

# An electrophysiological investigation of semantic priming with pictures of real objects

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## Abstract

Event-related potentials were recorded using color pictures of real objects. Participants made relatedness judgments for pictures that were highly, moderately, or unrelated to a picture of a preceding prime object (Experiment 1) or object identification decisions for related/easily identified, unrelated/easily identified, and unrelated/unidentifiable objects preceded by prime objects (Experiment 2). Unrelated pictures elicited larger event-related potential negativities between 225 and 500 ms than did related pictures, although the first portion of this epoch had a more frontal distribution than did the later portion. The later epoch differentiated the unrelated from the moderately related and the moderately related from the highly related pictures (Experiment 1), but the early epoch produced differences only between the unrelated and related pictures (Experiments 1 and 2). This pattern supports the existence of two separate components, an anterior, image-specific N300 and a later, central/parietal amodal N400.

**Descriptors:** ERPs, Picture processing, Semantic priming, Object recognition, N400, N300

Several decades of research have shown faster and/or more accurate responses to stimuli, for example, words such as *nurse* that follow semantically related prime words such as *doctor*. This semantic priming effect has been demonstrated for words (e.g., Carr, McCauley, Sperber & Parmelee, 1982; Marslen-Wilson & Welsh, 1978; Meyer & Schvaneveldt, 1971; Neely, 1976, 1977) and line drawings (e.g., Irvin & Lupker, 1983; Sperber, McCauley, Ragain, & Weil, 1979) as has been demonstrated cross-modally with words and line drawings (Bajo & Canas, 1989; Irvin & Lupker, 1983; Kroll & Potter, 1984; Theios & Amrhein, 1989; Vanderwart, 1984). Such effects have usually been interpreted as reflecting the organization or operation of processes within lexical, object, or semantic memory, in particular those used during word and object recognition. Although a number of theories have been proposed to specify the information processing locus of priming, no single theory has been successful in explaining the range of effects reported in the literature (see Neely, 1991, for a review). However, one approach that has met with considerable success in explaining a large subset of the effects is two-process theory (e.g., Neely, 1976, 1977, 1991; Posner & Snyder, 1975).

According to two-process theory, priming can result from one or both of two mechanisms. The first is thought to be automatic in that it onsets and offsets rapidly, occurs without effort, and places few demands on central processing resources. Most accounts of automatic priming suggest that it works via a mechanism known as spreading activation (Collins & Loftus, 1975), whereby nodes in

lexical or semantic memory are partially activated by the passive spread of activity from related nodes; the premise is that related concepts are richly interconnected. For example, if one reads the word *butter*, activation from the *butter* node will spread along interconnecting links to the nodes representing words such as *bread* and *toast* (among others), partially activating these nodes. If the words *bread* or *toast* are presented a short time later, they will be processed/recognized faster (i.e., they will be primed) than if they had been preceded by a word such as *table*, to which they are not linked. A similarly organized system is presumed to underlie picture/object recognition (e.g., Vanderwart, 1984), although the existence of cross-modal priming effects suggests that both pictures and words might automatically access a common amodal semantic system (e.g., Kroll & Potter, 1984).

The second mechanism thought to underlie priming under certain circumstances is effortful or attentional processing. Attentional processing occurs when participants are encouraged to attend to the relationship between prime and target items and to consciously use this information to aid in target processing. Compared with automatic spreading activation, attentional priming is relatively slow to onset, lasts over longer intervals, and places a drain on central processing resources (Posner & Snyder, 1975). Because of this resource drain, attentional priming is associated with costs; processing can be slowed beyond a neutral baseline if one attends to inappropriate information. The advantage of attentive processes is that they are powerful and are not limited by the existence of direct links in semantic or lexical memory. For example, using attentive processes a participant could realize that words denoting building parts are predictive of the names of birds. This information could then be used to facilitate processing of bird names (Neely, 1977).

This research was supported by grant HD25889.

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Event-related brain potentials (ERPs) are sensitive to semantic priming. Bentin, McCarthy, and Wood (1985) demonstrated that semantically primed written words produce a significantly smaller late negative wave than do unprimed words. They and others (e.g., Holcomb, 1988; Rugg, 1990) have suggested that this negative wave belongs to the N400 family of potentials, first reported for words in a sentence context (e.g., Kutas & Hillyard, 1980). Subsequent studies have demonstrated that the N400 is sensitive to the type of process engaged during priming. In tasks requiring automatic processing, N400 effects have been relatively small (Holcomb, 1988) or absent (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; West & Holcomb, 1998). However, in tasks involving deeper or attentive processing (e.g., semantic categorization, matching tasks, or attentive lexical decision), larger N400 priming effects have been found (e.g., Holcomb, 1988; Chwilla et al., 1995; West & Holcomb, 1998). These findings (and others) have been used to argue that the N400 to words reflects a post-lexical process and is relatively insensitive to automatic spreading activation. One possibility is that the N400 reflects the process whereby semantic information is integrated into a higher level conceptual representation (e.g., Brown & Hagoort, 1993; Holcomb, 1993); larger N400s are associated with more effortful integration.

As in the research on reaction time (RT), N400 semantic priming effects have also been demonstrated for simple line drawings (Barrett & Rugg, 1990; Holcomb & McPherson, 1994) and cross-modally between words and line drawings (Ganis, Kutas, & Sereno, 1996; Nigam, Hoffman, & Simons, 1992). Nigam et al. (1992) presented participants with sentences that ended with either a word or a line drawing in an effort to determine if words and pictures access a common semantic system. They reasoned that if separate semantic systems exist for pictures (images) and words, then this difference should be reflected in modality-specific N400 distributions. Incongruous pictures and words at the ends of sentences elicited larger N400s than did congruous words or pictures, and there were no differences in amplitude, latency, or scalp distribution of the N400s. The authors concluded that pictures and words access a common amodal semantic system (see Snodgrass, 1984).

However the failure of Nigam et al. (1992) to find distributional differences may have been due to their restricted electrode montage (five sites), which did not include frontal placements. In a replication and extension of that study, Ganis et al. (1996) used an extended recording montage (26 sites) and confirmed that pictures at the ends of sentences produce an N400-like effect that has a time course similar to that seen for words. However, the picture N400 had a significantly more frontal distribution that occurred earlier than the comparable word effect. This finding could be interpreted as supporting multiple semantic store theories, such as Paivio's dual-coding model (1990), where image and linguistic codes are proposed to be represented and processed in separate systems.

In two studies semantic priming effects have been investigated using pairs of pictures. Barrett and Rugg (1990) used sequentially presented pairs of line drawings of common objects in a relatedness judgment task. In this task, participants were asked to determine if the prime and target stimuli were semantically related or unrelated. Barrett and Rugg found larger N400s for unrelated than for related items and an earlier negativity at about 300 ms (N300) that, like the N400, was larger for unrelated pictures but was more frontally distributed than the N400. Other researchers had not reported N300-like components for words, so its occurrence with pictures was cited as possible evidence that the neural systems

involved in the semantic processing of objects differs from those used in the semantic processing of words.<sup>1</sup>

In a similar study, Holcomb and McPherson (1994) asked participants to make speeded object decisions about target pictures (line drawings) that were preceded by semantically related or unrelated pictures. Two-thirds of the targets depicted real objects and the other third were unrecognizable nonobjects. Their findings replicated the priming effects reported by Barrett and Rugg (1990), with unrelated targets generating larger N400s and N300s than related targets. The N300 was again larger at more anterior sites.<sup>2</sup> However, unlike Kroll and Potter (1984), they did not report a significant RT priming effect; unrelated target pictures were responded to only a nonsignificant 8 ms more slowly than were related pictures.

## EXPERIMENT 1

Although Barrett and Rugg's (1990) and Holcomb and McPherson's (1994) studies established that pictures in semantic priming tasks produce N400-like effects, they leave a number of important issues unresolved. First, is the picture N400 more frontal than the verbal N400, or is the apparent frontal distribution due to overlap with a second, earlier negativity? Ganis et al. (1996) suggested the former, but some support for the latter possibility was provided by Barrett and Rugg, and Holcomb and McPherson. If the picture N400 is not as frontal as has been suggested by these studies, then Nigam et al.'s (1992) conclusion about the N400 reflecting activity in an amodal semantic system may be correct.

Second, is the picture N400 priming affect sensitive to the same manipulations that effect the verbal N400? For example, are differences in the strength of the relationship between primes and targets reflected in the picture N400? Work with words suggests that the verbal N400 is sensitive to such manipulations (e.g., Kutas & Hillyard, 1988). Finding a similar pattern for picture N400s would bolster claims that these components reflect a similar, if not the same, information process (e.g., Nigam et al., 1992).

