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Concreteness Effects in Semantic Processing: ERP Evidence Supporting Dual-Coding Theory

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Dual-coding theory argues that processing advantages for concrete over abstract (verbal) stimuli result from the operation of 2 systems (i.e., imaginal and verbal) for concrete stimuli, rather than just 1 (for abstract stimuli). These verbal and imaginal systems have been linked with the left and right hemispheres of the brain, respectively. Context-availability theory argues that concreteness effects result from processing differences in a single system. The merits of these theories were investigated by examining the topographic distribution of event-related brain potentials in 2 experiments (lexical decision and concrete-abstract classification). The results were most consistent with dual-coding theory. In particular, different scalp distributions of an N400-like negativity were elicited by concrete and abstract words.

People find concrete verbal materials easier to process than abstract verbal materials. This assertion has been substantiated by a large number of studies using a variety of experimental tasks including recall, lexical decision, sentence comprehension, and sentence verification (for recent reviews, see Paivio, 1991; Schwanenflugel, 1991). However, despite these efforts consensus on a definitive explanation for this phenomenon remains elusive. The present study therefore reexamines one part of this global issue, specifically, the semantic processing of concrete and abstract words using an alternate experimental methodology, the measurement of event-related brain potentials (ERPs).

Dual-Coding Theory

There are two major theories that claim to be the definitive explanation for concreteness effects: dual-coding theory and context-availability theory.[1] Dual-coding theory argues that there are two separate processing systems: one verbal and one image based (Paivio, 1986, 1991). These two hypothesized systems are functionally distinct, yet interconnected such that the activation of a representational unit in one system can referentially (i.e., indirectly) activate the corresponding representational unit in the other system. The two systems are also thought to apply different processing mechanisms to these fundamentally different verbal and imaginal representations. Within this framework, Paivio argued that concrete words are processed by both systems, whereas abstract words are processed primarily by the verbal system. It is the hypothesized presence of two sets of processes and representational codes (verbal and imaginal) for concrete words that results in enhanced performance for these items.[2]

As mentioned previously, there is a substantial experimental literature aimed at exploring the merits of dual-coding theory. There are a number of apparently contradictory findings (reviewed by Schwanenflugel, 1991), and many of the relevant articles make rather strong claims concerning the empirical support for their respective positions. Of particular relevance to the work to be reported here are two recent reaction time (RT) studies that used semantic priming tasks.

Bleasdale (1987) focused on the dual-coding claim of separate memory stores for concrete and abstract words. He reported that concrete words preferentially prime semantically related concrete words and that abstract words preferentially prime semantically related abstract words (controlling for associative strength), which he argued is consistent with the existence of separate lexical stores for the two word types.

Using a somewhat different approach, Chiarello, Senehi, and Nuding (1987) attempted to determine the locus of concreteness effects during word recognition. Paivio (1986) suggested that the hypothetical verbal system may be located in the left hemisphere and the hypothetical imagery system may be located in the right hemisphere. If this is true, and if information about abstract words is stored only in the verbal system while information about concrete words is stored in both systems, then dual-coding theory predicts that larger differences between the processing of concrete and abstract words should occur in the right hemisphere than in the left.

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[1] A third approach, the age-of-acquisition hypothesis (Gilhooly & Gilhooly, 1979), has been extended to explain concreteness effects as being cumulative word-frequency effects. Specifically, children tend to learn concrete words before they learn abstract ones, resulting in greater cumulative exposure to concrete words. It is this greater exposure that supposedly makes concrete words easier to process (Brown & Watson, 1987; Coltheart, Laxon, & Keating, 1988; for a recent review, see Schwanenflugel, 1991).

[2] Dual-coding theory has also been used to explain differences in the processing of semantic attributes of pictures and words (e.g., Paivio, 1986). This aspect of dual-coding theory has also been controversial (e.g., Holcomb & McPherson, 1994; Kroll & Potter, 1984).

Chiarello et al. explored this notion by means of a lexical decision priming experiment in which the primes were presented at a central fixation point while the targets were presented in either the left or right visual fields (left visual field information being processed by the right hemisphere, right visual field information being processed by the left hemisphere). Under conditions in which priming was presumed to be influenced only by automatic spreading activation (i.e., a low proportion of related trials) there were no visual field differences for the two word types. However, under conditions in which relatively controlled processing was thought to be operating (i.e., a high proportion of semantically related trials), there was a larger difference between concrete and abstract words for left visual field (right-hemisphere) presentations. Because priming that is due to controlled processing is thought to occur after lexical access, Chiarello et al. concluded that the hemispheric differences in the processing of concrete and abstract words arise in a postlexical semantic integration stage.

Although the findings from the Bleasdale (1987) and Chiarello et al. (1987) studies would appear to be consistent with dual-coding theory, both of these studies have a number of methodological problems. These include a mixture of different prime-target semantic relations, with the blend of relations being different for the concrete and abstract conditions; a neutral prime (i.e., "BLANK") that has not been demonstrated to be neutral along the dimensions of concreteness or imageability; and relatively high (Chiarello et al.) and variable (both studies) error rates that render interpretation of the critical RT data ambiguous (Link, 1982).[3] All of these problems suggest that the conclusions of these studies must be viewed with caution.

The Context-Availability Model

The other major theory proposed to explain concreteness effects is the context-availability model (Bransford & McCarrell, 1974; Kieras, 1978), which depicts comprehension as heavily reliant on contextual support provided by either the stimulus or the subject's own knowledge base. According to this theory, abstract words presented in isolation need this contextual support more than concrete ones, because they are inherently more vague or ambiguous and are consequently harder to process. Differences in the processing of abstract and concrete materials are not due to the operation of separate processing systems or qualitatively different types of knowledge representations. Instead, such effects result from the lack of built-in contextual support present in abstract stimuli. Therefore, in contrast to dual-coding theory, context-availability theory can best be characterized as a single-code account of concreteness effects.[4]

The main empirical support for the context-availability interpretation of concreteness effects in semantic processing can be found in the work of Schwanenflugel and colleagues (Schwanenflugel, Harnishfeger, & Stowe, 1988; Schwanenflugel & Shoben, 1983; Schwanenflugel & Stowe, 1989). Schwanenflugel reasoned that if the context-availability explanation is correct, then explicitly providing an otherwise deficient supportive context should eliminate concreteness effects on RT. This is, in fact, what was generally found (Schwanenflugel et al., 1988; Schwanenflugel & Shoben, 1983; Schwanenflugel & Stowe, 1989) using a variety of experimental tasks and stimulus materials. Furthermore, it was reported that multiple regression analyses showed rated context availability to be a slightly better predictor of RT than rated concreteness.

However, as is the case with research supporting dual-coding theory, there are a number of questions concerning these studies. Here we briefly discuss two points, one conceptual and one methodological. First, the fact that the manipulation of context can diminish or reduce concreteness effects on RT may only mean that concreteness and context availability are distinct factors that influence at least one stage or process in common (e.g., the additive factors method, Sternberg, 1969); it does not necessarily imply that one factor is reducible to the other. For example, providing an appropriate context may help subjects to predict a subsequent stimulus word. This predictability afforded by context could supersede or circumvent the hypothetical natural advantage that characterizes concrete words, thus eliminating observable concreteness effects. Therefore, the effects of context manipulation may only obfuscate (i.e., interact with) the behavioral consequences of dual coding rather than disprove dual-coding theory.

Second, the somewhat higher correlations obtained by Schwanenflugel et al. (1988) between rated context availability and RT than between rated concreteness and RT cannot be used as a basis for inferring that context availability is the more potent factor without knowing at least two things: (a) that their

[3] There were a number of other methodological problems in these two studies. In the Bleasdale (1987) experiments, variable, subject-controlled (and unreported) priming intervals were used (Experiment 1) and concrete stimuli that are arguably rather abstract (e.g., *machine, ritual, leader, series, mad, old, plain, live, gore, motion, game*) were included. In the Chiarello et al. (1987) experiments another potential problem was in the lateralized presentation method used. Their data show a speed and accuracy advantage for responses to stimuli presented to the right visual field. This may have been due simply to superior left-hemisphere language skills. However, a more problematic possibility is that their subjects may not have been attending to the two visual fields equally. This could have been due to the fact that English is normally read from left to right, or because the first letter of each right-visual-field word was located closer to the fixation point than the corresponding letter of each left-visual-field word. Whatever its cause, a general shift of attention from the left to the right visual field could have interacted with the normal processing advantage for concrete stimuli, thereby accentuating the concrete-word advantage for the left visual field (i.e., right hemisphere). Furthermore, their subjects responded by pressing buttons with the index and middle fingers of the right hand only. Because the right hand is controlled by the left hemisphere, this could have put even greater demands on the attentional capacity available for left-hemisphere processing, further complicating comparisons between the visual fields.

[4] Although it may not be difficult to turn context availability into a dual-coding-like model (e.g., by making sentence and word level context effects result from different processes or structures), Schwanenflugel and colleagues (e.g., Schwanenflugel et al., 1988) have steadfastly argued against this. Therefore, in this article we will assume context availability to be a strong single-coding theory of concreteness effects.

rating procedure assessed concreteness and context availability with equal measurement error, and (b) that the ranges of the measured concreteness and context-availability ratings were equal. Without this information, differences in the correlations between these ratings and RT are difficult to interpret, especially in view of the high correlation obtained between rated concreteness and rated context availability.

The brief review presented above suggests that the relative merits of the dual-coding and context-availability explanations of concreteness effects in semantic processing have not been conclusively decided. The two experiments described in this article sought to shed additional light on this issue through the measurement of ERPs while subjects were engaged in processing individual concrete and abstract words. The rationale for this approach is explained after a brief introduction to relevant aspects of ERP research.

Event-Related Potentials (ERPs)

ERPs are the stimulus-bound portion of the ongoing electroencephalogram (EEG) obtained by averaging the measured electrical activity after multiple comparable stimulus events. This averaging serves to remove "noise" resulting from brain activity not relevant to the processing of the critical stimulus. The result is a waveform exhibiting a series of peaks and valleys known as *components.* The various components are usually referred to by their polarity (positive [P] or negative [N]) and by their order after the stimulus or their latency from stimulus onset. So, P3 is the third positive component, whereas N400 is a negative component peaking about 400 ms after the stimulus. Research has linked many of these components to specific cognitive and neural processes (see Hillyard & Picton, 1987, for an introduction and review).

N400

A number of recent studies have reported effects on a late negative component that onsets as early as 200 ms and peaks at about 400 ms after stimulus onset in response to visually presented words. Kutas and her colleagues (e.g., Kutas & Hillyard, 1980, 1984) demonstrated that the N400 component is larger to words that are anomalous (e.g., "He takes cream and sugar in his *attention*"), and is small or nonexistent to highly probable words (e.g., "He takes cream and sugar in his *coffee*"). In subsequent studies (e.g., Kutas, Lindamood, & Hillyard, 1984), it has been demonstrated that N400 amplitude is a monotonic function of the cloze probability of words in sentences. Specifically, N400 is larger for words that make sense but are less predictable than it is for words that are highly predictable based on the context.

These effects have also been found in studies using pairs of words and nonwords in lexical decision priming experiments (e.g., Bentin, McCarthy, & Wood, 1985; Holcomb, 1988; Holcomb & Neville, 1990) and in studies using simple sentences (e.g., sentence verification: Fischler, Bloom, Childers, Roucos, & Perry, 1983; Kounios & Holcomb, 1992). In general, the N400 to a target item is larger in amplitude when that item is either semantically unrelated to the prior context or is not an actual word.[5] However, in the case of nonwords, only those that follow the orthographic and phonological rules of the language generate large N400s (e.g., Holcomb & Neville, 1990). Kounios and Holcomb (1992) also isolated an effect of hierarchical level such that more specific words (e.g., exemplars such as DOG) yielded larger N400s than less specific words (e.g., categories such as ANIMAL). In summary, the body of the N400 literature suggests that this component is a prime candidate for exhibiting semantic effects based on aspects of both individual word meaning (e.g., concreteness) and context.

