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Semantic Processing and Memory for Attended and Unattended Words in Dichotic Listening: Behavioral and Electrophysiological Evidence

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Thirty-two Ss studied words presented to 1 ear, while ignoring a concurrent word list presented to the opposite ear. The N400 component of the event-related potentials elicited by attended words was modulated by semantic priming between successive words. The N400 elicited by unattended words was insensitive to semantic manipulation. Recognition memory was better for attended than for unattended words. However, the percentage of false positives was elevated equally for lures that were semantically related to "old" words, whether they had been attended or unattended. Words that were initially attended induced similar repetition effects in a lexical decision task as words that were initially unattended. Hence, both attended and unattended words are semantically processed and activate semantic representations. However, attended words form traces that are subsequently more available to conscious recollection than unattended words.

The question of whether words presented outside the focus of attention are semantically processed has important implications for several areas of cognitive research. This question has been examined by investigators interested in mechanisms of selective attention (for a review, see Johnston & Dark, 1986), in the automatic and conscious aspects of word perception (for a review, see Holender, 1986), and in the functional organization of the cerebral hemispheres (e.g., Lambert, Beard, & Thompson, 1988). Two very different points of view were initially put forward. The first considered semantic processing to be automatic and independent of the allocation of attention resources (e.g., Deutsch & Deutsch, 1963; Shiffrin, 1985). By contrast, proponents of the second view argued that the amount of semantic processing depends on the allocation of attention and that the meaning of unattended words is processed very little, if at all (Broadbent, 1971; Broadbent & Gathercole, 1990; Johnston & Dark, 1986; Kahneman & Treisman, 1984; Treisman, 1960, 1986).

The first view has been supported primarily by findings showing that unattended words may influence the processing of attended stimuli. For example, unattended words presented peripherally in the visual field were found to bias the meaning of centrally presented homographic targets even when the subjects were unable to report the disambiguating stimuli (Bradshaw, 1974). Using tachistoscopic presentation, others have shown that naming times (Dallas & Merikle, 1976; Underwood, 1976) or latencies for semantic judgments about target words (Shaffer & LaBerge, 1979) were faster for target words flanked by unattended words that were semantically related to the targets than by unrelated words.

Similar results have been obtained in dichotic listening tasks. For example, Mackay (1973) showed that words presented to the unattended ear bias the reported meaning of an attended homophone. Measures of skin conductance have shown that the electrodermal responses to words presented to the unattended ear were larger if they had been either directly associated with an electric shock or if they were semantically related to shock-associated words (Corteen & Dunn, 1974; Corteen & Wood, 1972; Dawson & Schell, 1982; Forster & Govier, 1978).[1] In addition, Lewis (1970) reported that the shadowing latencies for words in the attended ear were longer when the coincident words in the unattended ear were synonyms than when the attended and unattended words were unrelated.

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[1] Note, however, that evidence that is based on electrodermal studies should be treated with caution, because the effects are usually very difficult to elicit and may be dependent on careful selection of subjects. (For a discussion of this issue, see Holender, 1986.)

Advocates of the second view—that is, that semantic processing depends on the allocation of attention—have pointed out, however, that in all these studies the amount of semantic priming was greater when attention was divided between the stimuli presented than when attention was focused by precuing the target (Dallas & Merikle, 1976; Johnston & Wilson, 1980; Kahneman, Treisman, & Burkell, 1983). In addition, some of the results that supported semantic processing without attention have not been fully replicated. For example, word frequency effects (suggestive of lexical processing) were not observed when unattended words were presented outside of visual fixation (Inhoff & Rayner, 1986), and priming from parafoveally presented unattended words was not always evident (Inhoff, 1989). It has also been noted that semantic interference from unattended words decreases further along in a stimulus list, suggesting that the ability to focus attention improves with practice and that cross-channel interference results from the division of attention between the two channels rather than the processing of completely unattended stimuli (Ambler, Fisicaro, & Proctor, 1976; Treisman, Squire, & Green, 1974). Moreover, the influence of unattended words on processing of words in the attended channel is most conspicuous when the attended words lead rather than follow the unattended words (Broadbent & Gathercole, 1990). This result suggests that semantic processing of unattended words may be contingent on the priming from words in the attended channel.

If this "priming of nontargets by targets" hypothesis is valid, it may suggest a compromise between the two opposing views. One such compromise would posit that the meanings of unattended stimuli are processed at least partially, but the extent to which they become available to consciousness or affect conscious behavior depends on this processing surpassing a critical level. When attention is focused elsewhere, the amount of processing of unattended and unprimed words is usually insufficient to access specific semantic nodes and to have substantial consequences on the processing of attended stimuli. However, when the unattended stimuli are primed, the amount of information necessary for their identification may be reduced such that only partial processing is sufficient to gain full access to semantic memory. Such a model implies that the activation of semantic memory is not "all or none," and that specific nodes can be activated to varying degrees. Support for this view is provided by data showing that even when attention is directed to the prime, its priming potency is affected by the "level" to which it is processed (Henik, Friedrich, & Kellogg, 1983; Smith, Theodor, & Franklin, 1983). Also, the frequent repetition of unattended primes in a stimulus list leads to a substantial interaction with target processing (Broadbent & Gathercole, 1990; see also Lambert et al., 1988). Indeed, as has been frequently shown, repetition reduces the amount of processing required for word identification (e.g., Jacoby & Dallas, 1981; Morton, 1970, 1982; Moscovitch & Bentin, 1993).

The foregoing considerations imply that in the absence of priming from the attended channel or of robust manipulations such as stimulus repetition, the processing of unattended stimuli is incomplete and does not induce extensive semantic priming effects. Consistent with this assumption, Dark, Johnston, Myles-Worsley, and Farah (1985) found that a semantic relationship between primes and subsequently (rather than simultaneously) presented visually masked targets did not facilitate the identification of the targets if the primes were presented in unattended spatial locations. The outcome of Dark et al.'s study suggests that the semantic analysis of unattended words is very limited. However, these results might have been specific to the experimental procedures that were used, in that the spatial attention task (attending to four noncontiguous squares in a 3×3 matrix) was very difficult; thus, when more than one stimulus was simultaneously presented, all processing resources may have been absorbed by the selection task itself. Therefore, these results do not rule out the possibility that unattended words are semantically processed to some extent in less demanding circumstances.