Third, are the N400s and N300s reported for pictures specific to simple line drawings? All of the stimuli in these ERP picture studies used stimuli of this simple type (Barrett & Rugg, 1990; Ganis et al., 1996; Holcomb & McPherson, 1994; Nigam et al., 1992), and although the putative semantic nature of the N400 suggests that it should be obtained with more complex pictures, this question has yet to be addressed empirically. Prior picture N400s may have resulted entirely or in part from an atypical process that is not used during normal object recognition because the inherently more abstract nature of line drawings (e.g., due to lack of detail and lack of idiosyncratic features) may encourage the use of linguistically mediated processing.

<sup>1</sup>Barrett and Rugg (1990) investigated the possibilities that visual similarity between related pairs caused the N300 because the related pairs were rated more visually similar than were the unrelated pairs. They reaveraged the data of the most similar and least similar pairs and found no significant differences due to visual similarities.

<sup>2</sup>Like the N300 reported by Barrett and Rugg (1990) this component was maximal over frontal sites. The components reported here and by Barrett and Rugg appear to be from similar processes, but the time course seems to have been altered by different presentation methods. The stimuli used by Barrett and Rugg subtended angles of 2° by 2° in the visual field, whereas the pictures in the other studies subtended angles of 7° by 8°. Theios and Amrhein (1989) demonstrated that stimuli that subtend angles of less than 3° are processed significantly more slowly than are larger stimuli. The smaller visual angles in the study by Barrett and Rugg could have slowed down the processing associated with the N300.

Experiment 1 had three interrelated goals. The first was to determine if N400 semantic priming effects could be obtained with color pictures of real objects. If the pattern of N400 effects seen in prior ERP picture studies were due to the processing of simple line drawings in an atypical fashion (e.g., via verbal mediation), then the pattern of N400 effects in the current experiment would be different or possibly even absent. However, if the effects from prior picture studies were due to activity in an amodal semantic system or a picture specific semantic system, then a similar pattern of larger N400s to unrelated as compared to related pictures would be obtained.

The second goal was to determine if the anterior distribution of negativities seen in previous picture priming studies was the result of a single anterior N400-like component (Ganis et al., 1996) or whether there are actually two overlapping components (Barrett & Rugg, 1990; Holcomb & McPherson, 1994).

The final goal was to determine if the picture N400 priming effect is sensitive to the strength of the semantic relationship between the prime and target pictures. Prior studies with words have suggested that different types or degrees of relationship can affect the amplitude and possibly the latency of the N400 (e.g., Kutas & Hillyard, 1988). As in the previous word studies, we predicted that target pictures from pairs rated as moderately related would generate N400s of intermediate amplitude when compared with targets from highly related and unrelated pairs.

To accomplish these goals, a relatedness judgment task much like that used by Barrett and Rugg (1990) was employed. Participants were instructed to respond on one button labeled *yes* if they perceived a target picture as semantically related to the previous prime picture and to respond on another button labeled *no* if they perceived the target picture as semantically unrelated to the prime picture. This task requires that participants pay explicit attention to the prime/target relationship, which prior work with words has shown results in robust N400 priming effects (e.g., Holcomb, 1988).

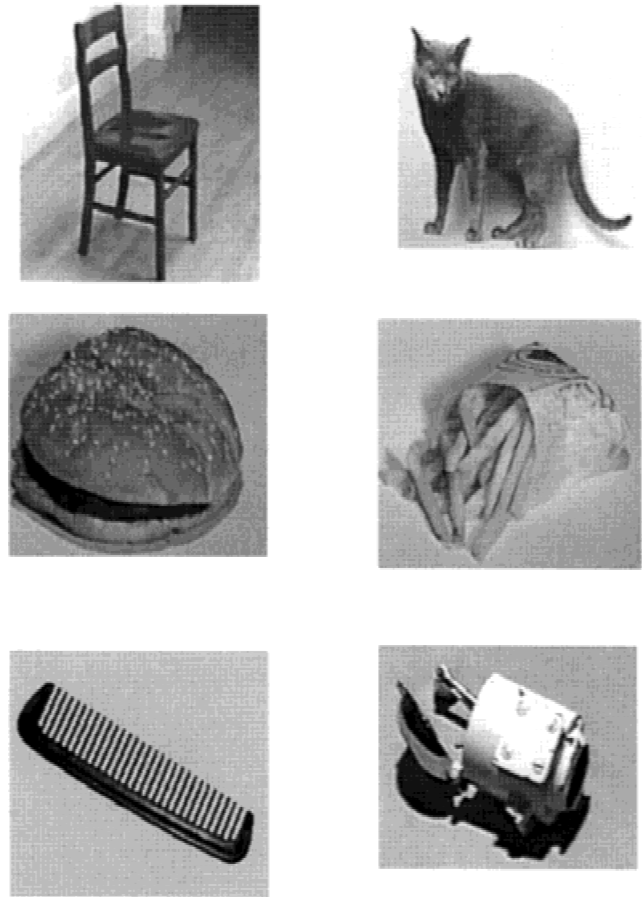
## Methods

**Participants.** Twelve right-handed native English-speaking volunteers participated in the study (8 men, 4 women; mean age = 21.5 years). All were from the Tufts University Psychology participant pool consisting of Tufts undergraduates taking introductory psychology courses. None of the participants had previously participated in an ERP experiment.

**Stimuli.** All pictures were of real objects and were taken in color with a video camcorder. The images were digitized using a Truevision Targa16 board inside a personal computer. This system allowed the experimenter to capture video input directly from the camcorder and to display the image on a computer monitor with a depth of 32,768 colors. For most of the pictures, the item appeared alone against a light brown background. However, some of the larger images were taken from other settings (see Figure 1 for example stimuli).

In constructing related pairs, several approaches were used. Most of the pairs were based on objects used in a number of prior line drawing priming studies (e.g., Holcomb & McPherson, 1994). However, real examples of these objects were digitized for this experiment. In addition, a large number of household, office, and neighborhood objects were recorded and digitized.

Prior to the ERP experiment, two rating studies were performed. In the first study, 9 undergraduate participants were asked



**Figure 1.** Sample stimuli used in the two experiments (these items were presented in color during the experiments). On the left are prime pictures and on the right target pictures. The top row is an example trial from the unrelated condition in both experiments, the middle row is an example trial from the highly related (Experiment 1) and related (Experiment 2) conditions, and the bottom row is an example trial from the unidentifiable condition in Experiment 2.

to identify 280 pictures of objects. Each picture was presented under the same stimulus conditions as the ERP experiment. The participant's task was to rapidly identify (verbally) the object in each picture. Only pictures where at least 7 of 9 participants correctly identified the object within 2 s were retained and of the 240 images selected, 90% were identified by all 9 participants.

A second rating experiment was performed with 8 new volunteers. These participants were shown the pictures retained from the first rating study, but these were organized into pairs. Their task was to rate how semantically related the objects in the two pictures were on a 7-point scale, where 1 = not at all related and 7 = highly related. The 120 pairs (relatedness range, 6.5–2.5) were split at the median (4.2) and placed in either the highly related ( $M = 5.9$ ) or moderately related ( $M = 2.8$ ) conditions.

From the master list of 60 highly related and 60 moderately related pairs, two sublists were formed, each consisting of 30 highly related, 30 moderately related, and 60 unrelated pairs. Unrelated pairs were formed by rearranging highly and moderately related primes and targets. The mean relatedness rating for the highly and moderately related items in each sublist were held constant. Six participants viewed one group, and the other 6 par-

ticipants viewed the second group. Each participant was exposed to each target picture only once, although across the two lists each target occurred once in both the highly/moderately related and unrelated conditions.

The angles that each picture subtended were held constant at 7° on the horizontal axis and 8° on the vertical axis. Although this angle exceeds the size of foveal vision, pretesting with pilot participants suggested that the critical features of the stimuli could be extracted without significant horizontal or vertical eye movements.

**Procedure.** Participants were given brief individual tours of the lab and then a detailed description of the task they were to perform. They were informed that they would be viewing pairs of pictures of objects taken with a video camera and digitized for presentation by the computer. The first picture of the pair appeared for 400 ms and was followed by a 600-ms interval during which the screen was blank. The second picture then appeared for 400 ms, followed by a 1,600-ms blank screen. Finally, a green "x" appeared on the screen signaling the beginning of the intertrial interval and indicating that the participant could blink or otherwise move their eyes without interfering with data collection. After a 2.5-s intertrial interval and 500 ms prior to the start of the next trial, the green "x" disappeared.