Two studies have examined the effects of concreteness on ERPs, although this was not the primary focus of either report. Using a concreteness judgment task to study memory, Paller, Kutas, Shimamura, and Squire (1987) found that concrete words were associated with a more negative-going ERP between 200 and 800 ms than were abstract words. However, they did not suggest a reason for such a difference nor did they identify the specific ERP component affected. Smith and Halgren (1987) used a lexical decision task and compared the ERPs of high- and low-frequency concrete and abstract words in a repetition priming paradigm. They reported that whereas low-frequency words generated a larger N400 than high-frequency words, there were no significant differences in the ERPs to concrete and abstract items. One possible reason for this null effect of concreteness may have been due to Smith and Halgren having used only 16 words of each type (usually 30 to 40 items are needed in ERP studies). This required that they collapse across the frequency variable, repetition variable, or both to look at concreteness. As will be evident in Experiment 1, repetition has a substantial impact on ERP concreteness effects.

Rationale

Time-course data provided by the ERP technique offer a form of evidence that is different from and complementary to the standard RT results on which most of the literature on the semantic processing of concrete and abstract materials is based. Such data can potentially clarify this issue by providing a window on to both semantic memory structures and processes (Kounios & Holcomb, 1992; see also Kounios, 1993, 1994; Kounios, Osman, & Meyer, 1987). The present study focuses on the structural question.

The essential feature of dual-coding theory is that there are separate verbal and imaginal processing systems, each operating on its own form of knowledge representation. On the basis of various neuropsychological syndromes (e.g., deep dyslexia, see Coltheart, 1980), this view has been extended to include the notion that these hypothetical systems are anatomically distinct and that they can be specifically identified with the left

[5] The N400, particularly if there is a button-pressing response to the eliciting stimulus, is usually superimposed on a positive ERP component (the P3 or P300) and therefore is only a "negative" voltage relative to the surrounding positive peaks. In this case the N400 is referred to as a *negative-going potential.* This reflects the polarity direction of the peak rather than the actual voltage that might actually be positive relative to a prestimulus baseline.

and right hemispheres (e.g., Paivio, 1986, chap. 12). If this is true, then one reasonable prediction might be that ERPs measured in response to concrete and abstract words would exhibit some form of distributional difference over various scalp locations. For instance, if only concrete words are processed in a right-hemisphere system, while both concrete and abstract words are processed by a left-hemisphere system, then one might predict greater ERP (e.g., N400) differences between concrete and abstract words over the right hemisphere than over the left. The topography of relevant ERP components might therefore provide evidence of separate neural and, by implication, cognitive structures.

Interpretation of ERP Topography

The interpretation of lateralized ERP components has had a rather controversial history. This has been partly due to the fact that determining the spatial relationship between scalp-recorded electrical activity and the underlying neural generators responsible for this activity is not a straightforward matter (see Nunez, 1981). For example, the measured amplitude of an ERP component could be greatest over, say, the right side of the head, thereby suggesting that the underlying neural generator is located in the right hemisphere. However, it could be the case that the generator is actually located in the left hemisphere, but that its spatial orientation is such that it "points" at the scalp on the right side of the head (Coles, 1989, discusses such an example).

Therefore, a clear-cut finding of right–left concreteness differences would be consistent with the neuropsychological literature, although we could not be certain that such ERP differences would precisely correspond to the hypothesized lateral structural differences. Similarly, ERP effects other than the desired right–left differences could, in principle, result from the hypothesized right–left hemisphere effect or from some other as yet unspecified anatomical arrangement. Fortunately, this indeterminacy is not problematic for the general argument concerning structure, because any clear topographic difference between the processing of concrete and abstract words would support dual-coding theory over single-coding theories such as the context-availability model. This is because such data would support the general structural claims of dual-coding theory that there are anatomically distinct imagery and verbal processing systems. Furthermore, it would be difficult to reconcile a finding of distinct topographical distributions for concrete and abstract words with context-availability theory without essentially turning it into a dual-coding theory. On the other hand, a failure to find distinctly different topographic distributions for the two word types would be more consistent with a single-code account of concreteness effects such as the context-availability model, although such a finding would be based on a null result and would therefore be a somewhat weaker conclusion.

Two experiments are described below. In Experiment 1, we examined ERPs and RTs to concrete and abstract words and pseudowords in a lexical decision task. In Experiment 2, we used only words in a concreteness judgment task. The primary goal of these experiments was to determine whether the topographic distribution of ERPs is consistent with a structural (e.g., dual-coding) interpretation of concreteness effects. Failure to find such evidence would provide some support for a nonstructural account, such as the context-availability model. The presence of such evidence would weigh against the context-availability model as an exclusively (i.e., strong) nonstructural interpretation of concreteness effects.

Experiment 1

A study by James (1975) was one of the first lexical decision experiments to report an RT advantage for concrete over abstract words. He demonstrated that when random letter strings were used for nonwords, and concrete and abstract items were used for words, the difference between the RTs to concrete and abstract words was not significant. To obtain a concreteness effect, wordlike nonwords (i.e., pseudowords) had to be used. This suggested to James (1975) that only when the distractor items resembled real words did subjects tap semantic (concreteness) information in making their lexical decisions. In his final experiment, James also showed that the concreteness effect could be attenuated by allowing subjects to preview the concrete and abstract words just prior to the experiment. This suggests that item repetition interacts with the concreteness effect in a manner similar to that produced by contextual manipulations (e.g., Schwanenflugel & Stowe, 1989), although this can only be inferred by comparing results across experiments. A more recent study by Kroll and Merves (1986) also compared lexical decisions for concrete and abstract words. Although concrete words elicited slightly faster responses in all three of their experiments, the difference was statistically reliable only when presentation of items was blocked such that concrete words were presented prior to abstract words.[6]

The current experiment was similar to the design used by James (1975, Experiments 1 and 3) and Kroll and Merves (1986, Experiment 2). We were interested in determining the following: (a) whether the RT differences between concrete and abstract words shown by James and by Kroll and Merves could be replicated and extended to the N400 component of the ERP; (b) whether the N400 (and other ERP components) would yield different scalp distributions for concrete and abstract words; (c) whether the pattern of concreteness effects (RT and ERP) seen after the first presentation of items would be reduced after a second presentation; and (d) whether wordlike nonwords formed from concrete and abstract real words would show concreteness effects similar to those seen for words.

[6] In Kroll and Merves's (1986) first experiment, concreteness was a between-subjects variable with only 8 subjects per group. Evidence that this weak statistical comparison was at the heart of their failure to find a significant concreteness effect can be seen in their item analysis, in which concreteness was highly significant ($p < .001$). In their second experiment, concreteness was a within-subject variable and here the difference was significant for both items and subjects (but not min F). However, when concreteness effects were examined separately for high- and low-frequency words, a conservative post hoc procedure showed that it was the low-frequency items that differentiated the two word types.

The last two items are worth additional comments. First, Rugg (1990) and others (e.g., Smith & Halgren, 1987) demonstrated that word repetition produces changes in the ERP that are similar to those produced by semantic contextual manipulations. In particular, the N400 has been shown to be larger both to initial presentations of words and to words presented without a supportive semantic context, but is smaller both to subsequent presentations of words and to words within congruent semantic contexts. One possibility for this similarity between semantic and repetition priming is that repetition produces its effects on the N400 by means of a reactivation of some aspect of the context under which the word was originally presented. In other words, word repetition might be thought of as a form of contextual priming (see Rugg & Doyle, in press, for a recent review of the N400 repetition priming literature). We included stimulus repetition as a factor in Experiment 1 to determine whether this type of contextual manipulation interacts with concreteness as predicted by context-availability theory. According to this theory, repetition (context) effects should be larger for abstract words than concrete words. Dual-coding theory, on the other hand, makes no specific predictions with regard to context effects.

Second, the fourth item is particularly important for theories of the functional significance of the N400. As mentioned above, Kounios and Holcomb (1992) suggested that the N400 is sensitive to structural aspects of semantic memory. Other work has expanded on this idea and proposed that the N400 actually reflects the integration of stored semantic information into a higher level representation (e.g., Holcomb, 1993; Rugg, 1987, 1990). If this view is correct, then the presence of a large N400 to pseudowords might be taken as evidence that these items also make contact with semantic information associated with real-word neighbors (e.g., Andrews, 1989). However, there is another possibility. Rugg and Doyle (in press) have argued that the N400 reflects integration at various levels as long as the information to be integrated can form a "unitized code." According to this view, one explanation for why pseudowords generate N400s is that they result in the integration of unitizable orthographic and phonological information. Random-letter strings, which do not generate N400s, do not activate unitizable information and therefore do not provide information to be integrated. The current study has the additional benefit of contributing to this debate because of the two types of pseudowords used. If pseudowords make contact with semantic information associated with real words, then any concreteness effects seen for real words should also be seen, to some degree, with pseudowords derived from concrete and abstract words. If, on the other hand, pseudoword N400s simply reflect the integration of orthographic/phonological information, then differences obtained between abstract and concrete words should not be seen for their pseudoword counterparts.

Method

Subjects. Twelve volunteers (5 women and 7 men) from the Tufts University community between 19 and 30 years of age ($M = 21.8$) participated in the study. All were right-handed native speakers of English with normal or corrected-to-normal visual acuity. Five subjects had at least one left-handed relative in the immediate family (brother, sister, mother, or father; see Kutas, Van Petten, & Besson, 1988).

Stimuli and procedure. The stimuli for this experiment were selected from a master list of 320 letter-strings (3 to 10 letters in length), 160 of which were actual English words and 160 of which were the same words selectively altered by one letter to form pronounceable pseudowords. From this master list, four sublists of 160 items were formed (A1, A2, B1, and B2). Each sublist contained 40 concrete words (e.g., TABLE; mean concreteness rating of 6.30 on a 1- to 7-point scale, Toglia & Battig, 1978), 40 abstract words (e.g., JUSTICE; mean concreteness rating of 2.61), 40 pseudowords formed from concrete words (e.g., TEBLE), and 40 pseudowords formed from abstract words (e.g., JASTICE). There were no significant differences in word frequency between the concrete and abstract items ($F < 1$; $M = 71$ and 70, respectively, Francis & Kucera, 1982), and there were no significant differences in word length ($F < 2.6$; both $M = 5.8$ letters). Items were assigned to sublists such that those used as words in the two A sublists served as pseudowords in the B sublists, and the pseudowords from the A sublists were the words in the B sublists. Sublists A2 and B2 contained the same items as A1 and B1 (respectively), but the arrangement of items had a different pseudorandom order. Subjects were presented with one sublist of 160 stimuli (e.g., A1) in one block of trials and, after a 2-min break, were presented with the same 160 items, but from the other sublist (e.g., A2) in a second block of trials. The 12 subjects were randomly divided into four subgroups of 3 subjects and each subgroup was presented with a different pair of lists (A1–A2, A2–A1, B1–B2, or B2–B1). As a result of this arrangement, the following occurred: (a) across subjects, each concrete and abstract word from the original master list appeared an equal number of times as both a word stimulus and as a pseudoword stimulus; (b) each subject saw every item (as either a word or pseudoword, but not both) exactly once per block; and (c) the repetition of items in Block 2 was in the same form (i.e., word or pseudoword) as it was in Block 1.

A trial consisted of a single target letter-string presented in uppercase letters at the center of a computer monitor and proceeded as follows. After an intertrial interval (ITI) of 3 s, subjects were alerted to the beginning of a new trial by the disappearance of the word *blink* from the center of the display monitor. Five-hundred milliseconds later, a target letter-string was displayed for 300 ms. Subjects were instructed to rapidly and accurately press (with one thumb) a button labeled *yes* to indicate that the stimulus was an actual English word or to press another button labeled *no* (with the other thumb) to indicate it was not. The hand used for each type of response was counterbalanced across subjects. Subjects were not told about the presence of the concrete and abstract words. Fifteen-hundred milliseconds after the onset of the target item, the word *blink* was displayed (in lowercase letters) to signal that it was permissible to blink and move one's eyes. Subjects were asked to refrain from moving (except for the button-pressing response) or blinking during the critical phase of each trial, defined as the period from *blink* offset to *blink* onset (i.e., approximately 2 s per trial). The two blocks of trials lasted approximately 10 min each (including three short breaks after every 40 trials). The order of items in the second block was different from that of the first block, pseudorandomized to prevent subjects from predicting the occurrence of specific items. No item was repeated (i.e., across a block boundary) without at least 28 intervening items and a 2-min interblock rest break (the average time between repetitions was 12 min). A 20-trial practice run preceded the first experimental block.