The possibility that both automatic and attention-based semantic processes may coexist during the identification of words has been suggested by studies of semantic priming (Carr, 1992; Neely, 1977, 1991; Posner, Sandson, Dhawan, & Shulman, 1989) and of the disambiguation of homographs (Frost & Bentin, 1992; Simpson & Burges, 1985). According to these models (e.g., Posner & Snyder, 1975), during a limited period of time following stimulus onset (up to a few hundred milliseconds), processing of word meaning is carried out automatically and is not affected by semantic expectations. Subsequently, this automatic semantic activation decays whereas attention-based semantic processing strategies prevail. The validity of such models may be limited, however, to the experimental paradigms in which they have been tested (i.e., to circumstances in which all the words were attended as semantic expectations were manipulated).

Converging evidence about the semantic processing of unattended words can be obtained by recording event-related brain potentials (ERPs) that have been shown to be sensitive indicators of semantic relationships between words. One advantage of ERP measures is that they can be obtained without requiring any overt responses from the subject and therefore, although they are sensitive to manipulations of attention, may provide indexes of semantic priming within a channel that remains entirely unattended. During the past decade many studies have demonstrated that the ERP elicited by words contains a negative component that peaks at about 400 ms after stimulus onset (N400), and that this component can be modulated by manipulating the semantic correspondence between that word and the context in which it is embedded (Kutas & Hillyard, 1980; for reviews, see Bentin, 1989, and Kutas & Van Petten, 1988). The N400 is also modulated by semantic priming in lexical decision tasks in the visual (Bentin, McCarthy, & Wood 1985) and auditory (Holcomb & Neville, 1990) modalities. Most important for the present study, it has been shown that when stimuli are attended, semantic priming modulates the amplitude of N400 even in the absence of any overt response (Kutas & Hillyard, 1984). On the other hand, it has been reported that semantic priming did not affect N400 if the prime was masked (Brown & Hagoort, 1993) or degraded (Holcomb, 1993), even though behavioral evidence for priming was present. Consequently, recent interpretations of N400 have suggested that this ERP does not reflect automatic semantic processing, but rather a process of integrating an identified word with semantic (or other) contextual information (Brown & Hagoort, 1993; see also Rugg, 1990). It is very likely that such an integrative process requires attentional resources and, therefore, should be sensitive to manipulations of attention. Indeed, recent studies have found that the N400 is sensitive to the amount of attention directed toward the stimulus that elicits it. For example, Nobre (1993) found that words presented to an unattended visual field elicit relatively small N400 components, and these components were not modulated either by semantic priming or by stimulus repetition (see also McCarthy & Nobre, 1993). Similarly, the ERP repetition effect was found to be smaller for unattended than for attended words (and nonwords) presented in the visual hemifields (Otten, Rugg, & Doyle, in press).

In a recent study we found that the degree to which semantic priming influenced the amplitude of N400 was influenced by the demand characteristics of the task in which the subjects were engaged (Bentin, Kutas, & Hillyard, 1993). In that study, subjects either detected and counted nonwords among a list of spoken words or studied the words in anticipation of a subsequent recognition test. Consistent with a "levels of processing" framework, the difference between the amplitude of N400 elicited by unprimed and primed words was significantly larger when words were studied for recognition than in the lexical decision task (see also Holcomb, 1988). The present study was designed in light of these results.

In the present design, different lists of words were presented dichotically, and subjects were instructed to memorize the words presented to one ear while ignoring the words presented to the other ear. In each list there were target words that immediately followed either a semantically related prime or an unrelated prime. An ERP index of semantic priming was obtained by comparing the difference in amplitude between the N400s elicited by primed and unprimed targets. The effect of selective attention on semantic priming was assessed by comparing this ERP effect for target words presented to the attended versus the unattended ear. To the extent that the attended words were processed more "deeply" (i.e., were more elaborated semantically during encoding in episodic memory) than unattended words, the N400 priming effect should be larger for attended than unattended targets.

A second aim of this study was to compare the effect of selective attention on direct and indirect[2] measures of memory. Although some factors may affect performance on these two types of tests similarly (e.g., Jacoby, 1983), there is a good deal of evidence that direct measures of memory such as recall and recognition performance can be dissociated from indirect measures of memory that are reflected, for example, by stimulus repetition effects (for literature reviews, see Richardson-Klavehn & Bjork, 1988, and Schacter, 1987). In particular, savings for repeated stimuli may be evidenced in subjects' performance even when they are not aware of the repetition. This dissociation has been found using both ERP (Bentin & Moscovitch, 1990; Bentin, Moscovitch, & Heth, 1992; Paller, 1990; for a recent overview, see Rugg & Doyle, in press) and reaction time (RT) measures (Moscovitch & Bentin, 1993; for a review of relevant data, see Schacter, 1987). If unattended words are not sufficiently processed to gain awareness but are nevertheless stored in memory, we might find traces of this storage using indirect measures. Furthermore, it is possible that indirect testing may reveal semantic elaboration of unattended words, the consequences of which may not be observable in direct tests.

General Method

General Procedure

Each subject was examined in three experimental phases. In Phase 1, subjects listened to two lists of words presented dichotically. They were instructed to attend to one ear only and to study the words presented to that ear in anticipation of a memory test. ERPs were recorded and provided indexes of semantic priming of targets presented to the attended and unattended ears. In Phase 2 the subjects were tested for recognition of words presented in Phase 1. "Old" and "new" words were presented one at a time binaurally. Among the old words, half had been initially presented in Phase 1 to the attended ear and the other half had been initially presented to the unattended ear. In addition, semantic processing of attended and unattended words was assessed indirectly by comparing the percentages of semantically based false alarms. In Phase 3 we examined the effect of attention during study on memory for words indirectly by assessing the effect of repeating some of these words in a lexical decision task. Half of the repeated words were attended in Phase 1 and half were unattended. The RTs in response to repeated words were compared to those in response to new words (i.e., words that were not presented to the subjects in any of the previous phases of this study).

Subjects reclined in a comfortable chair during testing. The intensity of sounds in the two ears was adjusted for each subject separately to achieve subjective equality between the two channels. The three phases were separated by 5-min rest intervals.

Subjects

The subjects were 32 paid undergraduate students (16 men and 16 women), all with normal hearing, ranging between 19 and 32 years in age. They were all right-handed with a mean handedness score of 0.80 (Oldfield, 1971) and without any left-handed relatives in their immediate family.