For each pair of pictures, participants were told to watch the first picture of the pair, a common recognizable object, in preparation for the second picture. Participants were informed that they would view pictures of target objects that would be either semantically related or unrelated to the object in the first picture and that the *yes* button should be pressed for related targets and the *no* button should be pressed for unrelated targets. A practice run consisting of 12 pairs of pictures (6 related) was used to familiarize participants with the task. The experiment was conducted as a single session divided into several blocks of approximately 30 trials each. One-minute rest breaks were given between blocks.

**ERP recording.** The electroencephalogram (EEG) was recorded from 13 tin electrodes attached to an electrode cap (Electrode-Cap International). Locations included seven standard international 10–20 system sites over lateral frontal (F7 and F8) and occipital (O1 and O2) sites and three midline sites (Fz, Cz, and Pz). In addition, six sites used in previous ERP language studies were included (e.g., Holcomb & Neville, 1990): (a) left and right temporoparietal (TPL and TPR, located 30% of the interaural distance lateral to a point 13% of the nasion–inion distance posterior to Cz), (b) left and right temporal (TL and TR, located 33% of the interaural distance lateral to Cz), and (c) left and right anterior temporal (ATL and ATR, located 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 5 kohms. Recordings were also taken from the right mastoid, beneath the left eye (blinks/vertical eye movements), and to the right of the right eye (lateral eye movements).

Participants sat in a comfortable chair in a sound-attenuated, electrically isolated room equipped with a two-way voice intercom in front of a computer monitor. Continuous EEG recording was taken and amplified by a Grass Model 12 Neurodata Acquisition system using a band pass filter with  $-3$  db cutoffs of 0.01 Hz and 100 Hz. The amplified EEG was sent to a microcomputer equipped with an analog-to-digital converter. The computer digitized the EEG at a rate of 200 Hz, stored the data on disk, and displayed a continuous record of EEG during the experiment. Off-line trials for which a correct response was provided between 200 and 2,000 ms

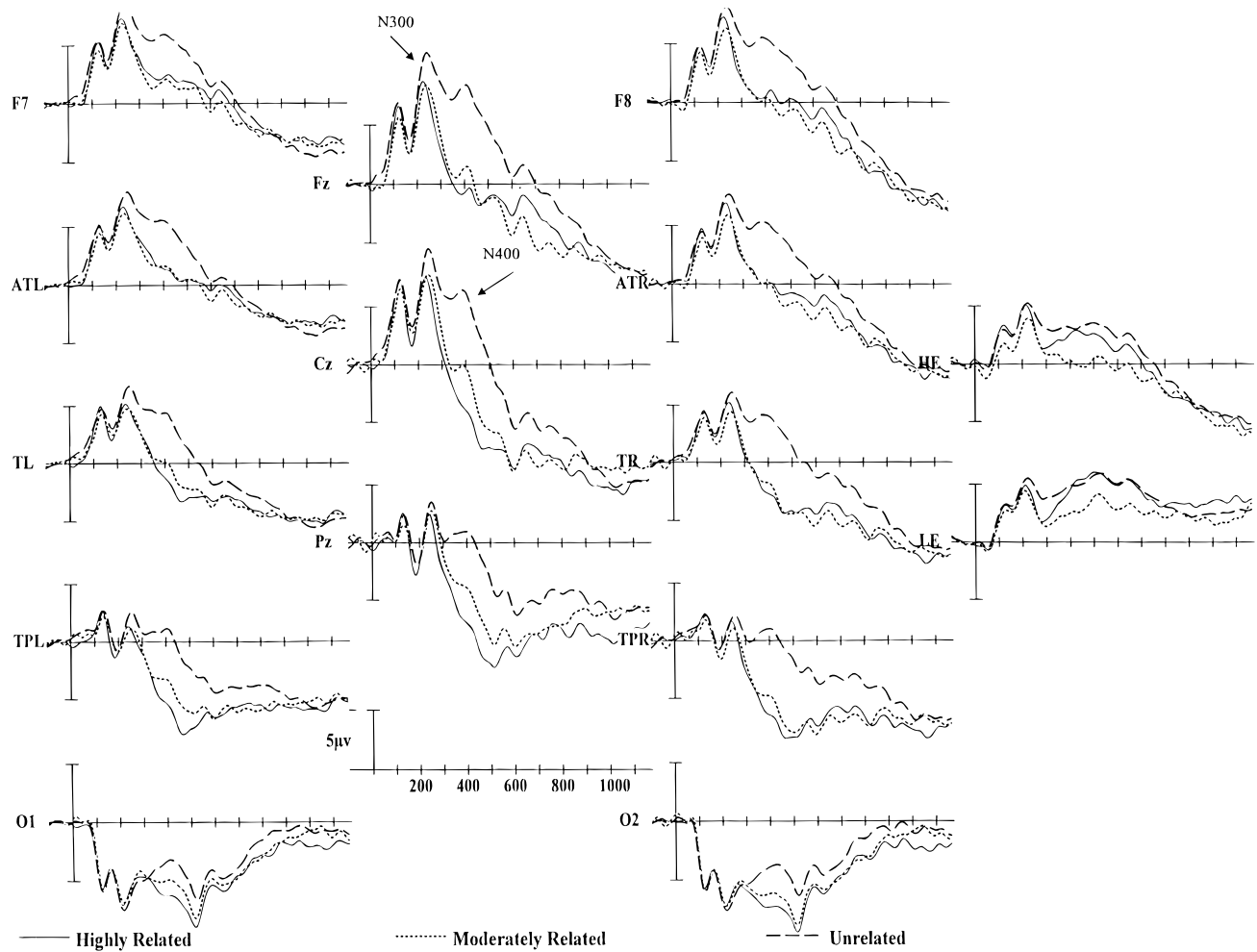
after the target onset were averaged into the various target conditions (epoch length = 100 ms before target onset to 1,187 ms after target onset). All trials with vertical or horizontal eye activity exceeding 60  $\mu$ V were automatically rejected. Moreover, if after inspection of the averaged activity at the eye channels there was evidence of residual eye artifact contamination, a lower artifact threshold was used during reaveraging until "clean" eye channel averages were obtained. After averaging, the ERPs were rereferenced to an average of the left and right mastoid.

**Data analysis.** The ERP data were quantified by calculating the mean amplitudes within windows relative to the 100 ms period prior to target onset. The epochs used were 225–325 ms, 325–500 ms, and 600–1000 ms. All analyses were performed using within-subjects analyses of variance (ANOVAs) with one, two, or three variables. Midline and lateral sites were analyzed separately. ANOVA variables were target type (highly related vs. moderately related vs. unrelated), electrode site (three midline sites: Fz vs. Cz vs. Pz; five lateral sites: frontal vs. anterior temporal vs. temporal vs. temporoparietal vs. occipital), and, for lateral sites, hemisphere (left vs. right). RT and error analyses used the single within-subject variable of target type. If a significant main effect or interaction involving target type was found, these analyses were followed with planned contrasts of highly related versus moderately related and moderately related versus unrelated. To determine if the N300 and N400 were generated by nonidentical neural generators, an analysis was performed contrasting the 225–325-ms epoch and the 325–500-ms epoch (the latency variable: early vs. middle). Because the hypothesis was that the N300 has a more anterior distribution than the N400, this analysis was performed contrasting the TPL/R and F7/8 sites. As recommended by McCarthy and Wood (1985) significant Target Type  $\times$  Electrode Site interactions were followed up by analyses of normalized amplitude values. Normalization was accomplished using a *z*-score procedure in which amplitudes are scaled within each level of relatedness to a mean of 0 and a standard deviation of 1 (see Kounios & Holcomb, 1994). Only normalized interactions are reported. Significant Target Type  $\times$  Electrode Site interactions were decomposed with simple effects tests to determine the scalp distribution of the effects. The results of these tests are reported by indicating which member of a pair of sites produced statistically larger (e.g., Fz > Cz) or equivalent (e.g., TPL/R = TL/R) effect sizes. The Geisser–Greenhouse correction (Geisser & Greenhouse, 1959) was applied to all repeated measures with greater than 1 degree of freedom.

## Results

**ERPs.** On average, about 7% of trials were rejected for vertical or horizontal eye artifacts (highly related = 8%, moderately related = 7%, unrelated = 7%). As can be seen in Figure 2, the waveforms from this experiment elicited a negativity peaking at approximately 120 ms (N100) followed by a positive-going potential with a peak between 180 and 200 ms (P200) and a second negative potential peaking between 200 and 300 ms (N300). The amplitude of the two negative potentials tended to decrease moving toward more posterior sites. At the most posterior lateral sites (O1/O2) there was a different pattern, which included a P100, N150, and P200. The early components were followed by a prominent, widely distributed negativity, which peaked near 400 ms (N400). The N400 was clearly visible at all sites anterior to O1/O2. Subsequent to the N400, there was a broad positivity that lasted until the end of the recording epoch at all but the most posterior sites.