EEG procedure. Tin electrodes (Electro-Cap International, Eaton, OH) were placed at several scalp sites, over the right mastoid bone, below the left eye, and to the right of the right eye, and all were referenced to the left mastoid. The scalp sites included standard International 10–20 System locations along the midline of the head (frontal [Fz], central [Cz], and parietal [Pz]) and over four lateral sites (occipital left [O1] and right [O2], frontal left [F7] and right [F8]). Six electrodes were also placed at nonstandard locations over left and right temporo-parietal cortex (30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz: WL and WR), left and right temporal cortex (33% of the interaural distance lateral to Cz: TL and TR), and left and right anterior temporal cortex (50% of the distance from T3/4 to F7/8: ATL and ATR).

The EEG was amplified with Grass Model 12 amplifiers (3 dB cutoffs at .01 and 100 Hz) and was digitized on-line at 200 Hz. Average ERPs were formed (off-line) from correct-response trials free of ocular and movement artifacts. (The average artifact rate was less than 10% across conditions.) This resulted in eight separate ERPs for each of the 13 scalp sites.

Data analysis. The approach to statistical analysis involved the use of a global within-subject analysis of variance (ANOVA) with two levels of block (1 vs. 2), two levels of stimulus type (concrete vs. abstract), and two levels of lexicality (word vs. pseudoword). These were followed in certain cases (in which specific predictions were made) by analyses contrasting the blocks and stimulus types separately. The Geisser–Greenhouse correction (Geisser & Greenhouse, 1959) was applied to all repeated measures containing more than one degree of freedom in the numerator.

The ERP data were quantified by calculating the mean amplitudes (relative to a 100 ms prestimulus baseline) in three latency windows (150 to 300, 300 to 500, and 500 to 800 ms). These windows were chosen because they correspond to the latency ranges of the P2, N400, and P3 waves reported in previous language studies (see Kutas & Van Petten, 1988). Although neither dual-coding nor context-availability theory make any firm empirical predictions concerning ERP components other than N400, analyses of the P2 and P3 time windows were included for the sake of completeness and to look for repetition effects that have been reported in earlier and later epochs (e.g., Rugg, 1987, 1990). The peak amplitude of the N400 component (the most negative point between 300 and 500 ms) was also calculated (see below). ERPs from midline and lateral sites were analyzed in separate ANOVAs. In addition to the block, stimulus type, and lexicality factors, lateral site ERP analyses included the factors of electrode site (occipital vs. Wernicke's vs. temporal vs. anterior-temporal vs. frontal) and hemisphere (right vs. left); midline site analyses included an electrode factor (Fz vs. Cz vs. Pz).

Finally, McCarthy and Wood (1985) pointed out a problem for studies designed to examine hypotheses about differences in underlying neural generators of ERP components using the ANOVA model. The problem arises in the case of an interaction between a distributional variable (e.g., electrode site or hemisphere) and a second independent variable of interest (e.g., concrete vs. abstract words). The presence of such interactions is usually taken as evidence for the existence of activity in different underlying neural populations across the levels of the second variable. However, McCarthy and Wood pointed out that there are cases in which a single neural source (component) might produce such an interaction as a result of multiplicative differences in source strength across the levels of the second variable (note that the ANOVA model assumes additivity). To circumvent this problem, we followed all significant ANOVA interactions involving scalp variables (viz., hemisphere and electrode site) with a second set of analyses in which the data were normalized using a procedure similar to that recommended by McCarthy and Wood. The technique involved converting the amplitude data to *z* scores separately for each level of the critical independent variable (e.g., word type) across the levels of the scalp variable (Rösler, Putz, Friederici, & Hahne, 1993). Following this transformation, follow-up ANOVAs were run. Note that whereas this procedure controls for the multiplicative problem, it cannot be used in place of the conventional amplitude ANOVA as it removes all main effects and interactions not involving scalp variables. Here we report only the conventional ANOVAs, but have noted when significant interactions with scalp variables were not significant after normalization.

Table 1
Reaction Times (RTs; in Milliseconds) and Percentage Correct for Concrete and Abstract Words and Pseudowords in the Lexical Decision Task

	Word		Pseudoword	
Stimulus	Concrete	Abstract	Concrete	Abstract
Block 1				
Mean RT	673	679	763	711
Percentage correct	93	89	93	94
Block 2				
Mean RT	635	649	710	747
Percentage correct	97	95	93	94

Results

RT and accuracy data. Across blocks and stimulus types, subjects responded to real-word stimuli significantly more quickly than to pseudoword stimuli [main effect of lexicality: $F(1, 11) = 33.92, p < .0001, MS_e = 3,818.4$; see Table 1], but were no faster at responding to concrete than abstract items (695 vs. 696 ms; main effect of word type: $F < 1.0$). However, a Stimulus Type × Lexicality × Block interaction indicated that although concrete words were classified as words slightly faster than their abstract counterparts in both trial blocks, concrete pseudowords were classified as nonwords more slowly than were abstract pseudowords in Block 1 and more quickly than abstract pseudowords in Block 2, $F(1, 11) = 13.22, p < .01, MS_e = 738.3$ (see Table 1). This impression was confirmed by simple effects tests looking at words and pseudowords separately. Concrete words were responded to significantly more quickly than abstract words, $F(1, 11) = 8.08, p < .05, MS_e = 146.2$, and this pattern did not change across blocks ($F < 1.0$). However, for pseudowords there were no main effects of stimulus type or block, although there was a significant interaction between these two variables, $F(1, 11) = 13.56, p < .01, MS_e = 1,710.2$. In Block 1, responses to concrete pseudowords were significantly slower than responses to abstract pseudowords, $F(1, 11) = 17.32, p < .01, MS_e = 911.6$, though in Block 2 responses to concrete pseudowords were significantly faster than responses to abstract pseudowords, $F(1, 11) = 7.94, p < .05, MS_e = 1,013.8$.

Subjects were relatively accurate in their responses and there was no overall accuracy difference between the word and pseudoword conditions (93.5% vs. 93.5%). However, subjects were more accurate at classifying concrete words than abstract words, and there was no corresponding difference for pseudowords [Stimulus Type × Lexicality interaction: $F(1, 11) = 6.47, p < .05, MS_e = 1.86$; see Table 1]. Finally, although subjects tended to become more accurate in classifying words in the second block, they did not differ across blocks for pseudowords [Block × Lexicality interaction: $F(1, 11) = 6.01, p < .05, MS_e = 3.06$].

ERP components and scalp distribution. The grand mean ERPs (averaged across all 12 subjects) for concrete words in Blocks 1 and 2 are plotted in Figure 1a. Plotted in Figure 1b, 1c, and 1d are the analogous waveforms for the abstract words, concrete pseudowords, and abstract pseudowords, respectively. Plotted in Figure 2 are the ERPs to concrete and abstract words in Block 1 (Part A) and Block 2 (Part B).

The ERPs in these figures show that there were several early (less than 400 ms) components elicited by all four conditions. They included a broadly distributed early negativity (N1) that peaked around 100 ms at all but the most posterior sites (i.e., O1, O2). At the posterior sites, there was an early positivity between 100 and 150 ms (P1) followed by a later N1 with a peak near 200 ms. At most sites, the N1 component was followed by a positivity between 180 and 300 ms (P2). The P2 actually had two peaks at some locations (Cz, TL, TR) and a clear intervening negativity at Pz.

There were also several later ERP components visible in the waveforms. Following the P2, there was a negative-going wave peaking around 400 ms and exhibiting a broad scalp distribution. As in previous visual studies (e.g., Neville, Kutas, Chesney, & Schmidt, 1987), this wave appeared to be slightly more negative over the left than the right hemisphere.[7] Following this negativity, there was a positive wave that peaked between 525 and 800 ms over central and posterior sites (Figures 1 and 2).

150 to 300 ms. Analyses of this epoch showed that there were differences between the two trial blocks [midline: $F(1, 11) = 5.76$, $p < .05$, $MS_e = 9.51$; lateral: $F(1, 11) = 6.35$, $p < .05$, $MS_e = 8.41$], with the ERPs to the first presentation of items (Block 1) being associated with more negative-going voltages than ERPs to repetitions (Block 2) of these same items.[8] At lateral sites, this repetition effect (i.e., the difference between Blocks 1 and 2) had a more anterior distribution [Blocks × Electrode Site interaction: $F(4, 44) = 4.57, p < .05$, $MS_e = 1.1$]. The only other significant difference was that pseudoword ERPs were more negative-going than word ERPs [midline: $F(1, 11) = 6.91$, $p < .05$, $MS_e = 8.41$; lateral: $F(1, 11) = 7.08$, $p < .05$, $MS_e = 11.21$], but this did not interact with the stimulus type or block variables.

300 to 500 ms. The mean amplitudes for this epoch are reported in Table 2. The effect of repetition (blocks) seen in the previous epoch (i.e., Block 1 more negative than Block 2) continued into the 300 to 500 ms range [main effect of block: midline, $F(1, 11) = 8.94$, $p < .05$, $MS_e = 11.39$; lateral, $F(1, 11) = 16.17$, $p < .01$, $MS_e = 5.34$]. Also, as in the previous epoch, pseudoword ERPs were more negative-going than real-word ERPs [main effect of lexicality: midline, $F(1, 11) = 26.75$, $p < .001$, $MS_e = 19.0$; lateral, $F(1, 11) = 27.59$, $p < .001$, $MS_e = 22.67$]. However, unlike the previous epoch, ERPs to concrete items were significantly more negative-going than ERPs to abstract items [midline: $F(1, 11) = 7.88, p < .05$, $MS_e = 9.44$; lateral: $F(1, 11) = 10.15$, $p < .01$, $MS_e = 11.93$], and at lateral sites this difference was larger at more anterior locations [Stimulus Type × Electrode Site interaction: lateral, $F(4, 44) = 6.24, p < .05, MS_e = 1.19$; see Figure 3].

Figure 2a suggests that there might have been subtle stimulus type differences across the hemispheres, especially to items presented for the first time (Block 1). Specifically, concrete words appeared to be more negative-going than abstract words over the right hemisphere in Block 1, whereas a similar effect was not apparent for the pseudowords. However, none of the important interactions involving the hemisphere variable were significant in the omnibus ANOVA. This might have been partly due to the rather broad temporal range of the mean amplitude measure used to quantify this region of the ERP. Given the importance of this type of effect for the dual-coding hypothesis, an attempt was made to get a more precise measure of the negativity in this time range. This was accomplished by measuring the amplitude of the most negative point between 300 and 500 ms.[9] Also, because Figure 2a suggests that only the real words produced a laterality difference between concrete and abstract items, words and pseudowords were analyzed separately. The ANOVAs on word ERPs revealed a Stimulus Type × Hemisphere × Electrode Site interaction in the first block, $F(4, 44) = 3.35, p < .05, MS_e = .44$, but not in the second block ($F < 1.0$, neither of the pseudoword analyses produced such effects). Follow-up analyses demonstrated that this interaction was due to the concrete words producing a more negative response than the abstract words over the right hemisphere in Block 1, $F(1, 11) = 6.40$, $p < .05, MS_e = 13.48$.

In summary, in the N400 window (300 to 500 ms) the following occurred: (a) concrete items (words and pseudowords) were associated with a more negative-going ERP than abstract items and this difference was larger over more anterior sites for lateral electrodes; (b) pseudowords were more negative-going than words; (c) with repetition, there was a decrement in the negativity in this latency range; and (d) over the right hemisphere, concrete words (but not pseudowords) were more negative-going than abstract words after their first presentation, but not after repetition. However, these latter effects were significant only when more powerful measurements and statistical comparisons were made.