[2] We use the terms *direct* and *indirect* measures of memory as proposed by Johnson and Hasher (1987). In the present study, direct measures were obtained in tasks in which the subjects were explicitly instructed to make reference to words that had been previously studied. Indirect measures were differences in task performance with previously studied words in comparison with words that were not so studied. (For an extensive analysis of direct and indirect measures of memory, see Richardson-Klavehn & Bjork, 1988.)

Stimuli

The stimuli used in this study were spoken words and nonwords. All stimuli were tape-recorded in a male voice and digitized (at 10,000 Hz), using the Haskins Laboratories PCM input/output system (Whalen, Wiley, Rubin, & Cooper, 1990). Following A/D conversion, each word was edited to eliminate irrelevant noises and silent periods at onset. In addition, differences among word durations were minimized, without affecting intelligibility. The durations of the resulting stimuli ranged from 310 ms to 790 ms, with a median of 460 ms. An IBM-AT compatible computer equipped with a Data Translation 2821 D/A card was used for reproduction. The stimuli were presented through headphones at a comfortable intensity.

ERP Recording

Subjects were tested in an electrically isolated and sound-treated room. The electroencephalogram (EEG) was recorded continuously with tin electrodes mounted in a commercially available elastic cap. Impedances were kept below 5 Kohm throughout the study. The recording sites were Fz, Cz, Pz, P3, P4, T5, and T6 as defined by the 10–20 system, and three additional lateral pairs placed over symmetrical right and left hemisphere locations: (a) a frontal pair placed midway between F7-8 and T3-4 (approximately over Broca's area and its right hemisphere homologue, BL and BR), (b) a temporoparietal pair placed 30% of the interaural distance posterior to Cz (approximately over Wernicke's area and its right hemisphere homologue, WL and WR), and (c) a central pair situated 33% lateral to Cz (approximately over Brodmann's Area 41, 41L, and 41R). Each scalp site was referred to an average of the left and right mastoids calculated off-line. Vertical eye movements and blinks were monitored through a bipolar montage above and below the right eye, and horizontal eye movements were monitored through a left-to-right montage at the external canthi.

The EEG was amplified by a Grass Model 12 polygraph with half-amplitude cutoffs of 0.01 Hz and 100 Hz, digitized on-line at a sampling rate of 170 Hz, and stored on magnetic tape along with stimulus codes for subsequent averaging. About 5% of the trials were rejected prior to averaging because of eye movements, blinks, muscle artifacts, or amplifier blocking.

ERP Analysis

On the basis of a previous study in which we investigated semantic priming effects in speech perception using these same stimuli (Bentin, Kutas, & Hillyard, 1993), we anticipated that semantically primed words would elicit waveforms that were less negative than unprimed words during a relatively long epoch starting at about 300 ms and ending at about 900 ms from stimulus onset. The mean amplitude in each experimental condition was calculated during this epoch; these values were normalized according to McCarthy and Wood (1985) to allow comparisons across electrode sites. The normalized mean amplitudes were subjected to factorial analyses of variance (ANOVA) in order to determine the reliability of the differences. The degrees of freedom were adjusted, whenever necessary, according to the Greenhouse-Geiser procedure to compensate for inhomogeneous variances and covariances across treatment levels.

Phase 1

Method

Stimuli and design. The stimuli in Phase 1 were 576 different words. Their frequency ranged between 10 and 2,110, with a mean frequency of 83.7 (Francis & Kucera, 1982). Two different words were simultaneously presented on each trial, one to each ear. The durations of the words presented to the two ears in one trial were identical for about 75% of the trials; in no trial did the difference exceed 20 ms.

Two lists (A and B) of 320 stimuli each were assembled. Each list contained 128 pairs of semantically related words; one word in each pair was designated prime and the other, target. The semantically related pairs in each list comprised 40 pairs of antonyms and 88 pairs of semantic category exemplars. The strength of the semantic association was determined by rating in a pilot survey (for details, see Bentin et al., 1993). The average ratings of the pairs in List A and in List B were identical, and there was no semantic relationship between words included in different lists.[3] The average frequencies of the words in List A were 84 for targets and 83 for primes. In List B the word frequency was 84 for targets and 91 for primes. In addition to the related word pairs, each of the lists contained 64 filler words, randomly interspersed among the pairs; across subjects the same filler words were used in both channels.

Each of the two stimulus lists had two forms designated A1, A2 and B1, B2. In each form, 64 of the target words (of which 20 were antonyms) immediately followed the primes to which they were semantically related, whereas the other 64 targets followed unrelated primes. The 64 targets that were presented in the "related" condition in one form were presented in the "unrelated" condition (i.e., following an unrelated prime) in the other form. The serial positions of the targets were identical across lists. For dichotic presentation, List A1 was paired with List B2 and List A2 with List B1. Targets in one channel were always presented with primes or fillers in the other channel. Therefore, assuming that both stimuli (regardless of selective attention) contributed to the response, the ERP in any given single trial was elicited either by two stimuli, neither of which was semantically primed (an unrelated target to one ear and a prime or a filler to the other ear), or by a combination of a semantically primed (target) and an unprimed stimulus (prime or filler).[4]

Sixteen subjects were assigned to Lists A1/B2 and the other 16 to Lists A2/B1. Within each group of 16, 8 received List A in the right ear and List B in the left and vice versa for the other 8. Within each group of 8, 4 were instructed to attend to the right ear and ignore the left, whereas the other 4 received the reverse instructions. Thus, across subjects, each target was presented equally in the related and unrelated conditions, in the attended and unattended channels, and to the left and right ears. Within each subject the ERPs elicited by trial targets preceded by semantically related primes could be compared with ERPs elicited by targets preceded by unrelated primes to assess the semantic priming effect. Because

[3] The stimuli lists are available from S. Bentin.

[4] Visual inspection revealed that ERPs elicited by attended targets that were paired with unattended fillers were similar to those elicited by attended targets paired with unattended primes. Furthermore, primes and fillers in the unattended channels did not differ in their ERP amplitudes. Therefore, no distinction was made between these two types of pairs.

related and unrelated targets were presented equally to the attended and unattended ears, the influence of attention on the semantic priming effect could also be assessed within each subject.

