

## Event-Related Brain Potentials Reflect Semantic Priming in an Object Decision Task

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Subjects made speeded object decisions about target line drawings which were preceded by semantically related or unrelated prime line drawings. One hundred of the targets depicted real objects and 50 others were unrecognizable non-objects. Similar to a recent picture-matching study, the ERPs from this study generated a larger negativity for unrelated than for related target pictures, between 325 and 550 msec (N400). Although these differences had a similar time course to those seen for the N400 component in semantic priming lexical decision tasks, they were more frontally distributed and were larger over the left rather than the right hemisphere. Non-objects, which were the picture equivalent of pseudowords, produced an even larger negativity with a somewhat different distribution. The results are discussed with regards to recent claims about amodal conceptual memory processes. © 1994 Academic Press, Inc.

For over a decade cognitive scientists have debated the degree of overlap between the processes and representations which are involved in understanding language and visual scenes. While there is a general consensus that words and pictures undergo certain modality-specific sensory and perceptual operations, the same degree of agreement cannot be found at the level of semantic or conceptual knowledge representation. On one side of this issue are studies and theories that have argued for a shared or "common" conceptual system (e.g., Kroll & Potter, 1984; Vanderwart, 1984), and on the other side are studies and theories that have argued for separate verbal and imagistic or "dual-coding" systems (e.g., Paivio, 1971, 1990).

Although a large body of research has focused on this topic, both sides can cite a substantial number of findings supporting their position. One possible reason for this lack of consensus is that the dependent measures typically used to address these questions (reaction time and response accuracy) are rather far removed from the important cognitive operations

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of interest. In other words, they are relatively "off-line" measures. The global aim of the current study was to begin a systematic series of studies comparing picture, and word processing using dependent variables (event-related brain potentials, ERPs) that are arguably more closely tied to the most critical underlying cognitive operations.

The N400 component of the ERP, so named because it is a negativity that usually peaks around 400 msec, has proven to be sensitive to the semantic processing of linguistic stimuli. Kutas and Hillyard (1980) were the first to demonstrate that the N400 is significantly smaller to sentence ending words that are semantically congruous (e.g., I take cream and sugar with my *coffee*.), compared to the N400 that is elicited by sentence ending words that are anomalous (e.g., I take cream and sugar with my *dog*.). Subsequent work has shown that the N400 can be elicited in word pair tasks, where a target word is either semantically related or unrelated to a prior prime word (e.g., Bentin, McCarthy, & Wood, 1985; Holcomb, 1988). The N400 is *larger* when the prime and target are not related and the difference in the ERPs between these two conditions is called the N400 priming effect. Early on, researchers in this area speculated that the N400 might be an index of lexically based semantic processes. Although there is still no complete consensus among those working in this area, there is relatively compelling evidence that the N400 effect is primarily sensitive to a post-lexical semantically based process (see Rugg, 1990; Holcomb, 1993, for a more complete account of the argument supporting this position). According to this view, the N400 reflects the degree of effort required to *integrate* the meaning of a concept into a higher level representation. This suggests that the N400 may be a useful tool in studying semantic/conceptual memory processes.

### PICTURE PRIMING AND ERPs

Recently, a handful of ERP studies have investigated priming phenomena using pictures as stimuli. Two questions addressed by this research are: Do pictures generate an N400? And, if so, how is it similar (or different) to that produced by words? The answers to these questions are important because they may help determine if ERPs will be useful in addressing the dual/common-code debate.

Some ERP work with pictorial stimuli has focused on the processing of human faces (see Adams & Pick, 1992; Barrett, Rugg, & Perrett, 1988; Barrett & Rugg, 1989). All of these experiments used black and white photographs of faces in tasks where subjects had to perform a type of semantic-matching task. For example, "discriminate whether a second picture was the same person (but different view) as the first or whether a second person had the same expression as the first. " In all three of these face-processing experiments, the non-matching target faces elicited

a larger negativity peaking at approximately 400 msec. This negativity was tentatively identified by Barrett et al. (1988) as the face equivalent of the N400 component seen in language tasks. Barrett and Rugg (1989) concluded that these match/non-match differences can be ". . . considered to reflect the modulation of an N400 component similar to that evoked by words, and thus suggest that such components can be modulated by associative priming between non-linguistic stimuli" (p. 913). Unlike Barrett et al. (1988) and Barrett and Rugg (1989), Adams and Pick (1992) were less committal in concluding that their differences were due to the modulation of the N400. One concern of these authors was the different distribution of the negativity to non-matching targets obtained in the affective judgment task.

In a study directly relevant to the current experiment, Barrett and Rugg (1990) eliminated any problems associated with faces by using line drawings of common objects. Stimuli were presented sequentially in prime/target pairs with one-half of the targets "matching" the primes via associative relationships (e.g., knife-fork and wrench-nut) and the other half mismatching the prime (e.g., knife-nut and wrench-fork). As anticipated, a negative wave peaking at 450 msec was larger (more negativegoing) to the non-matching targets than to the matching targets. However, the distribution of this negativity, which was roughly equivalent across the scalp, was more anterior and was not asymmetrical across the hemispheres as has been reported for the N400 to verbal stimuli (e.g., Kutas, Van Petten, & Besson, 1988). Also, the picture negativity peaked approximately 50 msec later (N450) than does the N400 in most visual language tasks (e.g., Kutas & Hillyard, 1980). Nevertheless, Barrett and Rugg concluded that modulation of this negativity provided further evidence that the N400 component ". . . is sensitive to semantic relationships between nonverbal stimuli" (p. 201).