500 to 800 ms. Figures 1 and 2 show that there were similar differences between the various conditions in this time period. Block 1 was more negative-going than Block 2 at the lateral sites, $F(1, 11) = 9.70, p < .01, MS_e = 6.84$, and concrete items were more negative-going than abstract items [midline: $F(1, 11) = 5.97$, $p < .05$, $MS_e = 6.87$; lateral: $F(1, 11) = 4.92$, $p < .05$, $MS_e = 11.76$]. At midline sites, the stimulus type difference was larger for pseudowords than for real words [Stimulus Type × Lexicality interaction: $F(1, 11) = 6.79$, $p < .05, MS_e = 1.85$]. Finally, the difference between concrete

[7] Note that this waveform, although negative-going, was entirely below baseline at most sites. Also note that in the concrete conditions, this wave does not appear to be as asymmetrical across the hemispheres.

[8] The differences between conditions will be referred to as more negative-going and less negative-going. The rationale for this choice (as opposed to more or less positive-going) is the assumption that the waveform being modulated in the 300- to 500-ms time band is a negative potential (N400). For consistency, the same terminology will be used in the other two time bands as well.

[9] In cases in which differences between conditions are maximal near the most negative (or positive) peak of an ERP component, measurement of peak amplitudes will tend to reveal subtle amplitude effects more readily than a mean amplitude measure. However, peak measures are usually not used with relatively broad components (such as the N400) because they only capture activity from a single point and are also more susceptible to noise contamination.

and abstract items appeared to be larger over the right hemisphere for the first presentation (Block 1), but not for the repetition of items [Block × Stimulus Type × Hemisphere interaction: $F(1, 11) = 7.99, p < .05, MS_e = 1.09$]. This observation was confirmed in simple effects follow-up analyses contrasting concrete and abstract items separately for Blocks 1 and 2. In Block 1, there was a significant Stimulus Type × Hemisphere interaction, $F(1, 11) = 4.62, p < .05, MS_e = 2.11$ ($p < .07$ after normalization), but in Block 2, this interaction did not approach significance ($F < 1.3$).

Discussion

RT data. Word stimuli yielded the standard (and expected) pattern of RT effects, namely, that responses were faster and more accurate to concrete words than to abstract words. The results for pseudowords were more complicated. A substantial advantage in RT was obtained for abstract pseudowords in Block 1. However, repetition produced a crossover interaction such that the concreteness effect on RT was reversed for Block 2 (i.e., concrete pseudowords were responded to more quickly).

Although a definitive explanation for these RT results is not possible at this time, there is at least one plausible (though ad hoc) scenario. This explanation makes several assumptions: (a) that semantic and episodic information have opposing influences on pseudowords formed from concrete and abstract words; (b) that semantic information (both concrete and abstract) is used in making lexical decisions such that the more semantic information retrieved in response to a letter string, the more likely it is that the string represents a word (James, 1975); (c) that pseudowords make contact with at least some of the semantic information stored in lexical memory with a corresponding real word (Andrews, 1989); and (d) that concrete concepts have more semantic information stored with them than abstract concepts (de Groot, 1989). In this case, nonword responses to concrete pseudowords should be slower than nonword responses to abstract pseudowords, because the concrete pseudowords will seem more wordlike. This pattern was, in fact, obtained for Block 1. However, this explanation becomes more complicated for the second block and requires the further assumption that the generally quicker RTs obtained in Block 2 resulted, in part, from some memory of the items (both word and nonword) that were presented in Block 1. If concrete items were remembered better than abstract items (see reviews by Paivio, 1986, 1991), then the disadvantage for concrete pseudowords in Block 1 might have been offset by facilitation (evident in Block 2) as a result of enhanced memory for the earlier response to the same item. Similarly, because abstract items are harder to remember, subjects might have responded more slowly to abstract pseudowords in Block 2 because responses to these items were not influenced as much by episodic information from Block 1.

ERP data. Between 300 and 500 ms and between 500 and 800 ms, concrete items were associated with more negative-going ERPs than were abstract items. In the earlier interval, this effect appeared to be modulating a negativity that was similar in latency to the N400 component (e.g., Kutas & Hillyard, 1980). However, continued differences in the later interval, which appeared to modulate a positivity, are not totally consistent with the notion that the difference between concrete and abstract items is solely an N400 effect (see the discussion on distributional differences below).

Attempts to determine whether the concreteness effects were asymmetrical across the hemispheres met with mixed results. A laterality effect for the 300- to 500-ms time window emerged when (a) words were analyzed separately from pseudowords, (b) the analysis was restricted to first presentations of items (i.e., Block 1), and (c) peak rather than average amplitude values were used. Under these circumstances, concrete and abstract words yielded significantly different ERPs over the right hemisphere, but not over the left hemisphere. This finding is consistent with the neuropsychological extension of dual-coding theory (e.g., Chiarello et al., 1987; Coltheart, 1980), if it is assumed that the right-hemisphere ERP difference in this latency range reflects some aspect of the activity in a right-hemisphere system specialized for the processing of concrete concepts (e.g., imagistic or perceptual information). Following this same logic, because both word types can be processed by the left-hemisphere verbal system, there was no difference in this region of the ERP over left-hemisphere sites.

There was also an unanticipated difference between concrete and abstract words in the N400 time window. The difference between the two word types increased in size moving toward more anterior scalp sites (see Figure 3). As N400 effects are most often larger over more posterior regions (see Kutas & Van Petten, 1988), this might be considered additional evidence that the concreteness effect is not specifically modulating the traditional N400 neural generator(s). Interestingly, Neville, Kutas, and Schmidt (1982) also reported a more frontally distributed negativity (N410); however, it was clearly larger over the left hemisphere. In contrast, the larger frontal differences between concrete and abstract words in the current experiment appear to be somewhat larger over the right hemisphere.

Evidence favoring dual-coding theory was stronger in the later interval (500 to 800 ms), where average amplitude values in the omnibus ANOVA and in subsequent follow-up analyses produced significant differences between concrete and abstract words between the hemispheres. As in the earlier latency range, ERPs to the first presentations of items were significantly different for concrete and abstract items over the right hemisphere (i.e., concrete more negative than abstract), but were statistically indiscriminable over the left hemisphere. The major difference between the results from the two time intervals was that this same trend was present for both words and pseudowords in the later interval and it was obtained without resorting to more strenuous measurement and statistical procedures. However, there was also a difference between the intervals with regard to the scalp distribution of the concreteness effect. Although the 300- to 500-ms epoch produced an increasingly larger effect moving toward anterior sites (see Figure 3), the 500- to 800-ms epoch produced effects of a similar size at all but the occipital sites (i.e., the later effect was more evenly distributed).

As in several previous ERP studies using the lexical decision task, wordlike nonwords generated larger negative-going poten-

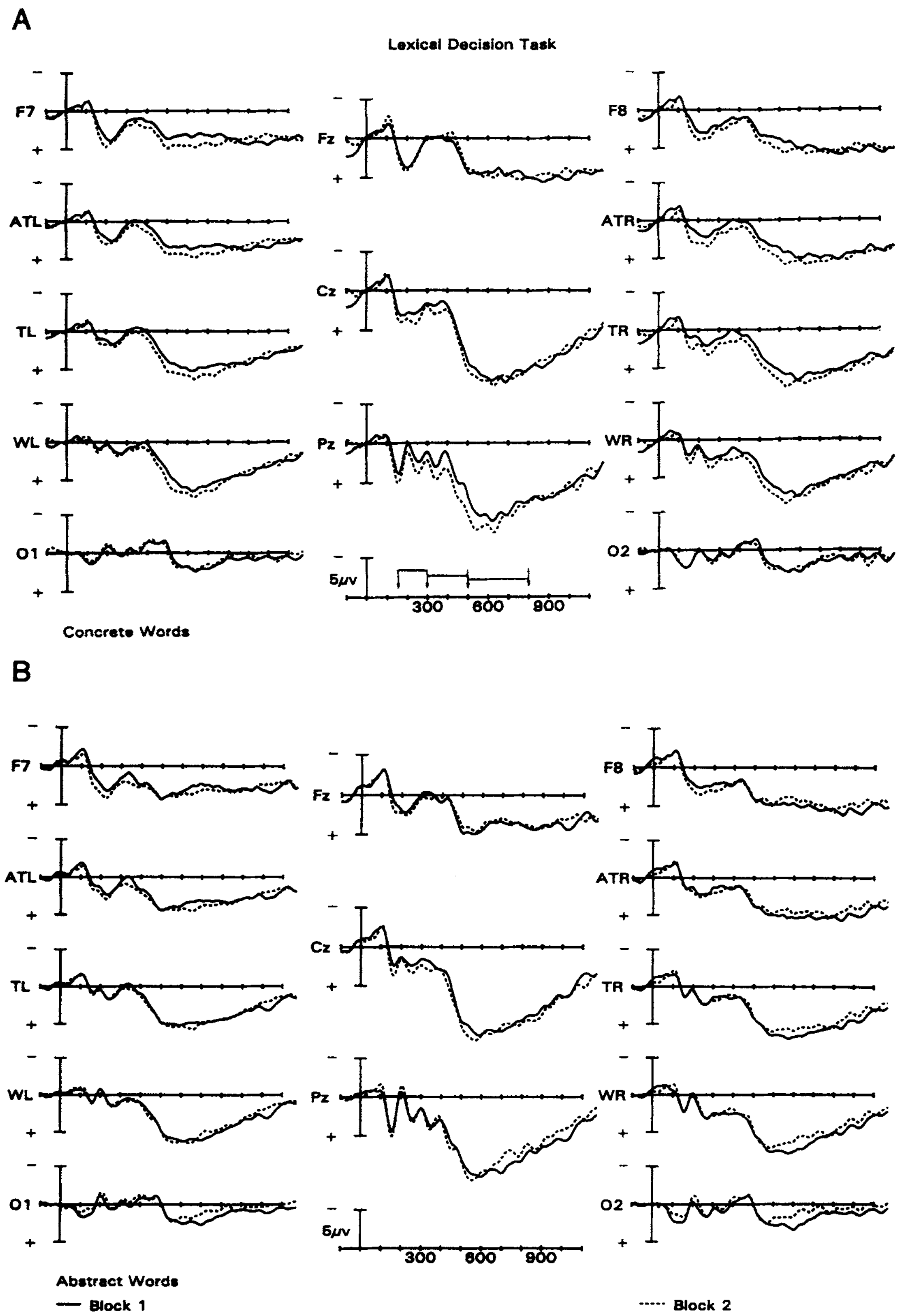
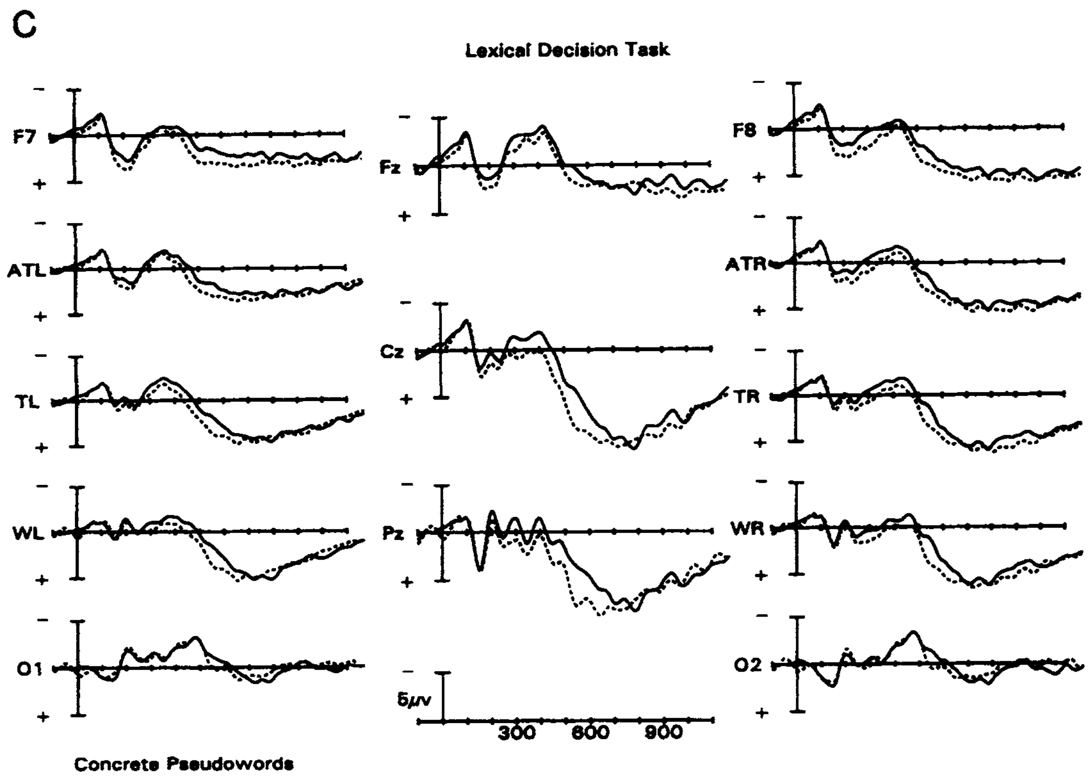
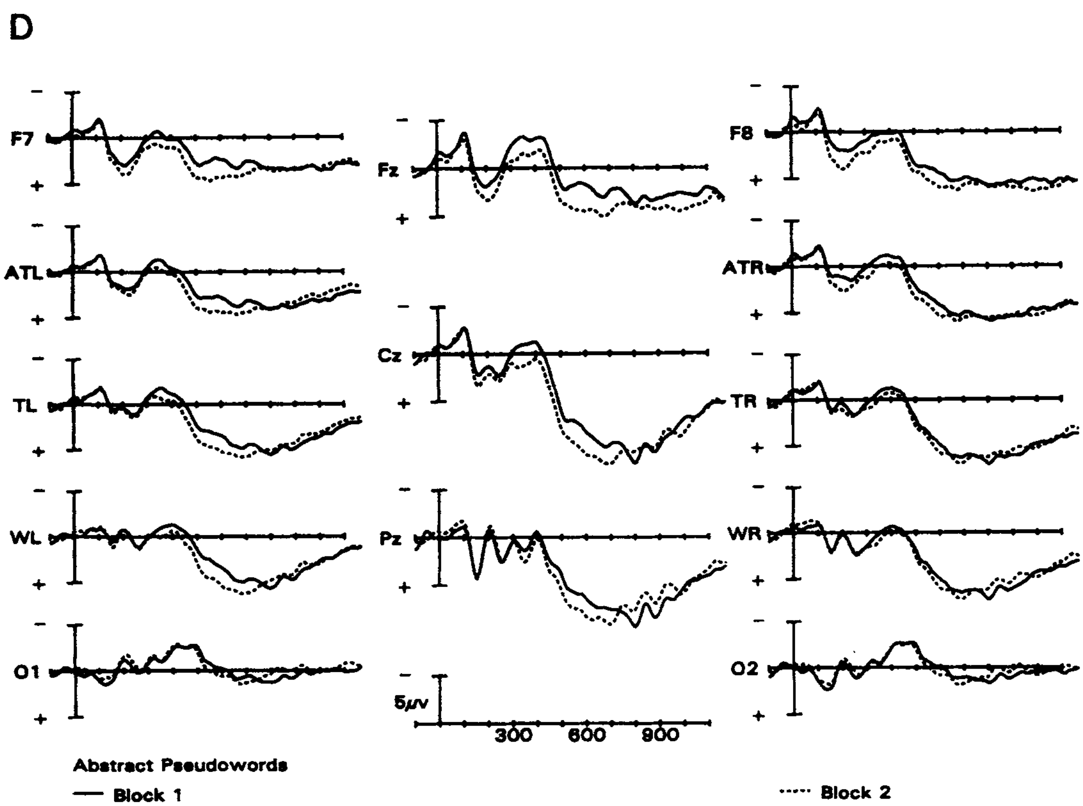


