this working memory resource more than abstract words and in turn should elicit a larger N700. If true, this study would be the first to demonstrate a time course for image-related working memory.

In summary, the results of the current experiment demonstrated that (1) postlexical semantic processing was necessary to produce both behavioral and ERP concreteness effects, and (2) at least two endogenous ERP components were modulated by tasks requiring higher-level cognitive processing of concrete and abstract words. First, there was a widespread and extended N400 in both the imagery and semantic conditions that was sensitive to concreteness. This N400 effect may reflect activation in a linguistic semantic system that is common to concrete and abstract words. Second, there was a frontally distributed N700 that was also sensitive to concreteness but which was most evident in the imagery task. This N700 effect may represent activation in a mental imagery subsystem that is relatively more available to concrete words than to abstract words. This imagery mechanism may involve activation in an information lookup system or in a working memory system. Future functional neuroimaging studies will attempt to distinguish between these mechanisms and determine the precise cortical regions involved when they are invoked. Finally, the results of this study support the extended dual-coding hypothesis that superior associative connections in a common linguistic semantic system and the use of mental imagery both contribute to cognitive processing advantages for concrete words over abstract words.

METHODS

Subjects

Thirty-six right-handed undergraduate students (21 female) from Tufts University aged 18 to 23 (mean: 19) served as subjects. Selection criteria required subjects to have learned English as their first language and to have normal or corrected-to-normal vision. Subjects received course credit for their participation. Fifteen subjects had at least one left-handed relative in their immediate family.

Stimuli and Procedures

Target words were acquired from the MRC Psycholinguistic Database version 2 (Oxford Text Archive, Oxford, UK). Ratings were also obtained from this database. Forty concrete (e.g., *spider*, *violin*, *umbrella*) nouns [rated 6.00–6.46 on a 7-point scale (mean: 6.16 ± 0.13) for concreteness] and forty abstract (e.g., *greed*, *equality*, *chaos*) nouns [rated 2.39–3.49 (mean: 2.93 ± 0.35) for concreteness] were selected as targets. Concrete and abstract words were equated for length [3 to 9 letters (concrete: 6.05 ± 1.32; abstract: 6.25 ± 1.75)], frequency [0–34 occurrences per million on the Kucera and Francis (1967) written frequency count (concrete: 9.07 ± 8.24, abstract: 9.68 ± 7.34)], and familiarity [rated 3.27–5.98 on a 7-point scale (concrete: 5.12 ± 0.40; abstract: 4.73 ± 0.56)].

Subjects were randomly assigned to one of three experimental conditions: (1) imagery, (2) semantic, and (3) surface. For the imagery group, the task required subjects to try to form a mental image of each target word. Target words were comprised of 40 concrete words and 40 abstract words. The target word was the final word in a sentence that the subjects were required to judge as either true or false. Subjects were presented with a total of 80 sentences. The form for 40 of these sentences (20 with concrete targets, 20 with abstract targets) was positive (e.g., "It is easy to form a mental picture of an elephant.") and for the other 40 was negative (e.g., "It is difficult to form a mental picture of an aptitude.") in order to make the task a little more difficult to ensure that the subjects remained engaged and interested in the task. This also allowed for counterbalancing of "yes" and "no" responses. Similarly, 40 sentences (20 with concrete targets, 20 with abstract targets) were true and 40 were false (assuming that all concrete words are imageable and all abstract words are not imageable). Thus, subjects were presented with eight sentence types: (1) concrete positive true, (2) concrete negative true, (3) concrete positive false, (4) concrete negative false, (5) abstract positive true, (6) abstract negative true, (7) abstract positive false, (8) abstract negative false. Target words were counterbalanced across subjects so that each target word was tested in each type of context.

For the semantic group, the task required subjects to process the meaning of the target word, but did not encourage the use of mental imagery. Target words consisted of the same 40 concrete and 40 abstract words used in the imagery condition. Also, as in the imagery condition, target words were presented at the end of sentences that subjects had to judge as either true or false (e.g., "It is common/unusual for people to have an elephant/aptitude."). Sentences were balanced as to concrete/abstract target, positive/negative, and true/false resulting again in eight sentence types. Target words were counterbalanced across subjects so that each target word was tested in each type of context.

For the surface group, the task was essentially a letter search task requiring subjects to process only the surface characteristics of the target word. Again target words consisted of the same words used in the imagery and semantic conditions and were presented at the end of sentences that subjects judged as either true or false (e.g., "There is/is not an 'n' in the word elephant/aptitude."). Sentences were balanced as to concrete/abstract target, positive/negative, and true/false, resulting in eight sentence types, and were counterbalanced across subjects.

The manner of stimulus presentation was identical for all conditions. The sentence stem (i.e., without the target word) appeared on the computer monitor with a plus sign centered below it. Subjects were instructed to read the sentence stem and then focus their gaze on the plus sign. When they felt ready they were to press a button on a response box, causing the sentence stem and plus sign to disappear. After a 500 msec delay the target word appeared in the center of the screen at the location where the plus sign had been and remained for 500 msec. Subjects were required to make a true/false response to each target word by pressing a button on the response box with either their left or right hand. Response hand was counterbalanced across subjects. After making this decision, the words "Press for next trial" appeared on the screen and remained until the subject pushed a button on the response box, at which time the next sentence stem appeared. Thus, the subjects controlled the pace at which sentences and targets were shown.