**Figure 2.** Grand average ERPs to highly related (solid line), moderately related (dotted line), and unrelated (dashed line) target pictures in Experiment 1. Stimulus onset is the vertical calibration bar (negative is up). Left hemisphere sites are in the left column, midline sites are in the middle column, and right hemisphere sites are in the right column. More anterior sites are toward the top, and posterior sites are toward the bottom. The lower eye (LE) channel used to detect blinks and vertical eye movements and horizontal eye (HE) channel used to detect horizontal eye movements are at the extreme right.

*Analyses by epoch.* In the analysis of the 225–325-ms epoch, there were main effects of target type, midline:  $F(2,22) = 17.07$ ,  $p < .0001$ ,  $\epsilon = 0.95$ ; lateral:  $F(2,22) = 9.93$ ,  $p < .001$ ,  $\epsilon = 0.98$ . Planned comparisons contrasting the highly and moderately related targets and the moderately related and unrelated targets revealed that the moderately related pictures produced significantly less negative ERPs than did the unrelated pictures, midline:  $F(1,11) = 12.88$ ,  $p < .004$ ; lateral:  $F(1,11) = 15.00$ ,  $p < .003$ , but that the highly related and moderately related pictures did not significantly differ. The moderately versus unrelated effect was modified by an interaction with electrode site,  $F(2,22) = 6.10$ ,  $p < .024$ ,  $\epsilon = 0.6$ ,  $Fz > Cz > Pz$ ; lateral:  $F(4,44) = 3.37$ ,  $p < .067$ ,  $\epsilon = 0.4$ ,  $F7/8 = ATL/R > TL/R > TPL/R > O1/2$ .

In the 325–500-ms epoch, there were again significant main effects of target type, midline:  $F(2,22) = 75.21$ ,  $p < .0001$ ,  $\epsilon = 0.83$ ; lateral:  $F(2,22) = 83.44$ ,  $p < .0001$ ,  $\epsilon = 0.75$ , and a Target Type  $\times$  Electrode Site interaction at lateral sites,  $F(8,88) = 10.58$ ,  $p < .0002$ ,  $\epsilon = 0.31$ . Planned comparisons revealed that the moderately related targets were significantly more negative going than were the highly related targets across the midline sites,  $F(1,11) = 13.16$ ,  $p < .004$ ,

and at more posterior sites in the lateral analyses, Target Type  $\times$  Electrode Site, lateral:  $F(2,22) = 5.65$ ,  $p < .02$ ,  $\epsilon = 0.33$ ,  $O1/2 < TPL/R > TL/R > ATL/R = F7/8$ . Also, the unrelated targets produced more negative-going ERPs than did the moderately related targets, midline:  $F(1,11) = 118.13$ ,  $p < .0001$ ; lateral:  $F(1,11) = 199.48$ ,  $p < .0001$ , and these differences were variable across the scalp, with larger effects at central and anterior sites, Target Type  $\times$  Electrode Site, midline:  $F(2,22) = 12.03$ ,  $p < .003$ ,  $\epsilon = 0.58$ ,  $Fz = Cz > Pz$ ; lateral:  $F(4,44) = 13.54$ ,  $p < .002$ ,  $\epsilon = 0.32$ ,  $O1/2 < TPL/R = TL/R = ATL/R > F7/8$ .

Another analysis was used to contrast the anterior/posterior scalp distribution of priming effects for the early (200–325 ms) and middle (325–500 ms) epochs (latency variable). The moderately related and unrelated conditions were compared at two pairs of lateral electrode sites (TPL/R vs. F7/8). In this analysis, there was a significant interaction of Electrode Site  $\times$  Latency  $\times$  Relatedness,  $F(1,11) = 7.92$ ,  $p < .017$ . Simple effects tests indicated that although the moderately related/unrelated differences were larger at F7/8 for the early epoch, the same comparisons were larger at TPL/R for the middle epoch.

In the 600–1000-ms epoch, there were significant main effects of target type, midline:  $F(2,22) = 6.45, p < .006, \epsilon = 0.99$ ; lateral:  $F(2,22) = 6.16, p < .01, \epsilon = 0.90$ , and a Target Type  $\times$  Hemisphere interaction at lateral sites,  $F(2,22) = 6.52, p < .009, \epsilon = 0.87$ . Planned comparisons revealed that the unrelated targets produced more negative-going ERPs than did the moderately related targets, midline:  $F(1,11) = 7.51, p < .02$ ; lateral:  $F(1,11) = 9.69, p < .01$ , and this difference was larger over the right than over the left hemisphere, Target Type  $\times$  Hemisphere, lateral:  $F(1,11) = 9.91, p < .01$ . There were no differences between the highly and moderately related items in this epoch.

**Behavioral analyses.** There was a significant RT effect of target type,  $F(2,22) = 5.60, p < .03$ . However, although followup analyses indicated that participants' responses were significantly slower to moderately related than to highly related targets,  $F(1,11) = 29.97, p < .0002$  (Table 1), the difference in RT between moderately related and unrelated targets was not significant ( $p > .39$ ). A subsequent post hoc analysis (Tukey HSD) found that participants responded only marginally faster to the highly related than to the unrelated targets ( $p > .1$ ). There were also significant differences in the numbers of errors made for the three types of targets,  $F(2,22) = 16.79, p < .0001$ . Followup analyses indicated that participants made significantly more errors for the moderately related than for either the highly related,  $F(1,11) = 39.14, p < .0001$ , or the unrelated targets,  $F(1,11) = 17.26, p < .0016$ .

### Discussion

Experiment 1 revealed that robust ERP priming effects could be obtained using color photographs of real objects in a task requiring an overt judgment of the relatedness of prime and target pictures. Between 325 and 500 ms, ERPs were significantly more negative for the unrelated than for the moderately related target pictures. There was also a smaller but statistically reliable difference between the highly and moderately related items, with moderately related items producing a more negative deflection. The time course (325–500 ms) and polarity of these effects suggest that they are similar to the N400 seen in studies using analogous linguistic materials (e.g., Holcomb & Neville, 1990).

Moreover, this pattern of results was very similar to those found in previous studies in which simple line drawings were used as stimuli (Barrett & Rugg, 1990; Holcomb & McPherson, 1994). This similarity among studies suggests that the previous findings with canonical abstract line drawings were not due to these pictures having been processed in a manner atypical of normal picture processing (e.g., through verbal mediation); the pictures in the current study were of real objects that, although representative of their semantic class, had numerous idiosyncratic features. The re-

sults of the current study also may have been due to linguistic mediation. However, because we used pictures of real objects, this interpretation would imply that virtually all object processing involves a verbal mediation process. At least two pieces of evidence suggest that it is unlikely that this is the primary route object processing takes in activating semantic representations. First, previous RT studies have shown that although words are named more quickly than pictures, semantic judgments are typically faster for pictures than for words (e.g., Theios & Amrhein, 1989). Second, the time course of the ERP effects seen here and in previous studies suggests that semantic priming with pictures onsets at least as early as do priming effects with words (e.g., Ganis et al., 1996). Both of these findings are inconsistent with the notion that pictures must be translated into a linguistic code before activating semantic information. A more likely explanation for the N400 effects seen here and in previous picture priming studies is that they reflect conceptual integration of information from either an amodal semantic system (i.e., one accessed by both words and objects) or an object-specific system.

There were also some subtle differences in the scalp distribution of the N400 across conditions. In the moderately related and unrelated contrast, the ERP priming effect had a central to frontal distribution, whereas in the highly related and moderately related contrast the effects were more posterior (see Figure 2). A similar finding was not reported by Kutas and Hillyard (1988) with highly, moderately, and unrelated word pairs. In their study, the N400s for moderately versus highly related pairs and moderately versus unrelated pairs had the same central/posterior distribution found here in the moderately related versus highly related contrast.

There was also evidence in the present study for the existence of an earlier negative component (see Figure 2), one with the same basic scalp distribution and time course as the N300 reported by Barrett and Rugg (1990) and Holcomb and McPherson (1994). In both of these prior studies, this component was thought to be specific to picture processing; an effect with a similar time course and distribution has not been reported in studies using words.<sup>3</sup> In the current experiment, this wave, like the N400, was largest to the unrelated pictures. However, there were three pieces of evidence suggesting that N300 and N400 are separate components. First, the N300 had a significantly more anterior distribution than the later N400. Second, unlike the N400, there was no difference between highly and moderately related items on the N300, which suggests the possibility that the more anterior scalp distribution for the moderately and unrelated items on the N400 may have been partially due to overlap with the earlier N300. Third, the central/posterior distribution for the N400 effect between the moderately related and highly related items is very similar to the distribution seen in comparable words studies (e.g., Holcomb, 1993).