In addition to the results with the N400, Barrett and Rugg (1990) reported that a second component (labeled the N300) was also larger to non-matching than matching targets. However, the N300 was more frontal in distribution and onset somewhat earlier. They pointed out that no language study has reported such a component and speculated that it might be specific to picture processing.

Latency and distributional differences aside, Barrett and Rugg's (1990) findings with the picture N400 would appear to be consistent with arguments for a common conceptual memory system. This interpretation was recently bolstered by the results of another ERP study. Nigam, Hoffman, and Simons (1992) directly compared the processing of line drawings to the processing of words. Sentences were presented visually, one word at a time, with the last item in the sentence presented either as a word (one group of subjects) or a line drawing (a second group of subjects). They found larger negativities (N400s) to anomalous words and anomalous pic-

tures than to semantically congruous words and pictures. The authors reported no differences in amplitude, latency, or scalp distribution between the negativities elicited by words and those elicited by pictures and, as a result, concluded that these N400 effects reflect activity in an amodal, abstract semantic system.

Although Nigam et al.'s conclusion may turn out to be correct, there are a number of reasons suggesting that it may be somewhat premature. First, because their picture task required reading a highly contextually constraining word-based sentence frame prior to the presentation of the sentence-terminating picture, the observed N400 effects could easily have resulted from some type of linguistic or imagistic mediation. That is, the priming effect might have taken place wholly within a language or an image specific system (as opposed to an amodal system). For example, because the sentence frames were of high contextual constraint subjects might have predicted final words and then used this predicted word to generate the appropriate image. When the sentence final picture was presented it would either mismatch or match this image, thus generating or failing to generate an N400. The point is that this could be construed as a "picture" specific response, as opposed to an amodal response. Nigam et al. argue against this type of interpretation based on the similar time course of picture and word negativities and the non-significant differences in scalp distribution between modalities. However, because they used very few electrode sites (none of which were over frontal areas), it is unclear how to interpret their failure to find distributional differences. Unlike N400s to visual words, the results of Barrett and Rugg (1990) suggest picture negativities are as large at frontal sites as they are at more posterior sites.

### THE CURRENT STUDY

As mentioned above, Barrett and Rugg (1990) used line drawings in their investigations of ERP semantic priming effects. However, the task employed was a relatedness judgement task. There are at least two problems with this design: first, it confounds the hand of responding and, more importantly, the subject's decision with the critical levels of the independent variable of interest (related/unrelated). In other words, the decision and overt behavioral response differ for the two critical levels of the independent variable of interest. Second, it *requires* the subject to make an overt semantic comparison. This becomes a particular problem when comparing these results to findings from the lexical decision semantic priming task (LDT), which is the dominant procedure used in word processing studies. In the LDT the semantic comparison of the prime

<sup>1</sup> In Paivio's dual-coding theory this could happen due to words and images being connected via what Paivio calls "referential" links between the verbal and image systems.

and target is generally thought to be more subtle. This is because the LDT does not mandate prime/target semantic comparisons, although it is usually argued that subjects use such information to help them make their decision. So, one question that remains after the Barrett and Rugg study is, would N400-like effects be present in a picture-pair ERP experiment if the task did not overtly require the subject to semantically compare the prime and target? Since most of the relevant ERP work using pairs of words has involved the LDT, the findings of a picture priming study that is modeled on the LDT is particularly relevant when making comparisons across modalities.

The specific purpose of the present study was to extend the findings of Barrett and Rugg (1990) by (a) using a task that is more directly comparable to procedures used to study word priming (b) examining a wider array of scalp sites so that more complete comparisons with language studies could be made. This was accomplished by using an object decision task (Kroll & Potter, 1984) in a paradigm similar to the original semantic priming paradigm of Meyer and Schvaneveldt (1971), and by recording ERPs from many of the same scalp sites that have been used in a number of word pair and sentence priming studies (e.g., Holcomb, 1993; Holcomb & Neville, 1990, 1991; Kutas et al., 1988).

On each trial subjects were presented with two line drawings (prime and target). A total of 150 pairs were presented with one third of the target pictures being related to the prior prime picture, one third of the target pictures being unrelated to the prime picture and the remaining one third of the targets being non-objects that were unrelated to the prime picture. All of the primes and all of the real picture targets were taken from the Snodgrass and Vanderwart (1980) set of standardized pictures. The non-object targets were selected from the similar study of Kroll and Potter (1984).

Following studies which have used words as stimuli (e.g., Bentin et al., 1985; Holcomb, 1988, 1993) and the picture study by Barrett and Rugg (1990), it was predicted that the unrelated and non-object target pictures would elicit: larger N400s than related target pictures. Further, it was predicted that both non-objects and unrelated real objects would produce a larger anterior N300 than related real pictures. Finally, based on the results of Nigam et al. (1992), it was predicted that the scalp distribution of the picture N400 would be similar to that seen in previous word pair priming studies.

## METHOD

### *Subjects*

Twelve right-handed, native English speaking, volunteers were used (five males) as subjects.