Recording of Event-Related Potentials

Thirteen active tin electrodes held in place by an elastic cap (Electro-Cap International, Eaton, OH) were attached to the scalp (see Figure 5). The electrodes were placed over standard International 10–20 System locations along the midline of the head [frontal (Fz), central (Cz), and parietal (Pz)] as well as four standard lateral sites [left and right frontal (F7 and F8) and occipital (O1 and O2)]. Electrodes were also placed at six nonstandard locations over left and right anterior temporal cortex (BA 22; 50% of the distance from T3/T4 to F7/F8: ATL and ATR), left and right temporal cortex (BA 42; 33% of the interaural distance lateral to Cz: TL and TR), and left and right temporo-parietal cortex (Wernicke's area and its right hemisphere homologue; 30% of the interaural distance lateral to a point 13% of the nasion–inion distance posterior to Pz: TPL and TPR). Electrodes

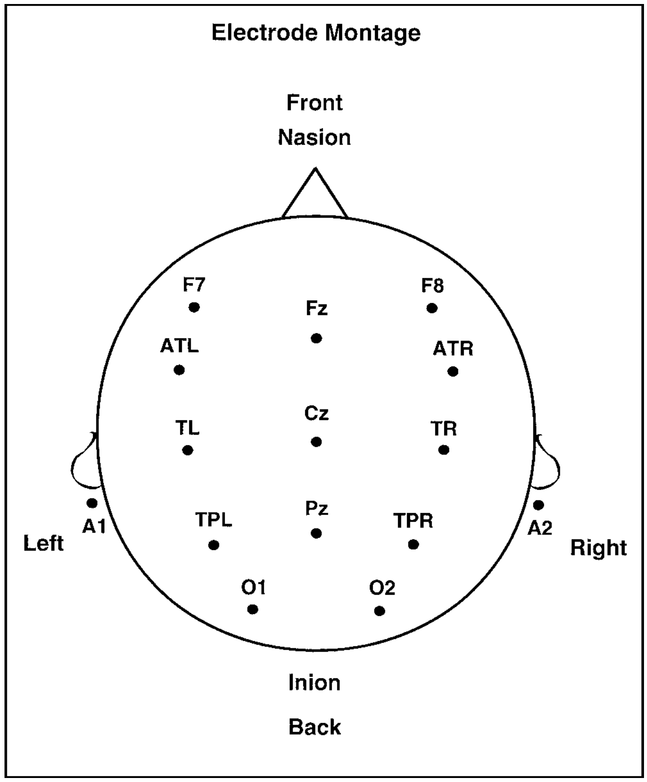

Figure 5. Montage of electrode placements on the scalp. A1 is the left mastoid reference electrode. A2 is the right mastoid recorded site.

were also placed below the left eye and beside the right eye to monitor vertical and horizontal eye movements. All active electrodes were referenced to an electrode placed on the mastoid bone behind the left ear. The right mastoid was actively recorded to detect any asymmetry between the mastoids or any significant activity at these sites. The EEG signal was amplified by a Grass Model 12 Neurodata Acquisition system with a bandpass of 0.01 to 100 Hz (3 dB cutoff) and was continuously sampled at 200 Hz by an analogue-to-digital converter. The stimuli presented to the subject and the subject's behavioral responses were simultaneously monitored by the digitizing computer. Average ERPs were formed off-line from trials free of ocular and muscular movements and the resulting data was filtered with a 20-Hz low-pass digital filter.

Data Analysis

The averaged ERPs were quantified by calculating mean amplitude values (relative to a 100 msec prestimulus baseline) for the voltage points in two latency windows (300–550 and 550–800 msec). Analyses of variance (ANOVAs) for repeated measures, having two levels of *word-type* (concrete vs. abstract) and grouped between-subjects by *task* (imagery vs. semantic vs. surface), were then performed. ERPs for midline and lateral sites were analyzed in separate ANOVAs. In addition to the aforementioned factors, midline site analyses included a factor of *electrode-site* (Fz vs. Cz vs. Pz); lateral site analyses included an *electrode-site* factor (frontal vs. anterior temporal vs. temporal vs. temporo-parietal vs. occipital) and a *hemisphere* factor (left vs. right). In cases with a significant main effect or interaction, planned contrasts were performed. In addition, separate ANOVAs for each individual group were performed to identify differences between the three groups. The Geisser–Greenhouse correction (Geisser & Greenhouse, 1959) was applied to all repeated measures with greater than one degree of freedom. Also, interaction effects involving electrode-site or hemisphere were interpreted only after normalizing (*z* score transformation) the data (McCarthy & Wood, 1985).

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Notes

1. This assumption is based on the spatial distinctiveness principle (Holcomb et al., 1999), which states that two or more different cognitive systems will tend to be more spatially distinct within the brain than will a single cognitive system. As a result, activation (e.g., by concrete and abstract words) of different systems will produce spatially distinct patterns of electrical activity at the scalp, while activation of a single system will produce electrical activity with similar spatial distributions.
2. By manipulating levels of cognitive processing, task difficulty is also varied (by definition). Therefore, overall differences between groups could be construed as resulting from a general effect of increased task difficulty. Effects of task difficulty should not, however, account for patterns of behavioral and ERP effects of word type that are different across tasks.
3. Although determination of surface characteristics of words in the surface task may elicit some "orthographic imagery," this type of imagery would not be expected to have the same properties or time course as in the imagery task and should not differ for concrete and abstract words.
4. Farah used the active cephalic site, FPz, as the reference electrode. Referencing to FPz, located at the front of the head, essentially cancels out any common activity at frontal sites and enhances activity of opposite polarity at posterior sites. The current study employed the more commonly used and relatively less active left mastoid bone as the reference site.

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