Unlike the N400 and N300, RT revealed only mixed evidence of priming. Although there was an overall difference between the target types, the planned comparisons of the moderately related and unrelated targets suggested that these items did not differ. Even the post hoc comparison of the highly related and unrelated targets revealed only marginally faster responses for the highly related items. Planned comparisons did reveal that participants

**Table 1.** Mean (SD) Reaction Times and Error Percentages for Target Types of Experiment 1

	Highly related	Moderately related	Unrelated
Reaction time (ms)	817 (106)	874 (109)	870 (134)
Percent error rate (%)	4 (4)	12 (5)	4 (3)

<sup>3</sup>Neville, Mills, and Lawson (1992) reported a negative potential with a similar peak latency and a frontal distribution (N280) to linguistic stimuli. However, the N280 was highly lateralized to the left hemisphere and occurred only to words without semantic content (closed-class words, e.g., *the*, *and*, *but*). It therefore seems unlikely that Barrett and Rugg's (1990) N300 is a member of this family.

were significantly slower in responding to the moderately related than to the highly related pictures and that they made significantly more errors in response to the moderately related than to either the highly related or unrelated items. However, similar comparisons with the ERPs revealed large and reliable differences among the highly, moderately, and unrelated items.

Holcomb and McPherson (1994) reported a similar pattern (large ERP and no RT priming) using an object decision task. However, although these findings went unexplained, there is at least one plausible explanation for the current pattern of ERP and RT findings. A problem with the relatedness decision task is that it confounds the relatedness dimension with decision and response processes. One possibility for the results obtained here is that although the N400 was primarily sensitive to the semantic properties of the prime–target relationship, RT was sensitive to this process and to decision- and/or response-based processes (e.g., Kounios & Holcomb, 1992). Because unrelated targets called for a different decision/response (*no*) than both types of related targets (*yes*), differences at this level may have masked or canceled out some of the RT effects of priming that occur in other tasks.

## EXPERIMENT 2

The primary goal of Experiment 2 was to determine if both ERP and RT measures of semantic priming could be obtained with real color pictures in the same study. A secondary goal of Experiment 2 was to determine if the ERP effects with pictures of real objects found in Experiment 1 would hold up in a different task with somewhat different stimulus parameters. One change from Experiment 1 was that participants were instructed to indicate whether they could identify the target pictures. An advantage of this task is that both related and unrelated targets require the same response (*yes*) and therefore RT measures of semantic priming are unconfounded with response/decision processes. Under these conditions, the effects of priming on RT should be directly discernible (e.g., Kroll & Potter, 1984) and, if present, should be consistent with those found for the ERPs.

To provide a differential response, a group of unidentifiable target images were paired with prime pictures of easily identifiable objects. Participants were instructed to press the *no* response button to all targets they could not identify and the *yes* button to all objects they could identify. The unidentifiable images were color pictures of unusual objects (e.g., the pump out of a washing machine, see Figure 1) or images of common items taken from unusual angles (i.e., noncanonical objects). The logic of this task is that by using “real” but unidentifiable images viewers would find it advantageous to use conceptual knowledge to help make their identity decisions. This assumption follows from the results of semantic priming lexical decision tasks where the inclusion of pseudowords (i.e., unidentifiable words) produces robust priming effects on the word stimuli (e.g., Meyer & Schvaneveldt, 1971). In such tasks, participants are thought to rely on an attentional strategy of matching the meaning of the prime and target stimuli to facilitate the lexical decision process (see Neely, 1991). We reasoned that participants would adopt a similar strategy with pictures if the picture conditions closely paralleled those known to produce such effects with words and that such a strategy should result in ERP semantic priming effects similar to those seen in Experiment 1. These effects should be similar because participants in both tasks were encouraged (explicitly in Experiment 1 and implicitly in Experiment 2) to adopt a strategy of using the semantic attributes of prime and target items to aid in their decision making. However,

it was predicted that Experiment 2 would produce at least one difference from Experiment 1. If the weak RT effects seen in Experiment 1 were due to the confounded decision/relatedness factors, then robust RT semantic priming should be obtained in Experiment 2 because these factors were now unconfounded. However, in at least one prior study using line drawings (Holcomb & McPherson, 1994) robust ERP semantic priming effects were found, but there was no evidence of priming on RT. The current experiment should help determine if Holcomb and McPherson’s RT finding and those from Experiment 1 were more typical of picture priming than would be suggested by the RT literature.

An added benefit of the object identity task is that it allows for the examination of ERP effects of unidentifiable pseudo-object processing. Prior studies with linguistic materials have suggested that pseudowords elicit an N400-like negativity that is as large or larger than that seen for real words (e.g., Holcomb & Neville, 1990). The most plausible explanation for why pseudowords generate larger N400s is that they partially activate the representations of a number of real words that the reader then attempts to semantically integrate. This view is supported by the finding that N400 amplitude is larger for pseudowords that resemble a relatively larger number of real words than for those that resemble a smaller number (O’Rourke & Holcomb, 1995). Similarly, Holcomb and McPherson (1994) reported a larger N400-like negativity to line drawings of pseudo-objects than to line drawings of real objects, which suggests that pseudo-objects, like pseudowords, partially activate the representations of real objects. However, Holcomb and McPherson also found an effect that has not been reported for pseudowords. Although the N400-like negativity was larger for nonobjects at central and anterior sites, at occipital sites nonobjects produced more positive-going ERPs in the N400 latency range than did line drawings of real objects. This inversion of polarity over visual areas of the brain is interesting because of reports from a recent positron emission tomography (PET) study in which increased blood flow was found in occipital areas for objects viewed from nonstandard perspectives (Kosslyn et al., 1994).

There were two further changes made in Experiment 2. First, the one-third of the moderately related targets with the lowest ratings were dropped, and the remaining items from the two related subcategories (highly related and moderately related) were merged to form a single related category of moderately to highly related items. This restructuring was done to equate the number of related and unrelated trials and to allow for a direct statistical comparison of the related and unrelated pictures (in Experiment 1, only the moderately related items were directly contrasted with the unrelated items). Second, the interval between the onset of the prime and the onset of the target (stimulus onset asynchrony [SOA]) was shortened somewhat from 1,000 ms to 650 ms to facilitate prime and target pictures being processed as a pair (e.g., Ratcliff & McCoon, 1981). Prior work with words (e.g., Anderson & Holcomb, 1995) has suggested that N400 priming effects are robust and relatively constant across SOAs in this range and that both of these durations are long enough to support attentive semantic priming (SOAs shorter than 500 ms are thought to be primarily conducive to automatic processing, e.g., Neely, 1977).

The following predictions were made for Experiment 2. Based on Experiment 1, the unrelated targets should elicit larger N400s and N300s than should related targets. However, unlike Experiment 1, RTs to related targets should be faster and more accurate than RTs to unrelated targets. Further predictions included longer RTs and larger anterior N400s for unidentifiable than for identifiable

able (i.e., unrelated) targets but larger posterior positivities for unidentifiable than for identifiable targets.

### Methods

**Participants.** Twelve new right-handed native English-speaking volunteers participated in this experiment (5 men, 7 women; mean age = 18.7 years).

**Stimuli.** The stimuli consisted of 100 related pairs of color pictures taken from the group of 120 related pairs used in Experiment 1 (the 20 pairs with the lowest ratings were dropped). Fifty images used in this experiment were not used in the previous experiment. These pictures were targets in an unidentifiable condition (see Figure 1, bottom row). The images for this condition were pictures of uncommon objects and pictures of common objects taken at such angles so as not to be identifiable. To check that these items were not identifiable, 8 participants performed a task, using the same exposure durations employed in the ERP experiment, in which 100 unidentifiable images were randomly mixed with 100 identifiable images from Experiment 1. Participants were asked to verbally identify each stimulus. The 100 identifiable images were properly identified 98% of the time. The 50 items chosen for the unidentifiable condition were never correctly identified by any of the 8 participants.

For the experimental stimuli, two lists of 150 pairs each were generated. The primes were all pictures of easily identifiable objects. The targets were (a) related to the prime, (b) unrelated to the prime, or (c) unidentifiable. The prime–target pairs used as related in one list were repaired and used in the unrelated condition in the other list. The same set of unidentifiable pictures were used for both lists.