Figure 1. Grand mean event-related brain potentials (ERPs) from 13 scalp sites in Block 1 (solid line) abstract pseudowords of Experiment 1 (D). In this and subsequent figures, the ERP waveforms for each the bottom, left-hemisphere sites on the left, and right-hemisphere sites on the right. The *x* axes display negative plotted up (as is the convention). Note that on the time legend of Part A, the three temporal left side; ATL = anterior temporal left; TL = left temporal area; WL = Wernicke's left; O1 = occipital side; ATR = anterior temporal right; TR = right temporal area; WR = Wernicke's right; O2 = occipital





and Block 2 (dashed line) for concrete words (A), abstract words (B), concrete pseudowords (C), and electrode site are plotted separately, with anterior sites shown at the top of each figure, posterior sites at time with the vertical calibration bar showing the onset of the stimulus. The *y* axes display voltages, with epochs used to analyze the ERPs (150–300, 300–500, and 500–800 ms) are indicated. F7 = frontal area, area, left side; Fz = frontal midline; Cz = central midline; Pz = parietal midline; F8 = frontal area, right area, right side.

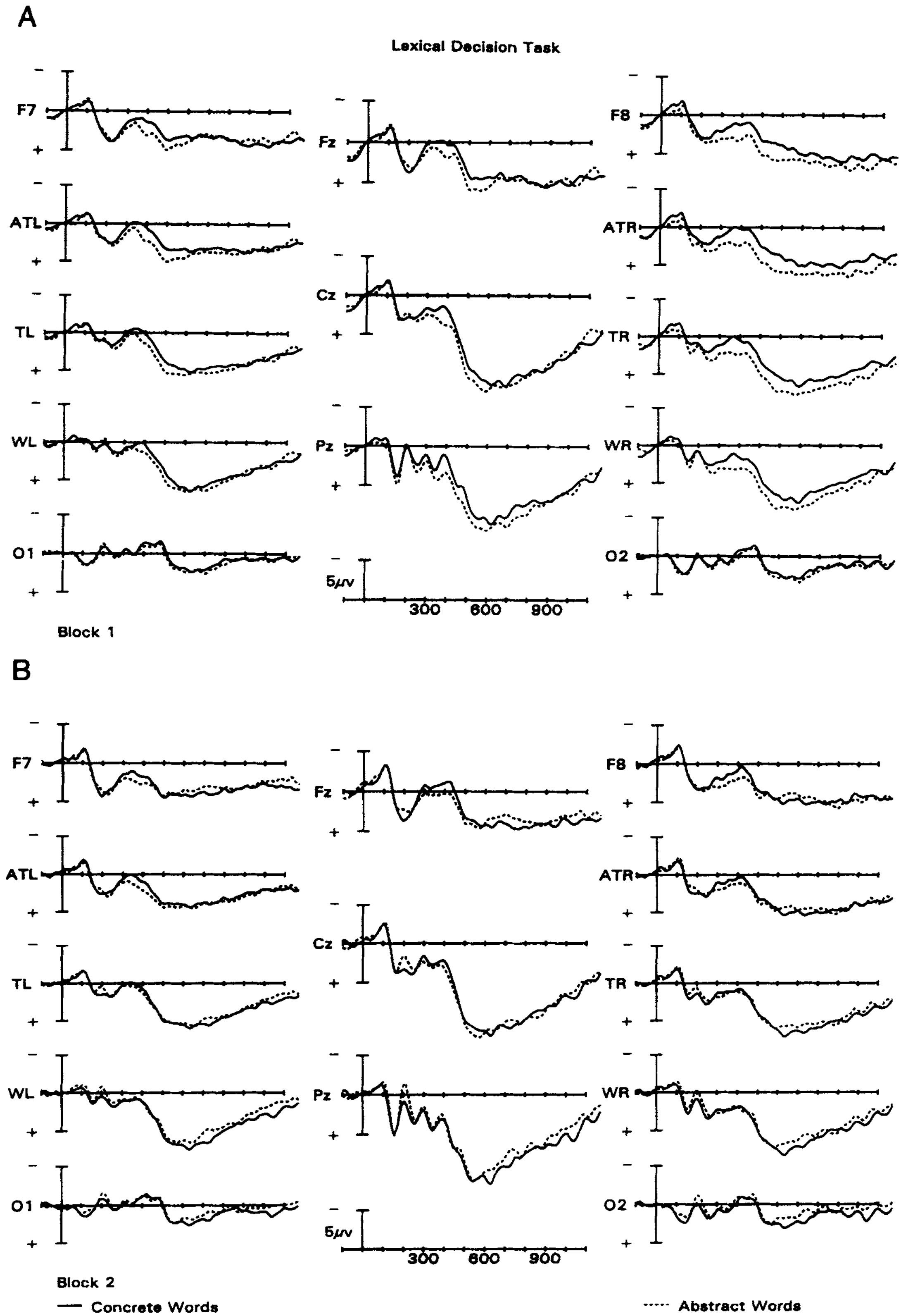


Figure 2. Grand mean event-related brain potentials (ERPs) for concrete (solid line) and abstract (dashed line) words in Block 1 (A) and Block 2 (B) of Experiment 1. F7 = frontal area, left side; ATL = anterior temporal left; TL = left temporal area; WL = Wernicke's left; O1 = occipital area, left side; Fz = frontal midline; Cz = central midline; Pz = parietal midline; F8 = frontal area, right side; ATR = anterior temporal right; TR = right temporal area; WR = Wernicke's right; O2 = occipital area, right side.

Table 2
Mean Amplitudes (in Microvolts) for Two Blocks of Concrete and Abstract Words and Pseudowords in the Lexical Decision Task (300 to 500 Milliseconds)

	Electrode site												
	Left hemisphere					Right hemisphere					Midline		
Stimulus	O1	WL	TL	ATL	F7	O2	WR	TR	ATR	F8	Fz	Cz	Pz
						Words							
Block 1													
Concrete	−0.9	1.0	0.6	0.7	1.2	−0.5	1.2	0.1	−0.1	0.8	−0.3	2.5	2.8
Abstract	−0.5	1.8	1.6	1.9	2.4	−0.1	2.9	2.0	1.8	2.4	1.3	4.2	4.5
Block 2													
Concrete	−0.7	2.1	1.6	1.6	2.3	0.0	2.7	1.7	1.2	1.6	0.0	4.3	5.0
Abstract	−0.8	2.0	1.9	2.4	2.9	−0.4	2.7	1.8	1.8	2.6	1.2	4.9	4.7
						Pseudowords							
Block 1													
Concrete	−2.0	−1.0	−1.3	−0.9	−0.2	−1.7	−0.5	−1.2	−1.0	0.0	−2.8	−0.4	0.3
Abstract	−2.0	−0.5	−0.5	0.0	0.5	−1.8	0.3	−0.2	−0.2	0.9	−2.1	0.7	1.4
Block 2													
Concrete	−2.2	−0.2	−0.4	−0.2	0.5	−1.9	0.3	−0.3	−0.1	0.9	−2.0	1.6	2.0
Abstract	−2.1	0.4	0.5	0.9	1.7	−1.7	0.8	0.4	0.7	1.9	−0.4	2.6	2.4

Note. O1 = occipital area, left side; WL = Wernicke's left; TL = left temporal area; ATL = anterior temporal left; F7 = frontal area, left side; O2 = occipital area, right side; WR = Wernicke's right; TR = right temporal area; ATR = anterior temporal right; F8 = frontal area, right side; Fz = frontal midline; Cz = central midline; Pz = parietel midline.

tials between 300 and 500 ms than did real words (e.g., Bentin et al., 1985; Holcomb, 1988, 1993). This difference has most frequently been interpreted as a modulation of the N400 component (e.g., Bentin et al., 1985; Holcomb & Neville, 1990), which may reflect attempts on the part of the subject to integrate stored information activated by these items into a higher level representation. However, as pointed out in the introduction, the specific nature of the higher level representation and the type of information being integrated is unclear. Rugg and Doyle (in press) have suggested that the N400 can