### *Stimuli*

The stimuli consisted of 100 related pairs of line drawings taken from the Snodgrass and Vanderwart (1980) norms. To these 100 pairs 50 additional pairs of line drawings were added for a total of 150. The latter category consisted of real object primes (also from Snodgrass & Vanderwart) and unreal non-object targets (taken from Kroll & Potter, 1984). As stated by Kroll and Potter (1984) these non-objects were ". . . line drawings of closed figures with an object-like appearance, created by tracing parts of drawings of real objects and regularizing the results" (p. 41). All prime and target pictures were digitized with a Logitech Scanman hand scanner (200 dots per in. resolution) and saved as bit mapped files on the hard disk of a microcomputer. At stimulus presentation time the images were displayed on a 20-in. NEC monitor (Model 5D) as black line drawings on a uniform white background. Each picture subtended 7° of horizontal and 8° of vertical visual angle.

The targets consisted of the following three categories: (1) real objects Related to the prime, (2) real objects Unrelated to the prime, and (3) Non-objects (also unrelated to the prime). From these stimuli two lists were generated each with 50 Related, 50 Unrelated, and 50 Non-object pairs. The lists were formed so that the primes and targets used as Related in list 1 were mixed and used as Unrelated pairs in list 2. Likewise, the Unrelated pairs from list 1 were rematched with their semantically appropriate primes and formed the Related pairs in list 2. The Non-object pictures were the same for both lists. Six subjects received list 1 and six received list 2. This design resulted in each prime and target picture being seen exactly once by all subjects and across subjects each real-object target picture occurring an equal number of times in both the Related and Unrelated conditions.

### *Procedure*

Subjects were given a brief tour of the laboratory and following electrode placement (see below) were seated in front of a computer monitor (20 in. NEC 5D) in a sound attenuated, electrically shielded room. A typical trial proceeded as follows. The trial started with the presentation of a picture (400 msec duration) and was followed by a 635-msec interval during which the screen was blank. Following the blank interval a second picture was presented (400 ms duration) and then the screen was again blanked for 1100 msec. After the blank screen the word "blink" appeared on the screen marking the beginning of the inter-trial interval. Subjects were told they could blink and move their eyes during this interval. Five-hundred milliseconds prior to the presentation of the next trial the screen was again blanked warning the subject to prepare for the next stimulus.

Subjects were told to watch the first picture (prime) of the pair, which was always a common recognizable object, and that this would prepare them for the second picture (target). They were informed that the second picture of each pair would sometimes be a line drawing of a common recognizable object and other times it would be a drawing of an unusual unrecognizable object. Subjects were asked to indicate whether they recognized the second picture by pressing one of two buttons on a pad resting in their lap. They were to respond by pressing the "yes" button if the object was recognized and the "no" button if the target depicted a non-object. The subjects were told to press the appropriate button as fast as possible, but to retain accuracy in the task. The selection of right/left thumb for the "yes" button was counterbalanced over subjects and lists.

<sup>2</sup>Barrett and Rugg (1990) used 2 x 2° pictures. We felt that images of this size were much smaller than the size subjects are normally used to dealing with, so we piloted several larger visual angles before selecting the current values. This was done by carefully monitoring eye movements to make sure that the selected size did not result in a significant number of vertical or horizontal eye movements that might contaminate the ERPs.

Prior to the experimental run a practice block consisting of 12 pairs of pictures was used to acclimate the subject to the task. The images used for practice were not used in the main experiment.

*ERP recording.* An electrode cap (Electro-Cap International) was used to hold the 13 active electrodes to the scalp. The locations for these electrodes included seven standard international 10-20 system locations: F7, F8, O1, O2, and three midline sites (Fz, Cz, and Pz). Six additional scalp sites were employed in a pattern previously used in ERP language studies (e.g., Holcomb, 1993; Holcomb & Neville, 1991). These included the following three pairs: (1) left and right temporal-parietal, which were over Wernicke's area and its right hemisphere homologue (WL and WR-30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz); (2) left and right temporal (TL and TR-33% of the interaural distance lateral to Cz); and (3) left and right anterior-temporal (ATL and ATR-50% of the distance between T3/4 and F7/8). These sites were all referenced to the left mastoid and the impedance between each recording site and the reference was reduced to below 5K. ohms. Readings were also taken from the right mastoid to check the assumption that the mastoid area was essentially electrically neutral. Two electrodes (left mastoid reference) were placed to monitor for eye artifacts: one beneath the left eye (to check for eye blinks and vertical eye movements), and the other to the right of the subject's right eye (to check for lateral eye movements). A final electrode was placed over the right mastoid and referenced to the left mastoid to verify that lateral differences seen at scalp sites was not due to differential activity at the mastoids.<sup>3</sup>

The EEG was amplified by a Grass Model 12 Neurodata Acquisition system (-3db cutoffs of 0.01 and 100 Hz) and continuously digitized (200 Hz) by an IBM AT compatible microcomputer. The raw EEG was stored on the hard disk of the AT computer.

*Data analysis.* Off-line, EEG epochs for the three target conditions (Related, Unrelated, and Non-object) were averaged separately to form the ERPS for each respective condition. Only target epochs free from artifact due to eye movements or amplifier blocking were included in the ERP data analyses. Also only data for which a correct answer was provided between 200 and 1500 ms after the target onset were used in the ERP and RT analyses.