**Procedure.** The stimulus timing and presentation parameters for this experiment were as follows. The first picture of the pair appeared for 400 ms followed by a 250-ms interval during which the screen was blank. The second picture then appeared for 400 ms followed by a 1,600-ms blank screen. Finally, a green “x” appeared on the screen, signaling the beginning of the intertrial interval and indicating that the participant could blink or otherwise move their eyes without interfering with data collection. After a 2.5-s intertrial interval and 500 ms prior to the start of the next trial, the green “x” disappeared. Participants were informed that they would view target pictures that would be either identifiable or unidentifiable and to quickly respond with the *yes* button if they could mentally identify the image and with the *no* button if the picture was of an object that they could not mentally identify. All ERP and data analysis procedures were the same as in Experiment 1, except that followup analyses included contrasts between related and unrelated items and between unrelated and unidentifiable items.

### Results

**ERPs.** Approximately 11% of trials were rejected for vertical or horizontal eye artifact (related = 11%, unrelated = 9%, unidentifiable = 13%). The overall morphology of the waveforms from this experiment is similar but not identical to that from Experiment 1 (cf. Figures 2 and 3). The biggest differences appear to be between 200–300 ms and 600–1,000 ms. In Experiment 1, the earlier region was dominated by a large frontal negativity and a posterior (occipital) positivity. In Experiment 2, this frontal negative, posterior positive peak appears to be either missing or greatly attenuated. The second difference was that the unidentifiable targets

produced a smaller late positivity at anterior sites than did the two identifiable targets.

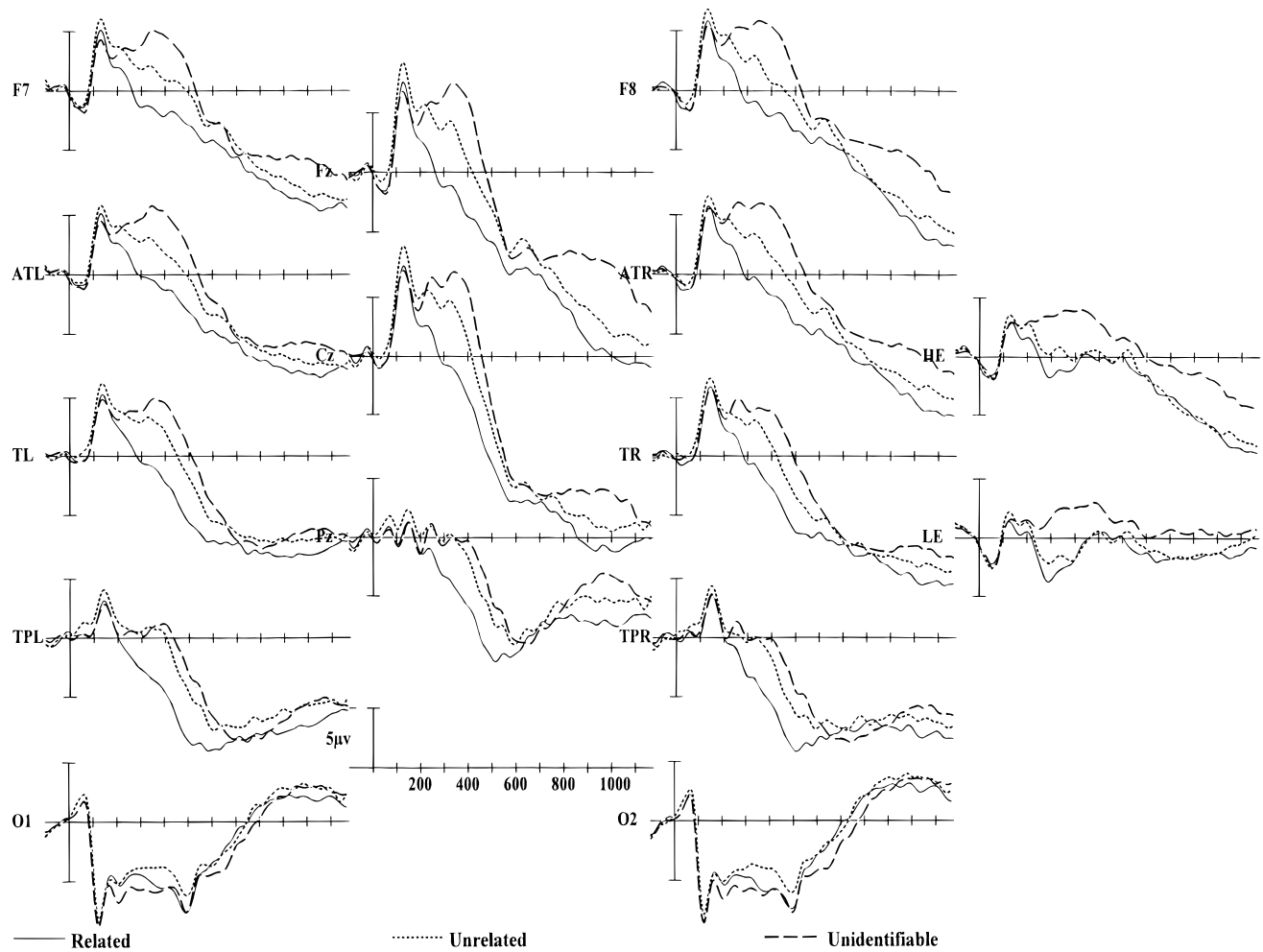
**Analyses by epoch.** Analyses of the 225–325-ms epoch revealed significant main effects for target type, midline:  $F(2,22) = 16.16, p < 0.0001, \epsilon = 0.85$ ; lateral:  $F(2,22) = 11.49, p < .0008, \epsilon = 0.86$ . There was also a Target Type  $\times$  Electrode Site interaction at the midline sites,  $F(4,44) = 3.62, p < .05, \epsilon = 0.46$ . Planned comparisons in the 225–325-ms epoch were used to contrast the related and unrelated targets and the unrelated and unidentifiable targets. Unrelated targets were significantly more negative than the related targets, main effect of target type, midline:  $F(1,11) = 12.94, p < .004$ ; lateral:  $F(1,11) = 11.63, p < .006$ , and unidentifiable targets were more negative than unrelated targets at the midline sites, main effect of target type:  $F(1,11) = 6.75, p < .02$ . However, a Target Type  $\times$  Electrode Site interaction indicated that at lateral sites the difference between unidentifiable and unrelated targets differed across the scalp,  $F(1,11) = 3.64, p < .05, \epsilon = 0.40$ . The unidentifiable targets were more negative than the unrelated targets at the four pairs of sites anterior to O1/O2 ( $F7/8 = \text{ATL/R} > \text{TL/R} > \text{TPL/R}$ ). However, at O1/O2, unidentifiable targets were actually significantly more positive going than unrelated targets, main effect of target type at O1/O2:  $F(1,11) = 4.69, p < .05$ .

In the 325–500-ms epoch, there were significant main effects for target type, midline:  $F(2,22) = 28.38, p < .0001, \epsilon = 0.77$ ; lateral:  $F(2,22) = 26.67, p < .0001, \epsilon = 0.81$ , and significant Target Type  $\times$  Electrode Site interactions, midline:  $F(4,44) = 3.96, p < .04, \epsilon = 0.48$ ; lateral:  $F(8,88) = 7.63, p < .003, \epsilon = 0.25$ . Planned comparisons in this epoch revealed that unrelated targets produced significantly more negative-going ERPs than did related targets, main effect of target type, midline:  $F(1,11) = 20.57, p < .0009$ ; lateral:  $F(1,11) = 17.14, p < .002$ , and at lateral sites this difference varied across the scalp, Target Type  $\times$  Electrode Site, lateral:  $F(4,44) = 6.52, p < .007, \epsilon = 0.47, \text{O1/2} < \text{TPL/R} = \text{TL/R} > \text{ATL/R} = \text{F7/8}$ . The unrelated and unidentifiable contrast showed that the ERPs to unidentifiable targets were significantly more negative going than were the ERPs to unrelated targets, midline:  $F(1,11) = 18.62, p < .0012$ ; lateral:  $F(1,11) = 17.27, p < .0016$ , and this difference tended to be larger at more anterior sites, midline:  $F(2,22) = 6.49, p < .018, \epsilon = 0.65, \text{Fz} = \text{Cz} > \text{Pz}$ ; lateral:  $F(8,88) = 5.41, p < .033, \epsilon = 0.29, \text{F7/8} = \text{ATL/R} > \text{TL/R} > \text{TPL/R}$ . At the occipital sites there was again an inversion of polarity, with unidentifiable targets producing marginally more positive ERPs than the unrelated targets,  $F(1,11) = 4.09, p < .09$ .

Another analysis was used to contrast the anterior/posterior scalp distribution of priming effects for the early (200–325 ms) and middle (325–500 ms) epochs (latency). As in Experiment 1, the related and unrelated conditions were compared at two pairs of lateral electrode sites (TPL/R vs. F7/8). In this analysis, there was a significant interaction of Electrode Site  $\times$  Latency  $\times$  Relatedness,  $F(1,11) = 8.71, p < .013$ . Simple effects tests indicated that although the related/unrelated differences were larger at F7/8 for the early epoch, the same comparisons were larger at TPL/R for the middle epoch.