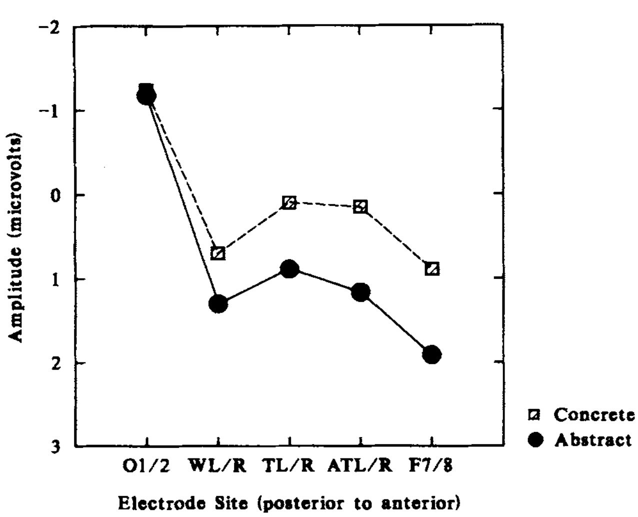


Figure 3. The 300- to 500-ms mean event-related brain potentials (ERPs) amplitude for word types (concrete and abstract) plotted as a function of scalp site in Experiment 1. O1/2 = occipital area, left side/right side; WL/R = Wernicke's left/right; TL/R = left/right temporal area; ATL/R = anterior temporal left/right; F7/8 = frontal area left side/right side.

reflect integration of unitizable information at various levels. So, it might be argued that pseudoword N400s reflect the subject's attempt to integrate orthographic and phonological information. Alternatively, the N400 to pseudowords might reflect attempts to integrate semantic information (from real-word neighbors) into a discourse- or message-level representation. Because this information does not fit with the ongoing discourse, it generates a large N400. In the case of a single-word lexical decision task, integration might simply reflect the subject's attempt to form an initial discourse structure, similar to what presumably happens to the first word in a sentence or paragraph.

In the current study, a difference was found between concrete and abstract pseudowords in the N400 time window. This difference, which took the form of a larger negativity to concrete than abstract pseudowords, was very similar to the pattern found for the real words used to derive the pseudowords. If this difference was due to modulation of the N400, as its latency range and distribution imply, then this suggests that the pseudowords had access to concreteness-based semantic information (see earlier discussion of Rugg & Doyle, in press). By this same logic, it seems most plausible that such semantic-level information is responsible for generating the pseudoword N400 effect in this and in other ERP lexical decision experiments.

Starting between 150 and 300 ms and continuing until the 500- to 800-ms range, the ERPs to first presentations of items were more negative-going than ERPs to these same items when they were repeated 12 min later. This comparatively long-lasting repetition effect appeared to be composed of both an early modulation of a negative ERP component (the N400) and modulation of a later positive component. It is interesting to note that, as suggested by James (1975), the differences between concrete and abstract items were larger for first presentations of items (i.e., prior to a context being set up) than after they had been repeated. This would appear to suggest, as predicted by context-availability theory, that the advantage concrete words have over abstract words is partially overcome by presenting them a second time. However, close examination of the ERPs from first and second presentations does not support this interpretation. What appears to happen with repetition, particularly in the N400 window, is that concrete words become more like abstract words, which, in turn, do not appear to change from first to second presentations. This is just the opposite of what context-availability theory predicts. Repetition (context) should tend to make abstract words more like concrete words. This interpretation is consistent with two other studies that have manipulated word frequency and context or repetition. Rugg (1990) reported a similar pattern of N400 repetition effects in a study that manipulated word frequency (greater than 100 per million and 1 per million). Low-frequency words (like concrete words) produced larger N400s than high-frequency words after their first presentation, but there were no frequency differences after a single repetition. Van Petten and Kutas (1990) reported a similar interaction on the N400 between word frequency and sentence context, such that effects of frequency tended to disappear as context built up across a sentence.

Experiment 2

Although there was some evidence favoring dual-coding theory in Experiment 1, these effects were either relatively small in size or unpredicted. The tenuous nature of these effects might be due to the selection of the lexical decision task as a vehicle for exploring concreteness effects. Although we, like James (1975), found evidence for the use of concreteness-based semantic information in this task, it is possible that making lexical decisions did not encourage subjects to use semantic information to the extent necessary for exhibiting more robust topographic ERP effects. To test this possibility, a semantic task was used in Experiment 2.

In selecting a task, it was deemed important that subjects use the appropriate type and amount of semantic information. Therefore, in Experiment 2, subjects were required to explicitly categorize words as being either concrete or abstract. Under such circumstances, it was reasoned that a failure to find evidence of lateral asymmetries (or some other relevant dissociation between the topographic distributions) for ERPs to concrete and abstract words would be difficult to reconcile with dual-coding theory. However, if a pattern similar to that suggested by Experiment 1 was obtained in Experiment 2, then this would further support the dual-coding position and would therefore be incompatible with a single-coding view such as the context-availability model. Furthermore, replication of the type of repetition by concreteness interaction found in Experiment 1 would also be inconsistent with the context-availability view.

A similar task was used by Paller et al. (1988) in an ERP study of implicit memory. As in our Experiment 1, they found that between 200 and 800 ms, concrete words generated more negative-going ERPs than did abstract words. It is noteworthy that the size of their concreteness effect appeared larger than that found in the current Experiment 1. However, because Paller et al. presented data only from midline electrodes, it is not clear whether their ERP concreteness effect was larger over the right hemisphere.

Method

Subjects. Twelve new volunteers (9 women and 3 men) between 21 and 35 years of age (M = 25.1) from the Tufts University community participated in the study. All were right-handed native speakers of English with normal or corrected-to-normal visual acuity. As in the previous experiment, 5 subjects had at least one left-handed relative in the immediate family.

Stimuli and procedures. The stimuli and procedures were similar to those used in Experiment 1, with the following exceptions. The pseudoword stimuli from Experiment 1 were removed from the stimulus lists leaving 80 stimulus words (40 concrete and 40 abstract).

Subjects were instructed to rapidly and accurately press a button labeled *concrete* with one thumb if the target word represented a concrete object, or to press a second button labeled *abstract* with their other thumb if the target word represented an abstract concept. The hand used for each type of response was counterbalanced across subjects. Each of the two experimental blocks of trials lasted approximately 5 min (including one short break after 40 trials). Within a block, no items were repeated, though each of the 80 words was repeated in the second block. The order of words in the second block was a pseudorandom rearrangement intended to prevent subjects from predicting the occurrence of specific items based on experience with the first block. No item was repeated (across the block boundary) without at least 28 intervening words and a 2-min interblock rest break. A 14-trial practice run preceded the first experimental block.

For the purposes of data analysis, separate ERPs were formed for concrete and abstract words (word type) in each of the two trial blocks (blocks) and for each of the 13 scalp sites. The same measurement windows used in Experiment 1 were used for these data.

Results

RT and accuracy data. Analysis of the RTs revealed a significant main effect of blocks, $F(1, 11) = 15.52$, $p < .01$, $MS_e = 928.07$, with faster responses for repeated items (717 vs. 683 ms). There was also a significant RT difference between the concrete and abstract words [main effect of word type: $F(1, 11) = 23.97$, $p < .001$, $MS_e = 2{,}717.98$], with concrete word RTs taking 663 ms and abstract words taking 737 ms. However, the Block × Word Type interaction was not significant ($F = 1.0$). The analysis of the accuracies yielded no significant differences, although there was a marginally significant trend for subjects to be more accurate in the second block (93.5% vs. 95.5%, $p < .065$), especially for concrete items (3% improvement for concrete items vs. a 0.2% improvement for abstract items; $p < .08$).

ERP components and scalp distribution. The grand mean ERPs to concrete and abstract words from Blocks 1 and 2 are plotted in Figure 4. Figure 5 displays the same ERPs rearranged so that concrete and abstract words are plotted together for Blocks 1 and 2, respectively. Generally, these figures show ERP components similar to those seen in Experiment 1 (cf. Figures 1 and 2).

150 to 300 ms. Analysis of the 150 to 300 ms window revealed a significant amplitude difference between the two blocks of trials [midline: $F(1, 11) = 14.86$, $p < .001$, $MS_e = 12.95$; lateral: $F(1, 11) = 13.62$, $p < .01$, $MS_e = 13.57$]

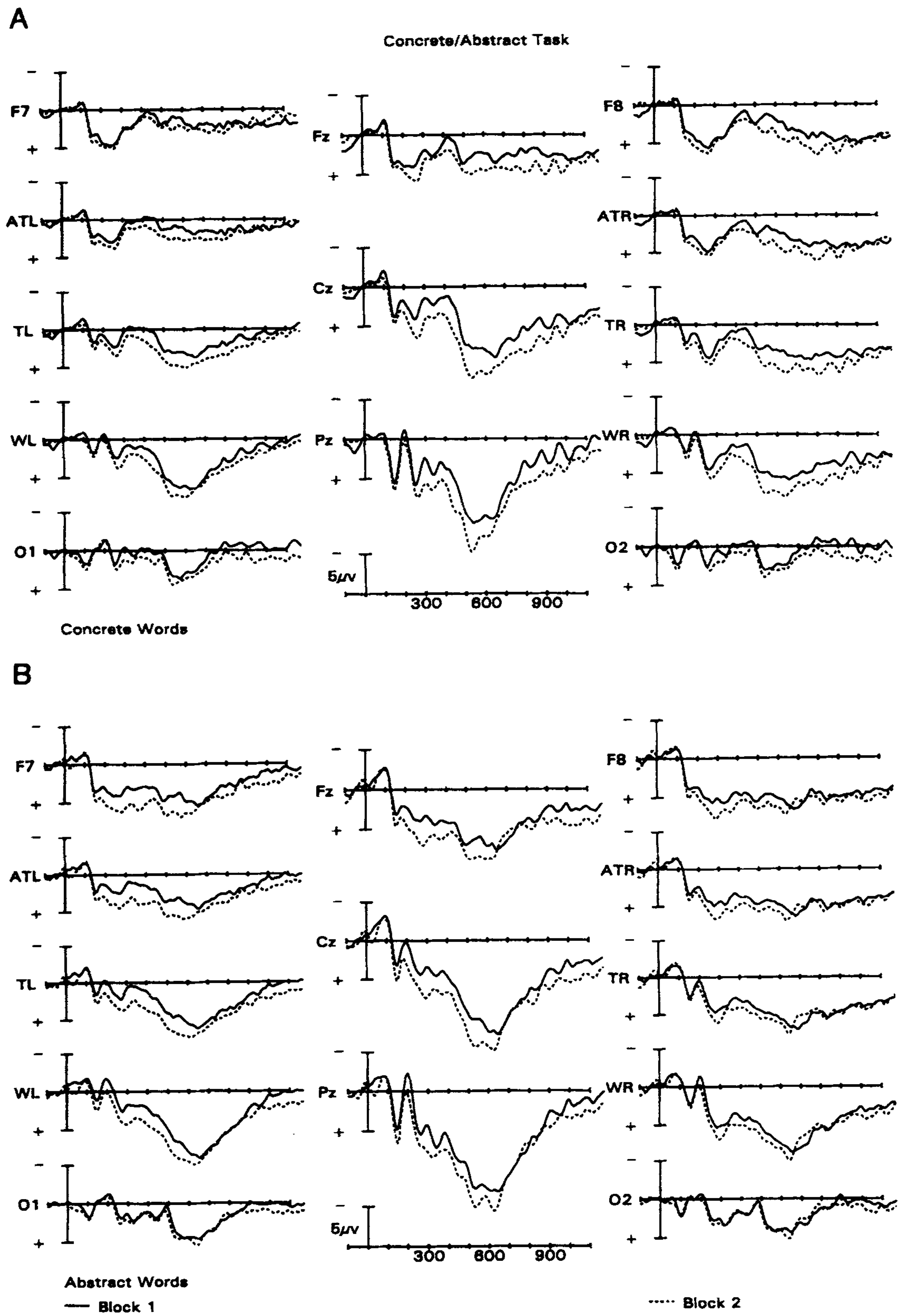


Figure 4. Grand mean event-related brain potentials (ERPs) from 13 scalp sites in Block 1 (solid line) and Block 2 (dashed line) for concrete words (A) and abstract words (B) of Experiment 2. F7 = frontal area, left side; ATL = anterior temporal left; TL = left temporal area; WL = Wernicke's left; O1 = occipital area, left side; Fz = frontal midline; Cz = central midline; Pz = parietal midline; F8 = frontal area, right side; ATR = anterior temporal right; TR = right temporal area; WR = Wernicke's right; O2 = occipital area, right side.