Procedure. After the application of the electrode cap and the intensity adjustment of the two auditory channels, subjects were instructed to attend to one ear (right or left) and to memorize the words presented to that ear while ignoring words presented to the other ear. An eye fixation mark was applied to the right or the left edge of a monitor screen, corresponding to the ear to be attended. After instructions, 44 practice trials were presented. The 320 dichotic test trials followed in four blocks of 80 trials each. The dichotic word pairs were presented at a rate of one every 1,000 ms; the between-pair interval varied with stimulus duration. Blocks were separated by 45-s intervals of silence.

Results

The pattern of the ERPs elicited by target words in the attended and unattended channels during the first 1,000 ms from stimulus onset was similar: Two main negative components were conspicuous (Figure 1). The first was a relatively sharp peak (N1) at a latency of about 100 ms. Following N1 there was a large and sustained negative deflection. On the basis of its sensitivity to semantic priming (see below), its scalp distribution, and its peak latency of between 400 and 600 ms, this potential was identified as N400.

Despite the overall similarity of the ERPs elicited by attended and unattended target words, the semantic priming effect on ERPs was very sensitive to attention. As expected, primed targets elicited smaller N400 amplitudes, but only for targets in the attended channel (Figure 2).

The statistical reliability of these observations was assessed by a mixed model ANOVA with three within-subjects and one between-subjects factors. The within-subjects factors were attention (attended, unattended targets), semantic relatedness (related, unrelated targets), and electrode site (BL, Fz, BR, 41L, Cz, 41R, WL, WR, P3, Pz, P4, T5, T6); the between-subjects factor was attended ear (right, left). Across groups, the mean N400 amplitude (over the interval 300–900 ms) elicited by unattended targets (−1.84 μV) was significantly more negative than that elicited by attended targets (−1.32 μV), $F(1, 30) = 15.31$, $p < .001$, $MS_e = 7.58$. The overall mean N400 amplitude elicited by unrelated targets (−1.75 μV) was significantly more negative than the mean amplitude elicited by related targets (−1.42 μV), $F(1, 30) = 8.24$, $p < .008$, $MS_e = 5.40$. This semantic priming effect, however, was different in the attended and unattended channels, as revealed by a significant Semantic Relatedness × Attention interaction, $F(1, 30) = 5.96$, $p < .02$, $MS_e = 4.91$. Planned comparisons revealed that whereas the semantic priming effect in the attended channel was reliable ($p < .01$), it did not reach significance in the unattended channel.

The overall mean amplitudes elicited at different sites were significantly different, $F(12, 360) = 11.44$, $p < .0001$, $MS_e = 2.18$. Post hoc Tukey honestly significant difference (HSD; $p < .01 = 0.70$ μV) comparisons revealed that the mean amplitudes were more negative at midline (−2.30

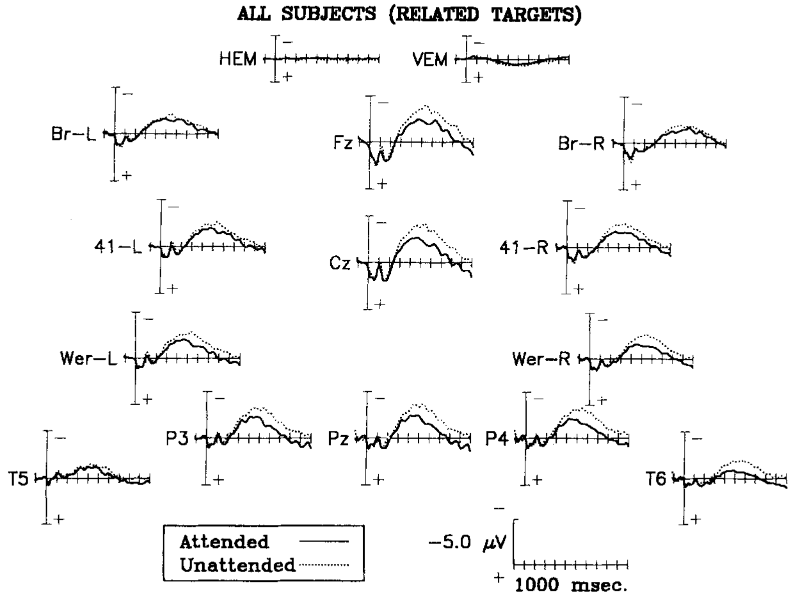

Figure 1. Event-related brain potentials (ERPs) elicited by attended and unattended target words in a dichotic listening task. Note that each waveform is elicited by a pair of words, one attended and one unattended. Therefore, the attention effect observed in this figure was induced by semantic relatedness that influenced the ERPs only if the targets were attended. In this and all additional figures presenting ERPs negative potentials are traced upward. HEM = horizontal eye movements; VEM = vertical eye movements; Br = Broca's area; L = left; R = right; F = frontal; z = midsaggital line; C = central; Wer = Wernicke; P = parietal; T = temporal.

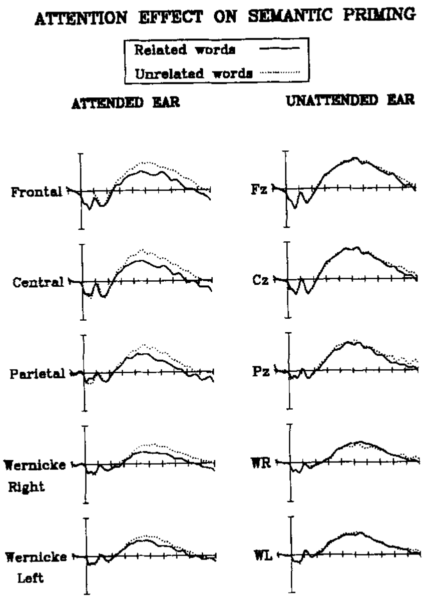

Figure 2. The semantic relatedness effect on event-related brain potentials (ERPs) in the attended and unattended channels. The calibration is 5 μV (negative-up).

μV) than at either the left (-1.38 μV) or the right hemisphere (-1.36 μV) sites. There were no other reliable differences among electrode sites.