In the 600–1,000-ms epoch, there was a significant main effect for target type at the midline sites,  $F(2,22) = 5.47, p < .02, \epsilon = 0.79$ , and significant Target Type  $\times$  Electrode Site interactions, midline:  $F(4,44) = 5.29, p < .01, \epsilon = 0.54$ ; lateral:  $F(8,88) = 4.43, p < .02, \epsilon = 0.27$ . Planned comparisons revealed that there were no significant differences in ERPs between the related and unrelated targets. However, the ERPs to unidentifiable targets were significantly more negative going than were those to the unrelated





**Figure 3.** Grand average ERPs to related (solid line), unrelated (dotted line), and unidentifiable (dashed line) target pictures in Experiment 2. For orientation, see Figure 2.

targets, but only at the more anterior sites, Target Type  $\times$  Electrode Site, midline:  $F(2,22) = 6.15$ ,  $p < .02$ ,  $\epsilon = 0.59$ ,  $Fz > Cz > Pz$ ; lateral:  $F(4,44) = 5.05$ ,  $p < .03$ ,  $\epsilon = 0.38$ ,  $F7/8 > ATL/R > TL/R = TPL/R = O1/2$ .

**Behavioral analyses.** The RT and error data are shown in Table 2. A main effect of target type was obtained for both the RT and error rates,  $F(2,22) = 71.30$ ,  $p < .0001$ ;  $F(1,11) = 3.83$ ,  $p < 0.05$ . The RTs to unrelated targets were significantly slower than those to related targets,  $F(1,11) = 29.87$ ,  $p < .0005$ , and RTs

to unidentifiable targets were significantly slower than those to unrelated targets, unrelated versus unidentifiable,  $F(1,11) = 81.25$ ,  $p < .0001$ . Participants also responded more accurately to related than to unrelated targets,  $F(1,11) = 8.19$ ,  $p < .05$ , but there was no difference between unrelated and unidentifiable targets ( $p > .2$ ).

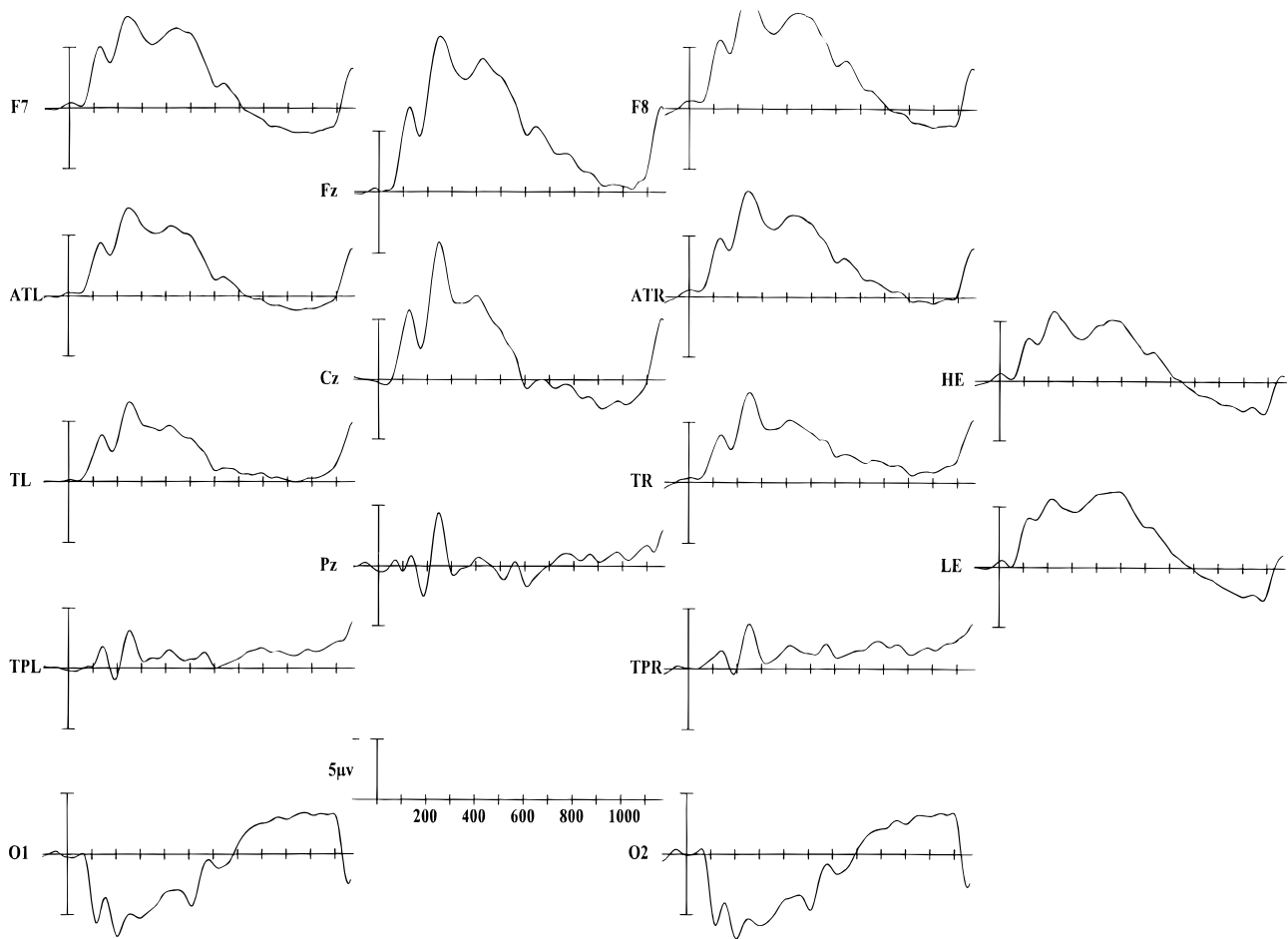
### Discussion

As predicted, unrelated targets elicited larger negativities between 225 and 500 ms than did related targets. The scalp distribution (central/parietal maximum), morphology and time course of the latter portion of this region (325–500 ms) suggests that this effect is a member of the N400 family. This finding replicates the N400 effects seen in Experiment 1 using a different task and somewhat different stimulus parameters. It also replicates the findings from an earlier study with line drawings (Holcomb & McPherson, 1994).

Participants also made significantly faster responses and made fewer errors to related than to unrelated target pictures. This finding is consistent with the literature on semantic priming and RT (see Neely, 1991, for a review of the word based priming literature and Kroll & Potter, 1984, for an example of RT picture priming) and suggests that the weak effects seen in Experiment 1 and by

**Table 2.** Mean (SD) Reaction Times and Error Percentages for Target Types of Experiment 2

	Related	Unrelated	No ID
Reaction time (ms)	613 (108)	653 (101)	811 (112)
Error rate (%)	1 (2)	3 (3)	6 (6)



**Figure 4.** Grand average ERPs to all prime pictures from Experiment 2. The ERP for target pictures onsets about 650 ms after the onset of the prime. For orientation, see Figure 2.

Holcomb and McPherson (1994) are not the only pattern possible when using pictures.

In addition to the RT and N400 findings, this experiment also revealed that as in Experiment 1 an earlier negativity (the N300) was larger to unrelated than related pictures, and this effect had a more frontal distribution than the later N400. This replication of the difference in distribution of the N300 and N400 effects is further evidence that the two components are generated in non-identical neural populations and therefore probably reflect somewhat different cognitive operations. However, although this difference was significant in the 225–325-ms measurement window, inspection of Figure 3 suggests that the anterior negative peak seen in Experiment 1 (Figure 2) was either missing or greatly attenuated in Experiment 2.

One possibility for this decline in amplitude may be the shortening of the interval between prime offset and target onset in Experiment 2 (250 ms vs. 600 ms in Experiment 1). In other words, the shorter interstimulus interval in Experiment 2 may have left the neural generators for the N300 peak in a somewhat more refractory state. Prior work was shown that a variety of ERP components have attenuated amplitudes at relatively shorter as compared with longer interstimulus intervals (e.g., Neville, Coffey, Holcomb, & Tallal, 1993). Evidence for this hypothesis can be seen in Figure 4, which plots the ERPs to the prime pictures and

the beginning of the ERP to targets in Experiment 2. Because the prime pictures followed a relatively long intertrial interval (i.e., the prior target picture occurred approximately 3 s earlier), the N300 to these stimuli should not have been refractory. Here, a clear anterior negative peak can be seen following the N1.