Following Barrett and Rugg (1990) the target ERPS were quantified by calculating mean amplitudes (baselined to the average of the 100 msec epoch pre-target onset) within three latency windows: 200 to 325 ms, 325 to 550 and 550 to 900 ms.<sup>4</sup> Finally, as several previous studies have shown different patterns of lateral asym-metries for ERPS recorded in the interval between primes and targets (e.g., Barrett & Rugg, 1989), the ERP data time locked to the presentation of the prime pictures (averaged across all the relatedness conditions) were quantified by measuring the mean amplitude between 200 and 600 msec and between 600 and 1000 msec.

The approach to data analysis involved the use of repeated measures ANOVAs (BMDP2V) with one, two, or three independent variables. These included three levels of Target Type (Related vs. Unrelated vs. Non-object) for RT, accuracy and each of the target ERP measures, and for ERP measures also included either three (midline sites-Fz vs. Cz vs. Pz) or five (lateral sites-Frontal vs. Anterior Temporal vs. Temporal vs. Wernicke's vs. Occipital) levels of Electrode Site and two levels of Hemisphere (lateral sites only-Left vs. Right). In cases with a significant main effect or interaction involving the Target Type variable, planned contrasts between the levels of this variable were

<sup>3</sup>There were no appreciable differences in the left mastoid recordings for any of the comparisons of interest.

<sup>4</sup>For the two earliest epochs we used slightly different ranges than those of Barrett and Rugg (200 to 325 msec vs. Barrett and Rugg's 250 to 350 msec and 325 to 550 msec vs. Barrett and Rugg's 350 to 550 msec). We choose our values based on the peak of the N300 at F7 and F8, which was about 240 msec (see Figs. 1 and 2).

TABLE 1 Mean Reaction Times in Msec (standard deviations) and Error Percentages (Standard Deviations) for the Three Target Types

	Related	Unrelated	Non-object
Reaction time	625 (97)	632 (106)	754 (142)
Error rate	3.3%(4.7)	5.8% (4.3)	2.5% (5.0)

performed (Related vs. Unrelated vs. Non-object). A final set of analyses were performed contrasting the five electrode sites and two hemispheres for the prime ERPs. The Geisser-Greenhouse correction (Geisser & Greenhouse, 1959) was applied to all repeated measures with greater than 1 degree of freedom.

## RESULTS

### *RT and Accuracy Analyses*

In the RT analyses there was a main effect of Target Type ( $F[2, 22] = 30.4$ ,  $p < .00001$ -see Table 1). Planned follow-up analyses did not reveal a significant difference between Related and Unrelated targets, but did demonstrate a difference between Unrelated and Non-object targets ( $F(1, 11) = 31.99$ ,  $p < .0001$ ). Unlike RT the accuracy data did not produce a significant difference between the Target Types (see Table 1), although the difference between the Related and Unrelated conditions approached significance [ $F(1, 11) = 3.86$ ,  $p < .075$ ].

### *ERP Analyses*

As can be seen in Figs. 1 and 2 the target ERPs from this experiment produced an early anteriorly distributed negative-going component which peaked at about 25 ms (N1). At the most posterior sites (O1 and O2) the ERPs were of opposite polarity (P1) in this same latency range and in the range of the next wave (N1). Note also that O1 and O2 produced a similar, but much later, positive/negative deflection starting at 550 msec; this probably reflects the P1/N1 response to the offset of the stimulus at 400 msec. Following N1, the most anterior lateral sites (F7, F8, ATL, ATR) produced a small positive-going wave (P2) followed by two negativities, one peaking at 250 msec and the second at about 400 msec. The more posterior sites also produced a positivity (P2) and, with the exception of the occipital sites, produced a single negative-going wave. Note that the more posterior negative-going wave did not actually extend past the positive side of the baseline. In general, the negativity near 400 msec, but not the earlier anterior negativity, was more negative over the left hemisphere. The exception to this was with Non-objects ERPs, which appeared to produce equivalent negativities across the hemispheres at anterior

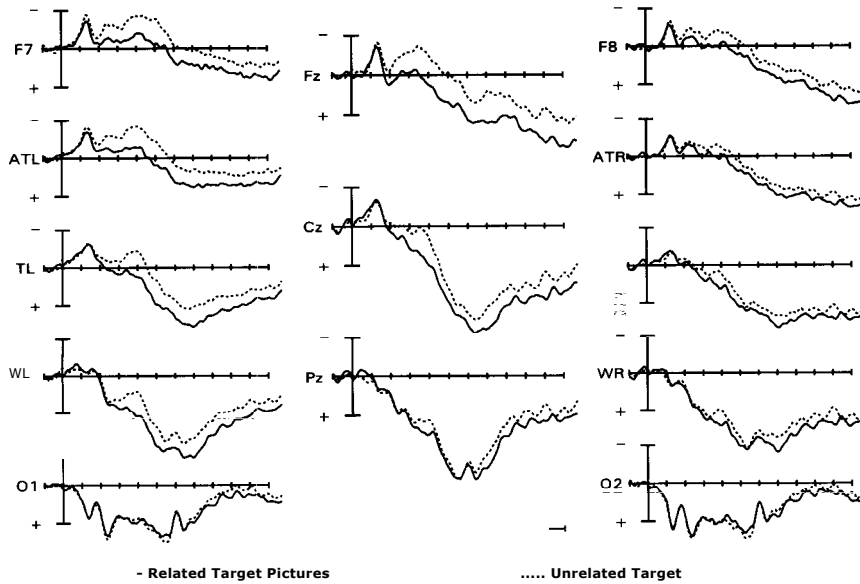


Fig. 1. Plotted in this figure are the grand average ERPS for the Related (solid) and Unrelated (dashed) target pictures. Stimulus onset is the vertical calibration bar (5 microvolts -negative up) and x-axis ticks are in 100 msec. increments.

sites (see Fig. 2). After the late negative wave all sites had a broad positive deflection that started between 300 and 600 msec (later at anterior sites). This wave was probably some combination of the P3 component and a later slow wave response (Ruchkin, Sutton, Kietzman, & Silver, 1980).