The between-subjects analysis showed that the N400 amplitudes elicited by subjects who attended to their right ear did not differ significantly from those elicited by subjects who attended their left ear, $F(1, 30) = 2.54$, $p > .12$, $MS_e = 33.7$. A nonsignificant two-way Semantic Priming $\times$ Attended Ear interaction indicated that the semantic priming effect also was similar in the attend-right and attend-left groups, $F(1, 30) = 1.45$, $p > .23$, $MS_e = 5.40$. However, informal interviews revealed that subjects found it easier to ignore words presented to the left ear than to ignore words presented to the right. Indeed, comparison of the semantic relatedness effect in unattended channels suggests a trend in this direction (Figure 3). Whereas for the attend-right group there was no sign of semantic priming effects in the unattended left ear, $F(1, 15) = 0.67$, for the attend-left ear group, unattended targets in the right ear elicited significantly less negativity in the related condition than in the unrelated condition, $F(1, 15) = 7.40$, $p < .01$, $MS_e = 1.77$. This Semantic Priming $\times$ Attended Ear interaction was only marginally significant, $F(1, 30) = 3.54$, $p < .06$, $MS_e = 5.07$, however, and its reliability is questionable because the three-way Attended Ear Group $\times$ Attention $\times$ Semantic Relatedness interaction in the overall ANOVA did not reach significance, $F(1, 30) = 2.07$, $p > .15$, $MS_e = 4.91$. Hence, although these data suggest that selective attention may not be as efficient in suppressing semantic priming in the unattended right as in the unattended left ear, a confirmation of this hypothesis requires additional evidence.

In summary, the results of Phase 1 demonstrated a strong effect of selective attention in dichotic listening, with only words presented to the attended ear showing a reliable N400 semantic priming effect. However, the absence of the N400 index of semantic priming for unattended words is not a sufficient basis for concluding that unattended words did not access semantic memory. For example, it is possible that semantic memory was in fact accessed but that N400 did not reflect such access. Therefore, other measures were used to examine whether the unattended words did or did not access semantic memory.

Phase 2

In Phase 2 we studied the effect of attention on semantic processing of words by observing the consequences of selective attention during study on memory for studied items. Typically, words that are semantically processed are recalled and recognized better than words that are only superficially processed (e.g., Craik & Lockhart, 1972; Jacoby & Craik, 1979; Lockhart, Craik, & Jacoby, 1976). Therefore, if words presented to the unattended ear did not access semantic memory as suggested by the ERP measure of semantic priming in Phase 1, we should expect a significant effect of attention during study on recognition memory performance: The percentage of recognized attended words should significantly exceed the percentage of recognized unattended words.

On the other hand, recent studies have shown that the level of processing of words at study primarily affects direct measures of memory. For example, Graf and Mandler (1984) and Graf, Mandler, and Haden (1982) found that a levels-of-processing manipulation did not affect the word

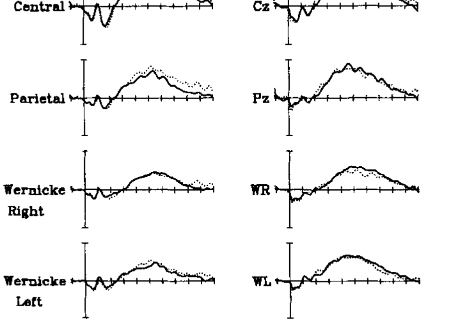

Figure 3. The semantic relatedness effect in unattended channels. Note that it apparently was more difficult to ignore the meaning of words presented to the right ear. The calibration is 5 μV (negative-up).

repetition effect in fragment and stem completion tests. Several authors suggested that this dissociation supports a distinction between different storage mechanisms such as explicit-declarative memory, that is, memory for facts and episodes, and an implicit-procedural memory, that is, memory for skills and other cognitive operations (e.g., Squire, 1987; Tulving & Schacter, 1990). Other authors have accounted for this dissociation in terms of the similarity of cognitive processes between study and test phases and distinguished, for example, between data driven and conceptually driven processes (e.g., Dunn & Kirsner, 1989; Roediger & Blaxton, 1987). Regardless of the interpretation, however, there is considerable evidence to indicate that direct tests of memory are insufficient to determine whether or not a semantic representation has been accessed at study. Therefore, we have included an indirect measure that should reflect semantic activation during study yet be independent of conscious recollection of the words, namely, the percentage of false categorization of new words as old (false-alarm errors). Several studies have shown that in a continuous recognition test, new words that were either associates of (Underwood, 1976) or semantically related to (Anisfeld & Knapp, 1968) old words were more often falsely recognized than unrelated new words. Moreover, Anisfeld and Knapp found that this higher rate of false alarm responses was not observed when study words did not elicit the test words in a free association test, even if the inverse relationship was found. This asymmetrical pattern suggests that a semantically induced false alarm reflects a process related to the initial encoding of the word rather than an artifact of testing for it. Therefore, semantically induced false alarms can be taken as evidence that the relevant old words had accessed their semantic representations during study.

Accordingly, in Phase 2 we assessed the effect of attention on the encoding of words in long-term memory both directly, by comparing the recognition of words originally presented in the attended and in the unattended channels, and indirectly, by comparing the percentage of false alarms to lures that were semantically related to either attended or unattended old words.[5]

Method

Stimuli and design. The stimulus list consisted of 210 words, presented binaurally. Among these were 100 old words, 50 of which had been presented in the attended channel and 50 in the unattended channel. All old words were presented as targets in Phase 1 equally selected among those that were semantically primed and unprimed. Because during Phase 1 the lists were counterbalanced across subjects, these same 100 words were presented to all subjects, with each word having been attended by half of the subjects and unattended by the other half. The other 110 words were new (i.e., they were not presented in Phase 1). Among the new words, 50 were "control" words and 60 were "lures." The lures were new words that were semantically related to old primes and fillers. Among the old words to which the lures were related, 30 were initially presented in the attended channel and 30 were initially presented in the unattended channel; in summary, although from the subject's point of view there were only two response categories (old and new), from the experimenters' point of view there were five stimulus categories: (a) old words that were attended in Phase 1, (b) old words that were unattended in Phase 1, (c) new words that were semantically related to words that were attended in Phase 1, (d) new words that were semantically related to words that were initially presented in the unattended channel, and (e) new stimuli that were unrelated to any of the stimuli presented in Phase 1.

The unrelated new words in this list were single members of word pairs whose semantic relationship rating was too low to have been included in the study lists. All the new words were recorded in the same male voice as the old words and similarly edited. Their word frequency was within the same range as the words included in the study lists.

Procedure. Phase 2 followed Phase 1 after a short break. The subjects were given two silent microswitch buttons mounted on joystick handles. They were instructed to press the right-hand button when they heard a word that they remembered being presented during Phase 1, regardless of the ear in which the word was presented, and the left-hand button when they heard a new word. Speed and accuracy were emphasized equally. The 210 test words were presented at a rate of one word every 2.5 s, in three blocks of 70 stimuli each. A silent period of 45 s separated consecutive blocks.