Although the peak of the N300 was attenuated to the targets, the relatedness effect did not appear to be affected. This finding suggests that the underlying N300 effect may not be generated by the same neural sources as those responsible for the large frontal negative peak seen between 200 and 300 ms in Figures 2 and 4 but rather may overlap with this peak in time (a similar argument has been made for the Nd and N1 in the auditory selective attention literature, see Näätänen, 1992).<sup>4</sup>

The unidentifiable pictures generated the largest negativities in all three measurement windows and produced the slowest RTs of all three target types. This pattern of findings is consistent with previous work on the ERP and behavior using the lexical decision

<sup>4</sup>One piece of evidence inconsistent with the refractory period explanation is that the N1 to targets in Experiment 2 does not seem to be smaller than the N1 in Experiment 1. However, the refractory dynamics for the two components might be somewhat different. For example, N1 refractory effects might not be as large here as in other studies because of differences in the physical attributes of primes and targets.

task. Pseudowords also produce significantly larger late negativities and slower RTs than do unrelated target words (e.g., Holcomb & Neville, 1990). This finding may seem inconsistent with a semantic/conceptual explanation of the N400 or alternatively with the effect actually being on the N400. How can an item without ties to a conceptual representation produce a conceptual effect? One possible explanation is that pseudowords and unidentifiable pictures partially activate the representations of a number of real words and/or objects which in turn activate conceptual representations (e.g., O'Rourke & Holcomb, 1995).

One piece of evidence that the negativity that differentiates unrelated pictures from unidentifiable pictures is not identical to the N400 generated by semantic priming can be seen in Figure 3. Although the difference between related and unrelated pictures tended to be larger over central and temporal-parietal sites, the differences between unidentifiable and unrelated pictures were most apparent over the most anterior sites, with unidentifiable objects being more negative, and over occipital sites, with unidentifiable objects being more positive. Moreover, the anterior effects extended into the epoch after the traditional N400 window (600–1,000 ms). These differences in scalp distribution and time course would appear to be consistent with the argument that somewhat different generators/processes are at work for the two types of objects. Holcomb and McPherson (1994) found the same basic pattern in their study contrasting line drawings of real and pseudo-

In a recent PET study aimed at testing a theory of object perception, Kosslyn et al. (1994) found increased blood flow in several brain areas for noncanonical as compared with canonical views of objects in a word-picture matching task. Because our unidentifiable objects were a combination of noncanonical and unfamiliar objects, some of the effects (as well as those of Holcomb & McPherson, 1994) might reflect similar differences in the processes underlying perception of canonical and noncanonical objects. Two areas identified in the Kosslyn et al. study are of particular interest with respect to the findings in the current experiments. The first area is the primary and secondary visual cortex (areas 17 and 18), which Kosslyn et al. found to be more active (i.e., higher blood flow) for noncanonical objects. In their model, visual cortex forms a system of interactive areas that help maintain a temporary mental image of an object (the visual buffer), which subsequent areas/systems use during recognition. This system is presumed to be more active for noncanonical objects because more visual features must be encoded for these objects to be recognized. An intriguing possibility is that the larger posterior positivity for unidentifiable objects between 200 and 325 ms in the current study and in Holcomb and McPherson's study reflects this greater activity for unidentifiable objects. The second area of interest is the dorsolateral prefrontal cortex (areas 9, 46, and 47), which Kosslyn et al. proposed is used, among other things, to look up stored properties of objects that are difficult to identify. This area had higher blood flow for noncanonical objects. One possibility is that our significantly larger anterior negativities for unidentifiable objects might reflect the greater involvement of these areas when participants attempt to match the features/parts of these objects with stored representations of known objects. The prolonged duration of the negativity could reflect multiple attempts by this system to match stored features with features of the object. The time course of these effects (and those of Holcomb & McPherson) are consistent with the presumed flow of information in the Kosslyn et al. model. The presumed effects on the visual buffer were seen

starting relatively early (200–325 ms), and presumed memory lookup/comparison effects occurred relatively later (325–500 ms and/or 600–1,000 ms).

## GENERAL DISCUSSION

Across two experiments and tasks, color pictures of real objects elicited larger late negativities when they were preceded by pictures of unrelated objects than when they were preceded by pictures of semantically related objects. The scalp distribution, morphology, and latency of the later phase of this semantic priming effect (325–500 ms) indicated that it was due to modulation of the N400 component, which has been reported in numerous previous ERP studies using linguistic stimuli (e.g., Holcomb & Neville, 1990). There was mixed evidence for behavioral measures of semantic priming with pictures. In Experiment 1, which used a relatedness judgment task, differences in RT between related and unrelated pictures were small or nonexistent. However, in Experiment 2, which used an object identity task, there were robust effects of semantic priming on RT.

This study provides additional although still incomplete evidence for ERP differences in the processing of pictures and words. Although the picture N400 was in many respects quite similar to the N400 produced by words, the scalp distribution found here and reported elsewhere (e.g., Ganis et al., 1996; Holcomb & McPherson, 1994; Holcomb & Neville, 1990) suggests that the neural generators of this component(s) are not identical for words and pictures. In the current study, the N400 to pictures was largest at temporal, temporal-parietal, and central sites, slightly smaller at anterior temporal and frontal sites, and almost nonexistent at occipital sites. This finding contrasts with those of word studies, which usually also show the largest effects at temporal and temporal-parietal sites but demonstrate more dramatic declines moving towards more anterior sites. Also, word studies usually produce relatively larger effects over occipital areas (e.g., Holcomb, 1993). However, part of the smaller occipital effect could be due to overlap with a positive wave with a posterior focus. The seemingly more anterior distribution for pictures may be due in part to the presence of an anterior component that is separate from the N400, namely the N300. Although not definitive, the results of the current study are most consistent with characterization of the N400 as an index of amodal semantic processing.

There has been no systematic exploration of the processing nature of the N300. The evidence from earlier studies (e.g., Barrett & Rugg, 1990; Holcomb & McPherson, 1994) suggesting that the N300 and N400 are distinct components was relatively weak because in the absence of a demonstrated differential responsiveness to independent variables the N300 may simply reflect the earlier onset of the N400 at more anterior sites. However, data from the current study indicate a disassociation. The contrast between unrelated and moderately related objects (Experiment 1) and unrelated and related objects (Experiment 2) both produced an N300 effect over anterior sites and a later N400 effect over somewhat more posterior sites (see Figures 2 and 3). However, the moderately related and highly related contrast from Experiment 1 produced only the more posterior N400 effect. Differences at more anterior sites were either very small (Fz) or nonexistent (F7/8). These data provide the first evidence that an N400 effect can occur without an N300 effect. In another study, McPherson and Holcomb (1992) found larger anterior N300 components for both pseudo-objects and pictures of scrambled objects when compared with pictures of real objects. However,

there were no differential effects of stimulus type on the later N400, suggesting that it is also possible to get an N300 effect without a comparable N400. Taken together with the differing scalp distributions, these findings suggest that the N300 and N400 are generated by nonidentical neural systems and that, therefore, they are separate components.

But what does the N300 reflect? The fact that N300 components have not been reported in previous language studies suggests that it has something to do with the processing of picture- or object-specific information. Although there is relatively strong support for the hypothesis that the N400 reflects the degree of effort involved in integrating amodal semantic information into a higher level conceptual representation, one possibility based on the current findings is that the N300 reflects a similar process that is specific to object or imagistic representations. Tentative support for this possibility comes from studies involving contrasts of two types of language stimuli, words that refer to concrete objects and words that refer to abstract concepts (e.g., Holcomb, Kounios, Anderson & West, 1998; Kounios & Holcomb, 1994). In these studies, concrete words produced larger N400-like negativities than did abstract words, particularly over

more anterior sites. According to dual-coding theories of representation (e.g., Paivio, 1990), concrete words activate information in two separate systems: one that is language based and one that is image based. If the more anterior negativity to concrete words reflects an image-based process (as was concluded by Kounios & Holcomb, 1994), then it might be a process similar to that seen here with the N300 for pictures. In other words, concrete words and pictures might be activating similar processes/representations that are reflected by anterior negativities. One apparent problem with this interpretation is that the anterior picture effect (N300) is somewhat earlier than the anterior concreteness effect (N400) reported by Kounios and Holcomb (1994). However, according to Paivio (1990), concrete words tap imagistic representations only after accessing their language-based code (via referential links between systems). Pictures would presumably have direct access to image-based information. Therefore, a slight delay might be expected in the image-based process for words as compared with pictures. To investigate this and other possibilities, future studies should include careful comparisons of ERPs to pictures and to various types of language materials.

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(RECEIVED August 19, 1997; ACCEPTED June 10, 1998)