The prime ERPs (Fig. 3) produced a similar set of components to those seen for the targets (N1, P2, N400) with a few exceptions. First, the P2 at the temporal and Wernicke's sites was more clearly defined in the prime ERPs. Second, while the anterior sites produced a slow late positivity similar to that found for the targets, the more posterior sites did not appear to produce the P3-like wave seen for targets. Finally, in place of the posterior late positivity the prime ERPs generated a slow negative response reminiscent of the contingent-negative variation (CNV-e.g., Walter, Cooper, Aldridge, McCallum, & Winter, 1964).

*Targets: 200 to 325 msec.* Examination of Figs. 1 and 2 show that there were clear differences between the target types in this latency window (main effect of Target Type, midline:  $F(1, 11) = 6.26$ ,  $p < .01$ ; lateral:  $F(1, 11) = 4.99$ ,  $p < .02$ ), but that these differences were not uniform across the scalp (Target Type by Electrode Site interaction, midline:  $F(4, 44) = 13.81$ ,  $p < .0001$ ; lateral:  $F(8, 88) = 31.64$ ,  $p < .00001$ ).

Planned follow-up analyses at the midline sites revealed that the Unrelated

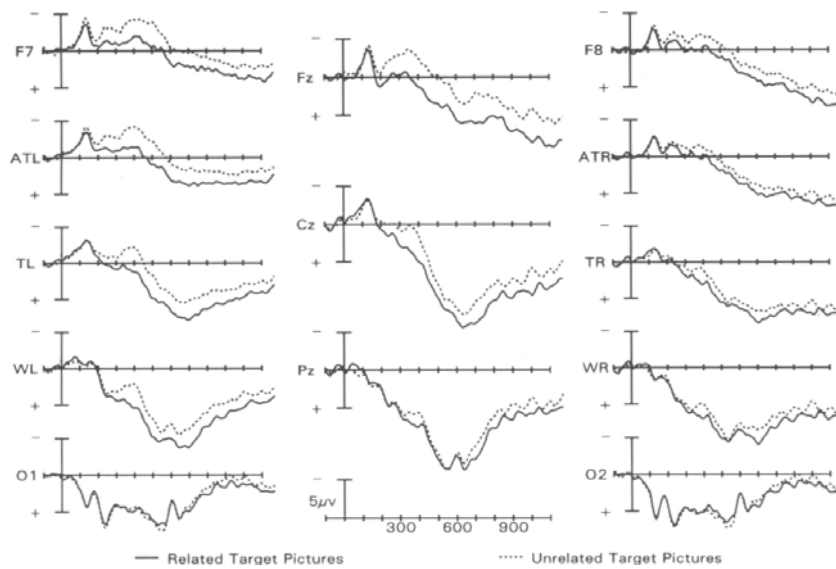


FIG. 2. Plotted in this figure are the grand average ERPs for the Unrelated (solid) and Non-object (dashed) target pictures. Stimulus onset is the vertical calibration bar.

targets were more negative-going than Related targets at the frontal site (Fz), but that this difference was virtually absent at the parietal site (Pz; Target Type by Electrode Site interaction:  $F(2, 22) = 6.19, p < .013$ ). The lateral site analyses produced a similar scalp gradient with the largest difference (Unrelated more negative than Related) frontally and no differences at the occipital sites (Target Type by Electrode Site interaction:  $F(4, 44) = 5.61, p < .015$ ). There were no significant differences in the hemispheric (left vs. right) distribution of this measure.

In the Unrelated/Non-object follow-up analyses a similar pattern was observed at the midline sites. Non-object targets were more negative than Unrelated targets at the frontal electrode, but there was almost no difference at the parietal electrode (Target Type by Electrode Site interaction:  $F(2, 22) = 4.79, p < .036$ ). In the lateral site analysis Non-object targets were more negative than Unrelated targets at the three most anterior electrodes (Temporal, Anterior Temporal and Frontal), but at posterior sites there were either no differences (Wernicke's) or the reverse trend (Occipital) (Target Type by Electrode Site interaction:  $F(4, 44) = 24.03, p < .00001$ ). Also these Unrelated/Non-object distributional effects tended to be greater over the *right* hemisphere (Target Type by Electrode Site by Hemisphere:  $F(4, 44) = 4.52, p < .02$ ).