Results

Words that had been attended at study were recognized faster and more accurately than words that had been presented to the unattended ear (Table 1).

The statistical reliability of these effects was tested by ANOVA with one within-subjects factor—attention (attended targets, unattended targets)—and one between-subjects factor—attended ear (left, right). The 16% decrease in the percentage of hit responses for unattended relative to attended words was reliable, $F(1, 30) = 100.20, p < .0001$, $MS_e = 43.14$, as was the 67-ms increase in RT, $F(1, 30) = 9.04, p < .006, MS_e = 7{,}922.6$. The percentage of hit responses was lower and the RTs were slower in the attend-left than in the attend-right group; however, these trends were not significant, $F(1, 30) = 2.14, p > .15, MS_e = 540.6$, and $F(1, 30) = 1.28, p > .26, MS_e = 53{,}130.6$, for accuracy and speed, respectively. Neither was the interaction between the attention and group factors significant for either the percentage of hits or for RT, $F(1, 30) = 0.67$ and $F(1, 30) = 1.01$, respectively.

The percentage of false alarms was higher for "lures" than for unrelated new words, $F(2, 60) = 4.59, p < .02$, $MS_e = 53.7$, and the RTs to these false alarms were faster for lures than for unrelated words, $F(2, 60) = 3.68, p < .04$, $MS_e = 17{,}986$. (See Figure 4 and Table 2.) Post hoc comparisons revealed that attention during study had no effect on the percentage of false alarms; the percentage of false alarms among lures that were related to targets in the attended channel (30%) did not differ from the percentage of false alarms among lures related to unattended targets

[5] In this and subsequent phases, ERPs were collected but the results were inconclusive due to confounding of P300 and N400 effects in these binary decision tasks. Therefore, these ERP results will not be presented in this article; they are available by request from S. Bentin.

Table 1
Percentage and Response Times (RTs; in Milliseconds) to Hit Responses in the Recognition Test

Attended ear	Attention at study: Attended M	Attended SE_M	Unattended M	Unattended SE_M	Attached era effect M	Attached era effect SE_M
Right						
RT	1,134	41	1,177	36	1,156	33
% Hit	57	4.3	39	4.6	48	3.5
Left						
RT	1,178	53	1,266	43	1,222	29
% Hit	53	4.2	43	3.9	40	3.2
Attention effect						
RT	1,156	27	1,223	34		
% Hit	52	3.1	35	3.0		

(29%), HSD ($p < .05$) = 4.4%. The same pattern was found for RTs: The RTs of false alarms to the lures related to attended targets did not differ from the RTs to lures related to unattended targets, HSD ($p < .05$) = 80.6 ms. As with hit responses, the attend-left and attend-right groups did not differ in the overall percentage of false alarms, $F(1, 30) = 0.64$, or in the RTs to the false alarms, $F(1, 30) = 0.42$. The interactions were also unreliable.

The subjects' ability to discriminate between old and the different categories of new words and the effect of selective attention on this ability were further assessed using the d' measure. Six d's were calculated for each subject, three reflecting the discrimination between old attended items and new items and three reflecting the discrimination between old unattended items and new items (Table 3). Differences between these measures were assessed by a two-way ANOVA with repeated measures. The factors were attention at study (attended, unattended) and new word type (unrelated, related to initially attended, related to initially unattended).

The ANOVA showed that old words that were attended at study were distinguished from new words significantly better ($d' = 0.69$) than old words that were unattended at study ($d' = 0.22$), $F(1, 31) = 67.28$, $p < .0001$, $MS_e = 0.160$. In addition, the ability to distinguish between old and new words varied significantly across the different types of new words ($d' = 0.57$, 0.37, and 0.42 for unrelated, related to attended, and related to unattended old targets, respectively), $F(2, 62) = 5.37$, $p < .01$, $MS_e = 0.124$. Most important, as demonstrated by the nonsignificant interaction between the factors attention and relatedness $F(2, 62) = 0.97$, $p > .36$, $MS_e = 0.008$, the effect of new word type on d' was similar for all old words, regardless of whether they were attended at study. Post hoc comparisons (Tukey-A) revealed that the distinction between old words and new words was significantly better when the new words were unrelated than when the new words were semantically related to old words that were either attended or unattended at study. The later two d' measures were not significantly different from each other.

Discussion of Phases 1 and 2

The results of Phase 1 indicated that the N400 semantic priming effect was greatly diminished for semantically related pairs presented to the unattended ear. In addition, as was found in Phase 2, the probability of explicitly recognizing the unattended words in a subsequent memory test was considerably lower than the probability of recognizing words that were attended at study. These results support a view that subjects did not process the meaning of unattended words at study as extensively as they processed the meanings of the attended words. However, the equally incremented false-alarm rates to lures that were related to unattended and attended old words indicated that unattended words did activate their semantic representations. These data therefore suggest that selective attention did not prevent spoken words from accessing semantic memory, although attention did influence the manner in which words were processed and the nature of the memory traces they formed.

The absence of the N400 semantic priming effect in the unattended ear contradicts the assumption that selective attention did not prevent semantic activation. However, this contradiction can be reconciled by assuming that at least some aspects of semantic priming of unattended words are automatic and that N400 is not sensitive to these aspects. Such an assumption is congruent with findings that N400 is modulated by expectancy or other nonautomatic aspects of processing words in context (e.g., Bentin, 1987; Holcomb, 1988, 1993; Kutas, Lindamood, & Hillyard, 1984). Moreover, Bentin and McCarthy (1994) recently found that N400 is sensitive to the complexity of tasks in which the subjects are engaged, suggesting that its modulation is influenced by attention mediated strategies (see also Bentin et al., 1993; Bentin & Peled, 1990; Karanaydis, Andrews, Ward, & McConaghi, 1991). It is also possible that the stimulus onset asynchrony (SOA) between prime and target words in this

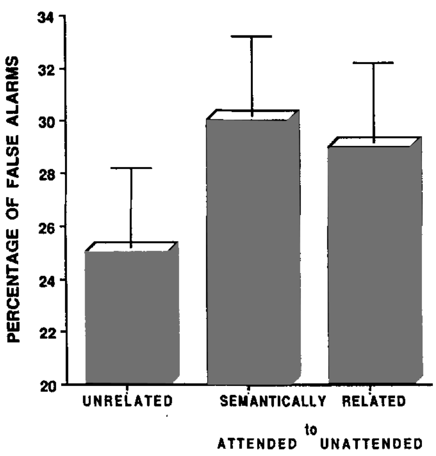

Figure 4. The percentage of false alarms induced by "new" words that were semantically related to "old" words presented to the attended ear or to the unattended ear, and induced by "new" words that were not related to any of the "old" words.