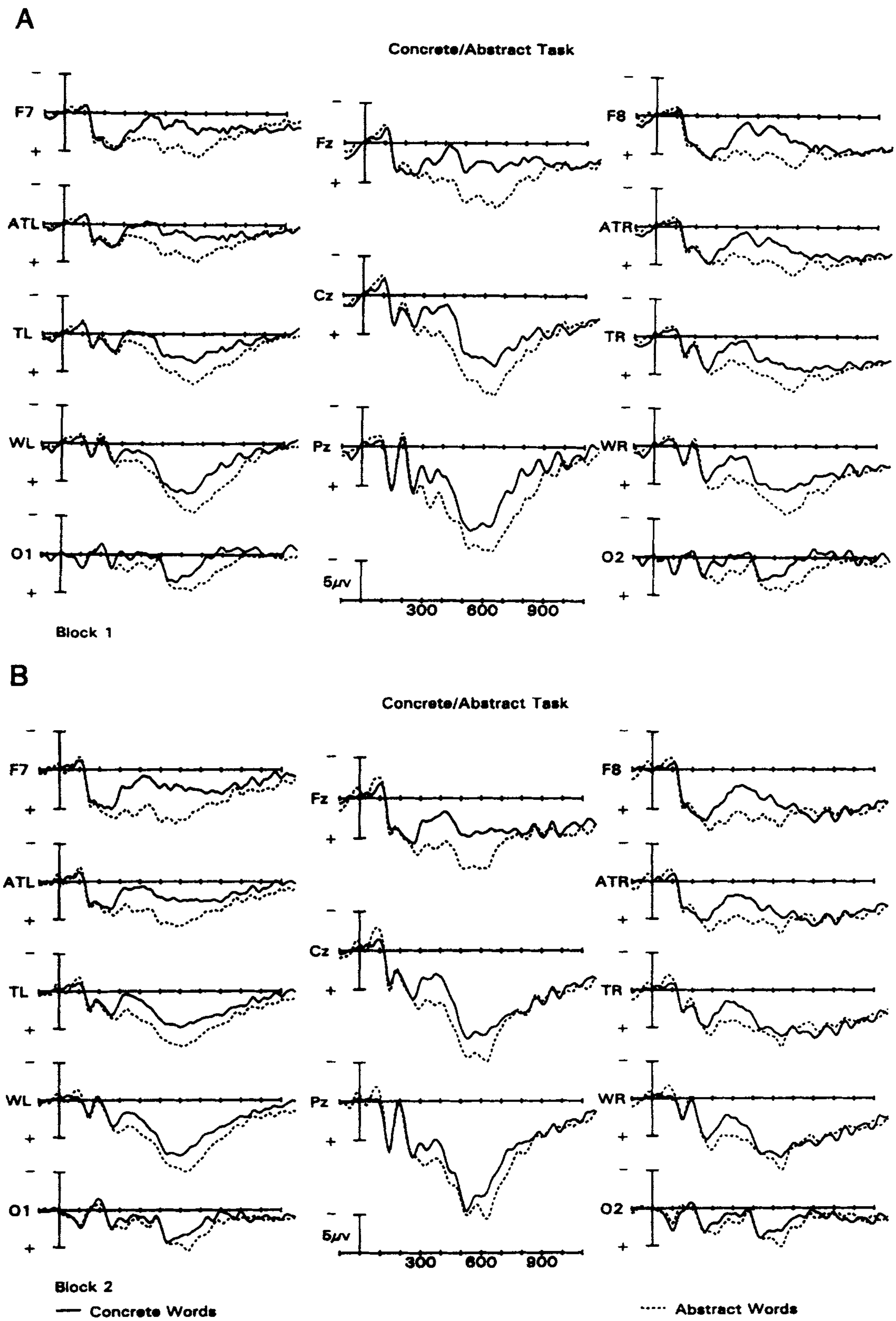


Figure 5. Grand mean event-related brain potentials (ERPs) for concrete (solid line) and abstract (dashed line) words in Block 1 (A) and Block 2 (B) of Experiment 2. F7 = frontal area, left side; ATL = anterior temporal left; TL = left temporal area; WL = Wernicke's left; O1 = occipital area, left side; Fz = frontal midline; Cz = central midline; Pz = parietal midline; F8 = frontal area, right side; ATR = anterior temporal right; TR = right temporal area; WR = Wernicke's right; O2 = occipital area, right side.

Table 3
Mean Amplitudes (in Microvolts) for Two Blocks of Concrete and Abstract Words in the Concreteness Judgment Task (300 to 500 Milliseconds)

	Electrode site												
	Left hemisphere					Right hemisphere					Midline		
Stimulus	O1	WL	TL	ATL	F7	O2	WR	TR	ATR	F8	Fz	Cz	Pz
						Block 1							
Concrete	−0.1	1.4	−0.1	−0.2	1.0	−0.2	1.4	0.7	1.1	1.8	0.8	1.9	4.2
Abstract	1.4	2.8	1.8	1.9	3.4	1.9	4.4	3.6	4.1	5.1	4.7	5.8	7.4
						Block 2							
Concrete	1.2	3.0	1.6	1.1	1.7	1.0	3.4	2.4	2.4	3.1	2.7	4.9	7.3
Abstract	1.8	4.8	3.9	4.0	5.4	1.9	5.6	4.7	5.3	6.3	6.4	8.1	9.2

Note. O1 = occipital area, left side; WL = Wernicke's left; TL = left temporal area; ATL = anterior temporal left; F7 = frontal area, left side; O2 = occipital area, right side; WR = Wernicke's right; TR = right temporal area; ATR = anterior temporal right; F8 = frontal area, right side; Fz = frontal midline; Cz = central midline; Pz = parietal midline.

with Block 1 being more negative than Block 2 (see Figure 4). The distribution of this repetition effect was roughly equivalent from anterior to posterior sites, with the exception of the rather small effect at the occipital sites. There were no significant differences between word types in this epoch.

300 to 500 ms. The mean amplitudes for the 300 to 500 ms epoch are reported in Table 3. As in the previous epoch, repeated words were associated with less negative-going ERPs than were first presentations [main effects for block: midline, $F(1, 11) = 8.85, p < .05, MS_e = 21.14$; lateral, $F(1, 11) = 11.15$, $p < .01$, $MS_e = 19.74$]. However, unlike the previous epoch, analysis of this latency band indicated that concrete words were significantly more negative-going than abstract words [main effects of word type: midline, $F(1, 11) = 21.07, p < .001$, $MS_e = 18.29$; lateral, $F(1, 11) = 28.44, p < .001, MS_e = 22.45$; see Figure 5]; this word type effect was larger at anterior than posterior sites [Word Type × Electrode Site interactions: midline, $F(1, 11) = 5.67$, $p < .05$, $MS_e = 0.92$; lateral, $F(1, 11) = 5.64, p < .05, MS_e = 2.07$; see Figure 6]. At lateral sites, there was a significant Block × Word Type × Hemisphere interaction, $F(1, 11) = 6.07$, $p < .05$, $MS_e = 1.24$, which indicated two things: (a) that the effects of repetition (blocks) were larger over the left hemisphere for abstract words (repetition effect for LH: 1.5 μV, for RH: 1.0 μV) but were more symmetrical over both hemispheres for concrete words (repetition effect for LH: 1.0 μV, RH: 1.2 μV); and (b) that in Block 1, but not Block 2, the difference between word types was bigger over the right hemisphere than the left hemisphere (Figure 6).

In summary, (a) concrete words produced more negative-going ERPs than did abstract words between 300 and 500 ms, and this difference was larger over more anterior and right-hemisphere sites (see Figure 6); (b) both word types produced a repetition effect, with second presentations of items yielding less negative-going ERPs than first presentations; and (c) this repetition effect was larger over the left than the right hemisphere for abstract words, but was more symmetrical across hemispheres for concrete words.

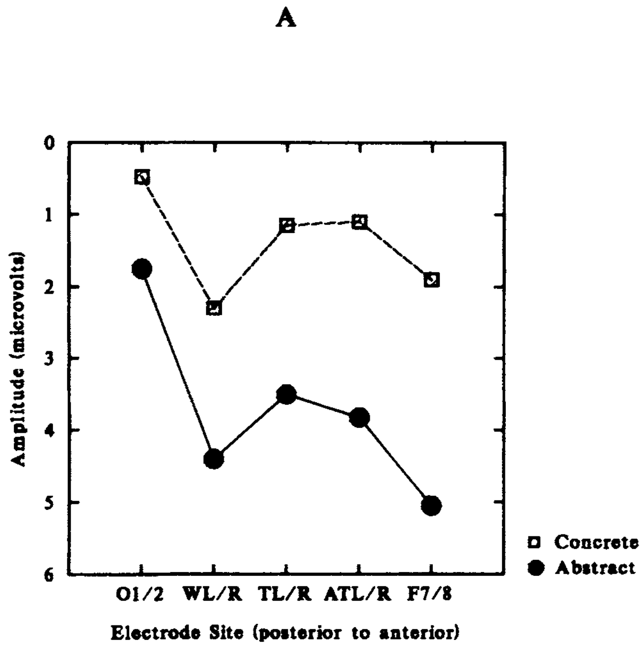
500 to 800 ms. As in the previous time window, the ERPs to concrete words were more negative-going than those to abstract words [midline: $F(1, 11) = 9.17, p < .05, MS_e = 36.39$; lateral: $F(1, 11) = 10.17, p < .01, MS_e = 49.43$]. Although the overall difference across blocks was only marginally significant ($p < .06$ for midline and lateral analyses), concrete words produced a larger repetition effect than abstract words [Word Type × Block interactions: midline, $F(1, 11) = 6.57, p < .05$, $MS_e = 4.02$; lateral, $F(1, 11) = 5.09, p < .05, MS_e = 6.97$; see Figure 4], and at lateral sites the repetition effect for concrete words was somewhat larger over the right hemisphere (1.3 vs. 2.1 μV), whereas for abstract words repetition had a larger effect over the left hemisphere [1.0 vs. 0.2 μV; Word Type × Block × Hemisphere interaction: $F(1, 11) = 13.00$, $p < .01, MS_e = 1.55$].

In summary, during 500 and 800 ms the following occurred: (a) Concrete words continued to produce more negative-going ERPs than abstract words; (b) concrete words produced a larger repetition effect than abstract words; and (c) the concrete repetition effect was larger over the right hemisphere, whereas the abstract repetition effect was larger over the left hemisphere.

Discussion

Overall, the results from this experiment tend to confirm the most important finding reported for Experiment 1, that is, ERPs to concrete words were more negative-going than ERPs to abstract words from 300 to 500 ms and from 500 to 800 ms. However, the size of the differences between the ERPs for the two word types was greater in Experiment 2 (cf. Figures 2a and 5a).