*Targets: 325 to 550 msec.* As can be seen in Figs. 1 and 2, there was

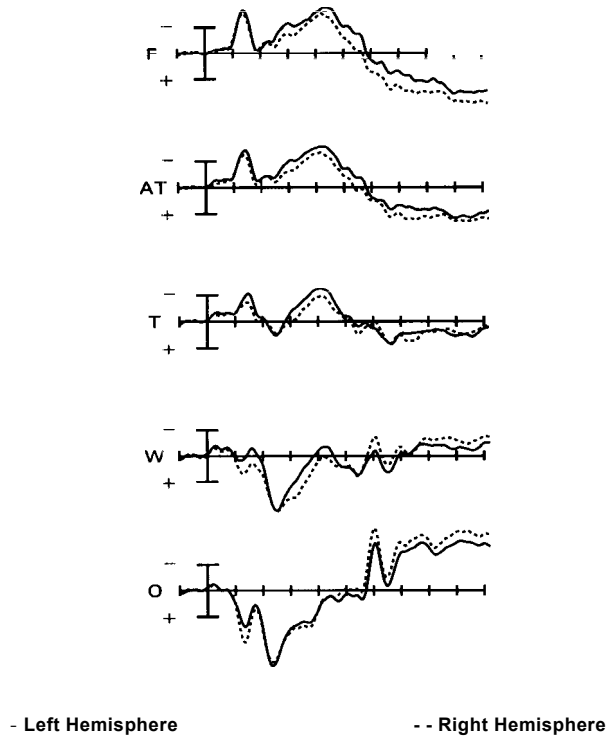


FIG. 3. Plotted in this figure are the grand average ERPs for all the prime pictures. The left (solid) and right (dashed) hemispheres are overlapped. Stimulus onset is the vertical calibration bar which is 2 microvolts.

also a difference between the three target types in this latency window (main effect of Target Type, lateral:  $F(2, 22) = 5.17, p < .022$ ) which varied across the scalp (Target Type by Electrode Site, midline:  $F(4, 44) = 6.20, p < .0035$ ; lateral:  $F(8, 88) = 17.22, p < .00001$ ).

Planned follow-up analyses at the midline sites demonstrated that the difference between target types had a clear frontal distribution in the Related/Unrelated contrast (Target Type by Electrode Site interaction:  $F(2, 22) = 5.43, p < .026$ ). In the lateral site Related/Unrelated follow-up analysis there was a main effect of Target Type ( $F(1, 11) = 5.91, p < .033$ , indicating that Unrelated targets were more negative-going than Related targets. And this difference between the Related and Unrelated conditions was larger over the *left* hemisphere (Target Type by Hemisphere interaction: ( $F(1, 11) = 5.77, p < .035$ ).

At the occipital sites, Related and Unrelated targets produced virtually equivalent measures, but across the remaining sites there was a substantial difference between targets, which did not appear to vary in size (Target Type by Electrode Site,  $F(4, 44) = 5.08$ ,  $p < .035$ ). This observation was confirmed by a second follow-up analysis that failed to find a Target Type by Electrode Site interaction when the occipital sites were removed ( $F = .48$ ), although the main effect of Target Type ( $F(1, 11) = 8.16$ ,  $p < .016$ ) and the Target Type by Hemisphere interaction ( $F(1, 11) = 5.64$ ,  $p < .037$ ) continued to be evident.

Contrasts between the Unrelated and Non-object targets revealed a somewhat different pattern. While the Non-object targets were clearly more negative than the Unrelated targets at the more anterior sites, over the back of the head (occipital sites) the Non-object targets were actually more *positive-going* than the Unrelated targets (Target Type by Electrode Site interaction,  $F(4, 44) = 13.39$ ,  $p < .0002$ ). Also the size of the Nonobject/Unrelated difference was larger over the *right* hemisphere at all but the Wernicke's sites (Target Type by Electrode Site by Hemisphere interaction,  $F(4, 44) = 7.47$ ,  $p < .0093$ ).

*Targets: 550 to 900 msec.* Figures 1 and 2 suggest that there continued to be differences between the three target types in this time period. However, in neither the midline nor the lateral analyses was the main effect of Target Type significant ( $ps > .11$ ), although there was a Target Type by Electrode Site interaction (midline:  $F(4, 44) = 9.04$ ,  $p < .0011$ ; lateral:  $F(8, 88) = 5.75$ ,  $p < .006$ ).

The follow-up analyses indicated a somewhat different pattern than that found in the 325 to 550 msec epoch. In the Unrelated/Related contrast Unrelated targets were consistently more negative than Related targets (midline: ( $F(1, 11) = 5.25$ ,  $p < .043$ ; lateral: ( $F(1, 11) = 6.35$ ,  $p < .029$ ). However, in the Non-object/Unrelated contrast, Non-object targets were more *positive* than Unrelated targets, but mainly at the posterior sites (Target Type by Electrode Site, midline:  $F(2, 22) = 5.66$ ,  $p < .0245$ ; lateral:  $F(4, 44) = 4.23$ ,  $p < .037$ ). Also the anterior/posterior distribution of the difference between Non-object and Unrelated targets was larger over the *right* hemisphere (Target Type by Electrode Site by Hemisphere:  $F(4, 44) = 4.34$ ,  $p < .049$ ).

*Prime analyses.* Plotted in Fig. 3 are the grand mean ERPs averaged across all of the prime pictures in this study. There were no significant lateral asymmetries in the 200 to 600 msec epoch (Hemisphere:  $F = 1.3$ ; Hemisphere by Electrode Site:  $F = 1.2$ ). However, from 600 to 1000 msec there was a difference in the pattern of lateral asymmetries at the front and back of the head (Hemisphere by Electrode Site:  $F(4, 44) = 3.64$ ,  $p < .041$ ). While the right hemisphere was more negative than the left at the two most posterior sites, the right hemisphere was more positive than the left at the two most anterior sites.