Table 2
Reaction Times (RTs; in milliseconds) and Standard Errors of the Mean to False-Alarm Responses in the Recognition Test

	Semantically related new words			
Attended ear	Attended	Unattended	Unrelated new words	Attended ear effect
Right				
RT	1,166	1,194	1,284	1,215
SE_M	50	57	64	33
Left				
RT	1,228	1,252	1,287	1,255
SE_M	49	33	57	27
Attention effect				
RT	1,197	1,223	1,285	
SE_M	35	33	42	

study (1,000 ms) was too long for an automatic priming component to be effective (e.g., Antos, 1979; Neely, 1977). Therefore, although unattended words may have activated the semantic network, the consequence of this activation on subsequently presented items (i.e., semantic priming) may have been insufficient to modulate the N400 component.

The recognition performance in Phase 2 indicated that unattended words formed weaker memory traces in episodic memory. This result suggests that, at study, unattended words were semantically less elaborated than attended words (Jacoby & Craik, 1979). This interpretation is consistent with the significantly reduced N400 index of semantic priming effect for words in the unattended channel. However, it is also possible that because the explicit recognition task requires paying attention to the test words, the cognitive process involved in encoding test words was more similar to those of encoding the attended words at study than encoding the unattended words. Thus, the better recognition performance for attended-channel words would be consistent with the principle of transfer appropriate processes (e.g., Morris, Bransford, & Franks, 1977). The pattern of false alarms suggests that a simple interpretation that is based on a levels-of-processing theory is not tenable. In particular, the false-alarm data suggest that when the semantic processing of studied words is tested indirectly, unattended words appeared to elicit a similar amount of activation of their semantic associates as did the attended words. The distinction between the effect of attention on explicit recognition and the indirect evidence of semantic processing at study that was observed in the pattern of the false alarms, leads us to suspect that indirect measures of memory might also reveal different effects of selective attention at study than direct measures. An indirect measure of memory that has been assessed in both ERP and RT studies is the repetition effect at long lags (e.g., Bentin et al., 1992; Moscovitch & Bentin, 1993; Rugg & Doyle, in press). In the final phase of the present study we explored the effect of attention at study on this repetition effect in memory.

Table 3
Values of d' Reflecting the Level of Discrimination Between Initially Attended and Unattended Old Words and Between New Words that Were Semantically Related Either to Attended or to Unattended Old Words or Unrelated

	New words type		
Old words type	Unrelated	Related to attended	Related to unattended
Attended	.82	.61	.65
Unattended	.32	.13	.20

Phase 3

There is evidence in the research literature that the effect of stimulus repetition can under some conditions be dissociated from explicit recognition of the repetition and of other direct measures memory (e.g., Tulving, Schacter, & Stark, 1982). Moreover, repetition facilitates task performance even when subjects are unaware of the repetition and do not remember the initial presentation (e.g., Johnston, Dark, & Jacoby, 1985; Moscovitch & Bentin, 1993). Therefore, repetition priming has been taken as an indirect index of memory (e.g., Jacoby & Witherspoon, 1982; for a review, see Schacter, 1987).

However, it has also been reported that if subjects do explicitly remember the first task-related encounter with a repeated stimulus, the repetition effect reflects this awareness (Jacoby, 1983). Explicit recollection should affect performance in indirect tests of memory particularly when the task is not repeated so that encoding processes do not entirely overlap (Roediger, Weldon, & Challis, 1989). Indeed, when conceptually driven[6] tasks were used, the magnitude of the repetition effect was affected by the level of processing at study, suggesting that it was sensitive to factors influencing direct measures of memory (Hammann, 1990).

From these considerations, the effect of selective attention on repetition priming is not readily predictable. On the one hand, the stochastic independence between repetition effects and direct measures of memory has led some authors to propose that repetition effects reflect a perceptual memory system that may be independent of the specific nature of encoding processes (Tulving & Schacter, 1990). Consistent with this hypothesis, several RT studies showed that, in contrast to direct measures of memory such as free recall or recognition, repetition priming (in stem completion tasks) is relatively unaffected by depth of processing manipulations (e.g., Graf & Mandler, 1984; Jacoby & Dallas, 1981). These results suggest that repetition priming would not be influenced by attentional factors during encoding. Accordingly, one might predict that the repetition effect should be equal for study items that were and were not attended.

[6] We refer here to the distinction between data driven tasks such as perceptual identification and conceptually driven tasks such as word generation that has been proposed by Roediger and his associates (e.g., Roediger et al., 1989).

On the other hand, Moscovitch and Bentin (1993) found a positive correlation between the repetition effect on RT in lexical decision and d' for word recognition. Furthermore, in contrast to RT, the magnitude of the ERP repetition priming effect was found to be sensitive to factors that affect direct measures of memory, such as the number and recency of repetitions (Bentin et al., 1992). Thus, as mentioned above, explicit recollection of the first presentation episode may enhance the magnitude of the repetition effect.

The results of Phase 2 indicated that, when studied without attention, words are less available to explicit recognition. This result suggests that the episodic traces formed by unattended words were weaker than those formed by attended words and, therefore, subjects may be less aware of repetition of unattended than of attended words. Assuming that explicit memory of the initial encounter magnifies the repetition effect, we would expect to find larger repetition effects for words that were attended at study than for unattended words. Such an outcome would be consistent with the results of Hawley and Johnston (1991), who found larger repetition effects in perceptual identification for attended than for unattended items.

In Phase 3 of this study we examined these various predictions. In addition to manipulating attention during the first presentation (in Phase 1) we also varied the number of previous encounters with the repeated stimulus. At the beginning of this Phase a subset of the initially attended and unattended words was presented binaurally along with an equal number of new words, and subjects were instructed to attend and study all of them. To the extent that episodic memory for repeated items influences the magnitude of the repetition effect, we should observe larger repetition effects in a subsequent lexical decision task for items that had been repeated twice than for those that have been repeated only once, and for items that had been attended at study than for items that had not been attended at study.