Furthermore, the small lateral asymmetries for concrete and abstract words seen in the N400 window (300 to 500 ms) for Experiment 1 were more robust in Experiment 2. The amplitude difference between concrete- and abstract-word ERPs was larger over the right than the left hemisphere, even when average amplitude measures were used (Figure 6b). In addition, ERP repetition effects (i.e., the difference between Blocks 1 and 2) had a different lateralized pattern for the two word classes. In the N400 window, repetition effects were roughly equivalent across the hemispheres for concrete words, but were larger over the left than right hemisphere for abstract words. In the later (i.e., 500 to 800 ms) epoch, spanning a slow positive shift in the ERP, the same trend held for the abstract-word repetition effect, although now the concrete-word repetition effect was clearly larger over the right than the



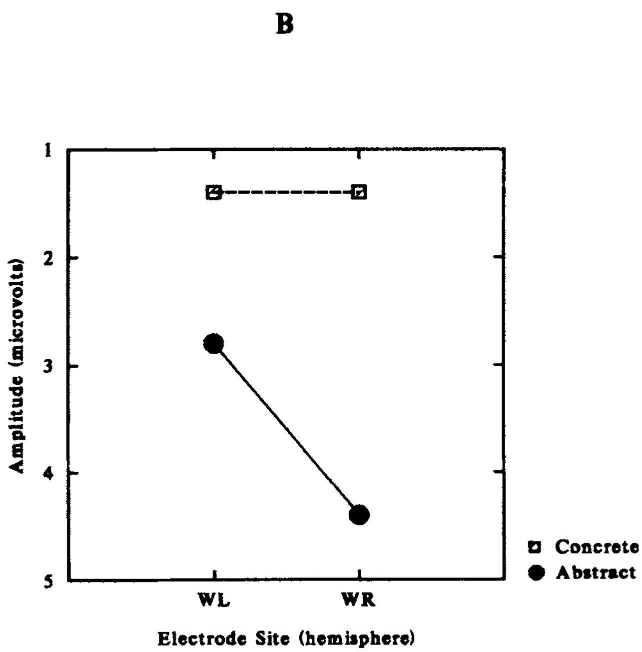


Figure 6. The 300- to 500-ms mean event-related brain potential (ERP) amplitude of Experiment 2 for (A) the word type effect (concrete vs. abstract) plotted as a function of scalp site and (B) the Block 1 word type effect plotted as a function of hemisphere for one lateral pair, Wernicke's left (WL) and Wernicke's right (WR). O1/2 = occipital area, left side/right side; WL/R = Wernicke's left/right; TL/R = left/right temporal area; ATL/R = anterior temporal left/right; F7/8 = frontal area left side/right side.

left hemisphere. Also, as in Experiment 1, the size of the 300 to 500 ms concreteness effect increased moving toward more anterior sites (Figure 6a).

One possible criticism of this experiment is that the differences between the ERPs for concrete and abstract words may be difficult to interpret because the task required subjects to make different responses to the two types of words. It may therefore be argued that the observed concreteness effects are not a result of dual coding, but of interactions of word type with decision or response selection mechanisms. However, this explanation is implausible for three reasons.

First, the N400 has been shown to reflect certain semantic variables while not being sensitive to the decision and response selection mechanisms that result in the eventual response. For instance, Kounios and Holcomb (1992) measured ERPs during a sentence verification task using sentences such as "All dogs are animals" and "No shirts are plants." They found additive effects of category level and subject–predicate relatedness on N400 amplitude, but no measureable effect on N400 of sentence truth value (as determined by the quantifiers *all, some,* and *no*). Because the task was to respond with button presses corresponding to true and false decisions, N400 amplitude thereby exhibited independence of decision and response selection mechanisms.

Second, the asymmetries observed in the present study are specifically those predicted by dual-coding theory. No published theory of decision or response selection mechanisms could easily be made to predict such effects. Such an alternative explanation might have been applicable to the results from Experiment 2 only if the stimulus–response mapping had not been counterbalanced across subjects (e.g., because each hemisphere controls the muscles involved in making the response with the contralateral hand).

Third, the most important results from Experiment 2 generally seem to be a more pronounced version of those obtained from Experiment 1. Given that the lexical decision task used in Experiment 1 required the same response for concrete and abstract words, and given that the overall pattern of effects observed in the two experiments appears similar, it seems unlikely that the effects obtained in Experiment 2 are due to the influence of decision or response selection mechanisms.

Finally, the overall pattern of repetition effects found in Experiment 2 was similar to that found in the first experiment, although in Experiment 2 abstract words produced a more reliable effect than in Experiment 1. This latter difference between experiments might have been due to the shorter interval between repetitions (each block lasted only half as long in Experiment 2) or to the increased emphasis on semantic information germane to the concreteness decision in Experiment 2. Regardless, failure to find larger repetition effects for abstract words is further evidence against context-availability theory.

General Discussion

Our study was aimed at contrasting the structural implications of dual- and single-coding theories of concreteness effects on semantic processing. Paivio's (1986) dual-coding theory argues that the processing advantage of concrete over abstract verbal stimuli results from the operation of two separate systems (verbal and imagistic) in the case of concrete words, but only a single (verbal) system in the case of abstract words. On the other hand, context-availability theory (e.g., Schwanenflugel & Shoben, 1983) proposes that concrete and abstract words are represented and processed in a single system and attributes the processing advantage for concrete concepts to their having a greater amount of built-in context. In the experiments described here, evidence was obtained that appears to best support a modified dual-coding account. Concrete and abstract words produced different scalp distributions of a late ERP negativity (the N400) that has been shown to be sensitive to semantic processes. This finding supports the earlier evidence from neuropsychological studies (e.g., Coltheart, 1980) and laterality studies (e.g., Chiarello et al., 1987; Day, 1977) that some aspect of the verbal and imaginal systems are associated with different underlying neural systems.

The viability of this structural account was investigated by examining the topographic distribution of ERPs in two semantic-processing experiments. The major findings of these experiments can be summarized and interpreted as follows:

1. Concrete words elicited larger negativities in the N400 region than did abstract words. Because N400 has been linked with semantic processing (e.g., Kounios & Holcomb, 1992; Kutas & Hillyard, 1980, 1984), this greater neural activity occurring in response to concrete words is consistent with the notion that concrete words activate more semantic information in memory than abstract words (cf. de Groot, 1989).[10]

2. The N400 advantage for concrete words was greater over the right hemisphere than the left. This suggests that at least some of the additional semantic information activated by concrete words is of a different type than that activated by abstract words. This conclusion is consistent with dual-coding theory, which states that both concrete and abstract words are processed by the left-hemisphere verbal system, but that the right-hemisphere imaginal system primarily processes concrete words. Moreover, there were also larger differences between word types over anterior sites than at posterior sites. This latter effect has not been reported in previous studies, nor was it specifically predicted by dual-coding theory. Nevertheless, it can be taken as further support for the general notion of different neural systems, which is incompatible with single-coding theories.

3. Abstract words either produced no N400 repetition effect (Experiment 1) or a larger effect over the left hemisphere (Experiment 2), whereas concrete words produced a large repetition effect over both hemispheres in both experiments. Also, repetition tended to eliminate (Experiment 1) or decrease (Experiment 2) the size of the difference between the word types. These results raise a number of questions, mostly concerning the interpretation of ERP results and their relationship to cognitive theory. For example, if the right-hemisphere system processes only concrete words, why is there any N400 activity over the right hemisphere in response to abstract words? There are three points that need to be made with regard to this issue. First, as explained earlier, the topographic distribution of ERP components is rarely sharply defined. Some of the N400 activity measured over the right hemisphere may, in fact, originate in the left hemisphere, radiating outward from its source by volume conduction (see Duffy, Iyer, & Surwillo, 1989, for a detailed explanation). Therefore, right-hemisphere N400 activity to abstract words might be due, in part or entirely, to a left-hemisphere generator. Second, there is no reason to think that abstract words are associated with no imagistic information whatsoever. Even Paivio (1986) has suggested that some abstract words may induce activity in the imaginal system. The point is that, in general, this activity should be less extensive than for concrete items. Finally, as there is no baseline of N400 activity with which to compare the response of either word type, it is difficult to know just how much N400 activity abstract words are actually producing over the right hemisphere. Therefore, it is possible that there was no N400 activity to abstract words over the right hemisphere. However, previous work with single-word tasks (e.g., Holcomb & Neville, 1990) has shown that ERPs at these same scalp sites can contain substantially less negativity in the N400 region (300 to 500 ms) than was present to the abstract words in this study, which suggests that there may have been some right-hemisphere N400 activity to these words in the current studies.

As proposed in the introduction, the interactions between concreteness and context of the sort used by Schwanenflugel (Schwanenflugel et al., 1988; Schwanenflugel & Shoben, 1983; Schwanenflugel & Stowe, 1989) to argue that concreteness effects are reducible to context availability may only mean that these two factors affect a common process, and not necessarily that the two factors are really the same. For example, context may exert its influence by (separately) operating within the verbal and the imaginal systems, whereas concreteness may provide its influence by operating between these interconnected systems. The resulting parallelism of influence would naturally predict interacting effects on a performance parameter such as RT. In the current study we found evidence for such an interaction in the ERP data; concrete final words out of context (i.e., after a single presentation) yielded larger N400s than did out-of-context abstract words. However, in context (i.e., after repetition), concrete and abstract words yielded smaller and either equivalent N400s (Experiment 1) or N400s with different scalp distributions (Experiment 2). These findings are consistent with the notion that concreteness and context are separate factors that tap a common process indexed by the N400. Furthermore, context can apparently attenuate or eliminate the influence of concreteness on performance by creating a floor effect on this critical process.

At first glance, this latter finding may seem to support context-availability theory, which also predicts that context should eliminate differences between concrete and abstract words. However, it should be remembered that context-availability theory also predicts that context should have a larger effect on abstract than concrete words. In other words, context-availability theory predicts a larger N400 repetition

[10] Whether this additional information associated with concrete concepts is purely imagistic or also includes a more verbal component is unclear. The larger N400 for concrete words over both hemispheres might be taken as evidence for the latter. Alternatively, the larger left-hemisphere N400 for concrete words could be due to volume conduction from the right hemisphere, in which case the actual left-hemisphere system might be equally active for both word types.

effect for abstract words. This was clearly not the case; concrete words produced larger repetition effects in both experiments.

There are at least two caveats to the aforementioned interpretation. First, the repetition of words in the current experiments may not have tapped the same contextual processes as those studied by Schwanenflugel and colleagues. It may be that a sentence context would have produced ERP results more in line with context-availability theory, such as larger N400 effects for abstract than concrete words presented in and out of context.

Second, as mentioned after Experiment 1, the 300–500 ms effects might not actually be true N400 effects. Evidence supporting this possibility includes the larger differences at more frontal sites (N400 is usually larger over posterior sites) and the presence of differences extending beyond the traditional N400 temporal window (500–800 ms). However, evidence consistent with a traditional N400 interpretation of the current findings includes: (a) the presence of an overall repetition effect in the N400 temporal window (such repetition effects have been attributed to the N400 in several previous studies; see Rugg & Doyle, in press), (b) the finding of a greater repetition effect over the right hemisphere than the left for concrete words in Experiment 2 (the N400 effect has often been reported to be larger over the right hemisphere), and (c) the general morphology and latency characteristics of the negativity present in the N400 temporal window. We are currently conducting studies designed to investigate both the context and N400 issues.

Perhaps more damaging to context-availability theory (or any single-coding theory) was the finding of distinct ERP scalp distributions for the two word types. The difference between concrete and abstract words was larger over the right than the left hemisphere and over more anterior than posterior regions of both hemispheres. These findings strongly suggest that different neural populations underlie at least some of the processes involved in comprehending the two word types and are therefore more consistent with dual-coding theory.

A proponent of context-availability theory might argue that the evidence provided in this study for localization of the two hypothetical processing systems is not conclusive. For example, it could be that some unidentified property of words (other than concreteness or imageability) actually produced the obtained topographic distribution of ERPs. However, in the absence of a good candidate it seems unproductive to claim that some unidentified variable is producing the topographic distribution of ERPs specifically predicted by dual-coding theory, unless a particular nuisance variable were proposed along with a testable theoretical rationale to account for its mimicry of the predicted effects. One of the attractive aspects of dual-coding theory is that it makes specific, testable predictions. An alternative position should not be given serious consideration unless it affords comparable specificity and testability.

In conclusion, although context-availability theory appears unable to deal with the scalp distribution differences between word types and the larger effects of context for concrete words, it nevertheless does appear to be correct in its general assertion that context modifies concreteness effects. Therefore, it appears that an adequate theory of concreteness effects should include both a dual-coding component for representing and processing the two word types and a contextual component that is capable of modifying word processing within each system.

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