## DISCUSSION

### *ERP Findings*

The ERPs revealed clear effects of the Target Type variable, including a substantially larger negativity for Unrelated than Related target pictures between 325 and 550 msec. The Non-object pictures, which were designed to be the picture equivalent of pseudowords, also produced a large negative-going response that was significantly larger than the negativity to Unrelated pictures. These differences have a similar time course to those seen for the N400 component in semantic priming lexical decision tasks (e.g., Holcomb & Neville, 1990). In addition to the larger negativity, the non-object pictures also produced a larger positivity from 600 to 900 msec over the midline and some lateral sites. It seems likely that this difference is due to the P3 or P300 component (see Donchin, 1981) and reflects the extra effort required to update working memory whenever an unusual and unrecognizable non-object was presented.

Along with Barrett and Rugg (1990), who also found a larger negativity to unrelated than related pictures, these data would seem to support the position proposed by Nigam et al. (1992) that the N400 reflects activity in an amodal, abstract semantic system. However, there are at least two problems with this proposal. First, the distribution of the picture N400, at least in the current study, was quite different from that seen for words in analogous LDT studies (e.g., Bentin et al., 1985; Holcomb & Neville, 1990) and sentence studies (e.g., Kutas & Hillyard, 1980). Typically the N400 effect (the difference between primed and unprimed words) is largest over central (Cz) and lateral posterior electrodes (e.g., Wernicke's area) and, at least in reading tasks, is usually slightly larger over the right than the left hemisphere (e.g., Kutas et al., 1988). In the current experiment the N400 effect was largest at the Fz site along the midline, and its distribution over lateral sites was relatively equivalent except over the occipital electrodes where there was no difference between Related and Unrelated targets. Also the N400 effect was significantly larger over *left* hemisphere electrodes.<sup>5</sup> This is a substantial difference in distribution from that seen in language tasks where the N400 effect is almost always larger over more posterior sites and is usually slightly larger over right than left hemisphere sites. Similar results in the Nigam et al. (1992) study might have gone unnoticed as they did not record from sites anterior to Cz and they only used a single pair of lateral electrodes (Wernicke's area).<sup>6</sup>

<sup>5</sup>This point can be seen best in Fig. 1 by comparing the Related and Unrelated conditions at the WR (Wernicke's right) and F7 sites. In most word-pair priming tasks (e.g., Holcomb, 1993) the WR site produces one of the largest priming effects and F7 one of the smallest. Here just the reverse occurs.

<sup>6</sup>The Wernicke's sites did not reveal hemispheric asymmetries in the current study either.

One explanation for the difference in the anterior/posterior distribution of the picture and word N400 is the presence of an overlapping component that only appears to change the distribution of the N400. Evidence favoring this explanation can be found in the similarity of the findings for the 200 to 325 msec measure in the current study and a similar measure in the Barrett and Rugg (1990) report. In both studies, at lateral sites, this time domain produced a significant difference between related and unrelated targets that had a clearly frontal distribution, while the measure of the N400 had a flat scalp distribution (except at occipital sites where there were no differences between related and unrelated targets). Barrett and Rugg referred to the early effect as the N300. If measurement of the frontal N400 effect (which is statistically the same as the more posterior effect) was partly contaminated by residual N300 activity (as would be expected if they overlap in time) then the "true" underlying N400 may, in fact, have a more posterior distribution.

Although this explanation might be partly correct, it cannot explain all of the distributional differences between pictures and words. In particular the absence of an occipital N400 effect in the current picture data is problematical. While the largest N400 differences in language studies are usually not seen at occipital sites, these sites typically do produce effects that are larger than those seen at the most anterior electrodes (e.g., Holcomb, 1988; Holcomb & Neville, 1990; Kutas et al., 1988). It is hard to imagine how an overlapping frontal negativity could have eliminated the occipital effect. It is also hard to see how an overlapping N300, that was not significantly asymmetrical across the hemispheres, could have reversed the lateral asymmetry of the later N400 from that seen in most visual language studies.

Barrett and Rugg (1990) recorded from temporal and frontal sites over the two hemispheres. As reported here, they too found that the picture N400 effect was roughly equivalent across frontal, temporal and parietal lateral sites. They did not record from the midline central (Cz) or frontal (Fz) sites, so it is unclear if they would have found the clear midline frontal distribution for this effect seen here. However, they did not, as found here, report a left hemisphere distribution for the picture N400. One possibility for this is that their temporal and frontal sites were not as laterally placed (by about 25%) as those used in the current study. Another possibility is the difference in the nature of the tasks in the two studies. As this is the first relatively strong *left* hemisphere N400 effect and the first ERP object decision task we are aware of, it is possible that some aspect of the processing brought on by making this type of decision is more strongly reflected by a somewhat different configuration of neural generators. However, relating this lateral asymmetry to a possible left hemisphere processing system is rendered more difficult by its relatively anterior distribution. Had the effect also been seen over left occipital

sites, then it would have been tempting to speculate that a left hemisphere visual system process (e.g., having to do with image formation, Farrah, Peronnet, Gonen, & Giard, 1988; Goldenberg, Steiner, Podreka & Deecke, 1992) might have been contributing to the effect.

There were also significant differences between the Unrelated and Non-object images. With the exception of the most posterior sites, Nonobjects were more negative going between 200 and 550 msec and then became more positive going between 600 and 900 msec than the Unrelated pictures. At the occipital sites Non-objects were actually more *positive* than Unrelated pictures between 200 and 900 msec. The Unrelated/ Non-object difference had a clear *right* hemisphere maximum in the N400 latency range. So, in addition to being more frontal than the Related/ Unrelated differences, Non-object/Unrelated differences also had the opposite lateral distribution. This latter finding is quite different from analogous language studies. Pseudoword/unrelated word differences although sometimes somewhat more anterior in distribution, usually have a similar lateral distribution to that seen for related/unrelated words (e.g., Holcomb & Neville, 1990).

The analyses of the prime ERPS revealed that the CNV portion of the waveform (600 to 1000 msec) was asymmetrical across the hemispheres. However, the direction of this asymmetry varied with the anterior/posterior location of the recording site. At frontal electrodes the left hemisphere was more negative than the right, while the reverse was true for the posterior sites. This posterior right-more-negative-than-left effect was similar to that reported by Barrett et al. (1988) and Barrett and Rugg (1989) when subjects had to match pairs of faces and suggests that this asymmetry may reflect a general right hemisphere picture process that subjects use in the interval between task relevant pairs of pictures. However, the left-more-negative-than-right effect found for the more frontal sites was not reported in any of the Barrett and Rugg picture studies. There are at least three possibilities for this discrepancy at frontal sites. First, the object decision task engaged a somewhat different set of preparatory and/or short-term memory processes than the matching task used by Barrett and Rugg. For example, the maintenance of information about the prime through the prime/target interval would not seem as crucial in the object decision task where the appropriate response can be made without even dealing with the prime. A second possibility is that the differences were due to differences in face and non-face picture processes. Unfortunately Barrett and Rugg (1990) did not report the CNV data from their line drawings study. If the pattern in that study had resembled the pattern seen here then it would suggest that the frontal effect is specific to nonfaces. However, if the pattern of frontal CNVs in their line drawing study had resembled their face results then it would support the task based explanation of the differences. A third possibility is that the

discrepancy in frontal effects was due to differences in the placement of the electrodes. As noted earlier the current study used more laterally located frontal and anterior temporal sites than the Barrett and Rugg studies. Resolution of this discrepancy will require further empirical efforts.

### *Behavioral Findings*

As predicted the RTs to the Non-object targets were significantly slower than the RTs of the Unrelated targets. This suggests that these items appropriately influenced the object decision forcing subjects to use information other than that available in the surface features of the pictures. It was assumed that this "other" information would be conceptual or semantic, as has been shown in the LDT when pronounceable non-words are used. However, unexpectedly, the RT difference between Related and Unrelated target pictures did not support this conclusion. Responses to Unrelated targets were only 7 msec slower, on average, than those for the Related targets. If subjects had been using semantic information to help make the object reality decision, then larger semantic priming effects should have been evident in the RTs.

An earlier study (Kroll & Potter, 1984) found significantly faster RTs for judgements involving related line drawings. However, there were two obvious differences between the current experiment and the Kroll and Potter study. In their study target and prime images were presented simultaneously, while in the current study they were presented sequentially with an onset to onset interval of 1035 ms. This difference in prime/target presentation timing probably contributed to the longer average RT in Kroll and Potter's study. One possible repercussion of the lengthening of the response might have been to give the priming process a longer interval over which to develop, thus increasing its magnitude. Another difference between the current experiment and the Kroll and Potter study was that their subjects had to decide whether either of the two simultaneous stimuli was a Non-object. This probably forced subjects to actively process the meaning of both pictures. In the current study subjects were given no explicit task for the prime stimulus and were only told to look at it. Thus subjects in the current study may not have processed the prime as fully as Kroll and Potter's subjects, which in turn might have weakened the RT priming effect.

Neither of the above arguments fit very well with the robust semantic priming effect found in the ERP data. A final possibility, one that is consistent with the ERP results, is that there was a significant semantic priming effect, but that it was not apparent in the RTs due to the response strategy adopted by subjects. Evidence for this can be found in the accuracy data. Although not significant ( $p < .075$ ), the error rate for the Unrelated targets (5.8%) was somewhat higher than for the Related

targets (3.3%) suggesting that there was a tendency for subjects to trade response speed for a somewhat lower accuracy in the Unrelated condition. So, it is possible that had subjects equated their accuracy between the Related and Unrelated targets that there would have been a significant RT priming effect.

## CONCLUSIONS

Compared to language, the study of ERP measures of picture processing has just barely begun. The results of the current experiment suggest several possible future directions. If ERPs are to be used to help determine if conceptual memory is amodal, then more careful chronometric comparisons of cross-modal processing will be needed. In the case of spoken and written language we have recently reported (Holcomb & Anderson, 1993) that very rapid cross-modal activation of meaning (as measured by N400) can take place when a prime word is presented visually and a target word is presented auditorily. It will be important to determine if a similarly rapid effect occurs between pictures and words. Another important issue is whether the picture N300 can be further dissociated from the N400. In particular, if this negativity reflects activation of a functionally unique population of neurons, then there should be at least one variable to which it (but not N400) is differently sensitive.

Finally, future studies will need to compare the distributional differences and similarities of ERPs recorded to stimuli presented in picture and verbal form. In particular, it will be interesting to see if the lateral asymmetries reported here will hold up in other tasks and with other stimuli (e.g., with pictures of real objects). However, in the meantime, it would seem prudent to be cautious about attributing the N400 to a modality non-specific process.

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