Method

Stimuli and design. The second study list included 80 "old" words that were presented initially in Phase 1 and 80 "new" words (i.e., words that were not presented previously in this study). Among the 80 old words 40 were initially presented to the attended ear and 40 to the unattended ear. Because most items that were targets in Phase 1 had been presented in Phase 2, all the repeated words in the present phase were initially presented as primes and fillers. These 160 words were presented binaurally, one every 1,750 ms, in two equal blocks of 80 words each.

The stimuli in the lexical decision task were 224 words and 64 nonwords. Among the words, 64 were new and 160 were repeated from the first study list. Of the repeated words, 80 were primes and fillers that were presented only in Phase 1, 40 to the attended and 40 to the unattended ear. The other 80 repeated words were those that were presented again in the second study list, at the beginning of Phase 3; hence, these 80 words were repeated twice before being presented in the lexical decision task.

Thus, in the lexical decision task there were five conditions of word presentation: (a) initially attended—repeated twice, (b) initially unattended—repeated twice, (c) initially attended—repeated once, (d) initially unattended—repeated once, (e) new words. Across subjects, the same words were repeated in each condition. New words did not differ in either their word frequency or average length from the repeated words.

The new words were fillers selected from the same pool of semantically related pairs as the other items used in this study. Only one member of each pair was included in the present list. They were recorded by the same speaker, analyzed, digitized, edited, and reproduced identically. The nonwords were pronounceable and legal phonological structures, previously used in a lexical decision study (Bentin, Kutas, & Hillyard, 1993).

Procedure for the lexical decision task. After the presentation of the second study list followed by a 5-min break, subjects were told that the expected memory test was being replaced by a different task, and they were given instructions for the lexical decision task. They pressed one button if they heard a word and another button if they heard a nonword. The right hand was always used for words. Speed and accuracy were emphasized equally.

Following a 24-item (6 nonwords) practice session, the test list was presented in four blocks of 72 stimuli each. Words and nonwords were presented binaurally at a rate of one stimulus every 1,750 ms. A 45-s silent interval separated the blocks.

Results

The average RTs to words for each stimulus class are presented in Figure 5. The RTs to repeated words were faster than to new words, words that were repeated twice were faster than words that were repeated once, and the RT repetition effect was the same whether the word had initially been attended or unattended.

An ANOVA showed that the repetition effect was statistically reliable, $F(4, 120) = 42.02, p < .0001, MS_e = 827.6$. Post hoc Tukey's *(a)* comparisons (HSD = 23.95, $p < .01$) revealed that (a) the RTs to new words were significantly longer than to all repeated words; (b) regardless of attention-directing instruction at study, the RTs to words that were repeated twice were faster than to words that were repeated once; and (c) RTs to initially attended and unattended words did not differ.

The results of the lexical decision study showed that repeated items were processed more rapidly than new items

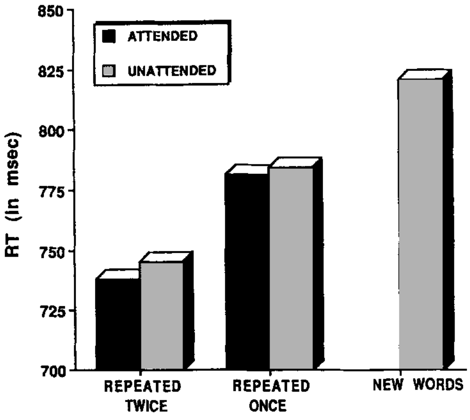

Figure 5. Lexical decision time for "new" and repeated words, initially presented to the attended and to the unattended ear. RT = reaction time.

and that although the RTs were sensitive to the strength of the memory trace, selective attention during initial encoding did not affect the repetition effect.

General Discussion

The present study examined the effects of selective attention on semantic processing and on the encoding of spoken words in a dichotic listening task. The amplitude of the N400 brain potential elicited by target words that were semantically related to immediately preceding primes was significantly reduced for words presented to the attended ear, but not for words in the unattended ear. In a subsequent direct test of memory, words that had been attended at study were more likely to be recognized than words that had not been attended. These results indicate that if neither primes nor targets are attended, the N400 semantic priming effect is severely compromised, and that the episodic memory trace established by unattended words is less accessible to direct retrieval.

On the other hand, subjects made an equal number of false alarms during the recognition test in response to lures that were semantic associates of initially attended or unattended words. Furthermore, RTs for lexical decision were facilitated equally by stimulus repetition regardless of whether the first presentation of the repeated words had been to the attended or to the unattended ear. These effects suggest that unattended words induced at least some semantic activity in the cognitive system and that the effects of this activity persisted over time.

The present results indicate that words in the unattended channel are less available to conscious processing and conscious recollection but may still access their semantic representations. On the basis of these results, we propose that one function of attention during encoding is to increase the accessibility of stored representations to conscious retrieval. At least some activation of semantic memory, however, seems to be possible without attention. (For a more detailed elaboration of this view, see Bentin, in press.)

The present findings may help us to understand more fully some of the factors that influence N400 amplitude. In particular, it appears that attention can modulate the effects of semantic priming on N400, although it may not be necessary for the mere generation of this component. As has been demonstrated in several studies, attention plays an important role in semantic priming (e.g., Fishler 1977; Fishler & Bloom, 1979; Neely, 1991), and it is the attentionally mediated component of priming that might account for the N400 modulation in Phase 1 (cf. Holcomb, 1988). Additional support for this hypothesis was obtained in a previous study in which the semantic priming effect on N400 was found to be smaller in a shallow task (counting nonwords) than in a deep task (memorize words) (Bentin et al., 1993). Hence, even when the words were attended, the level of processing affected the size of the N400 modulation by semantic priming.

The sensitivity of N400 to semantic priming (Bentin et al. 1985; Holcomb, 1988), to semantic congruity in sentences (Kutas & Hillyard, 1980), and its apparent insensitivity to incongruity in some musical contexts (Besson & Macar, 1987; Paller, McCarthy, & Wood, 1992), formed the basis of an early model according to which the N400 was presumed to be elicited by lexical access or word identification processes (e.g., Bentin, 1987). More recent studies, however, have found that nonlexical items such as familiar and unfamiliar faces may also elicit N400-like components (Bentin & McCarthy, 1994). Accordingly, several nonlexical accounts for the N400 elicitation have been proposed. Some have related the N400 to the process of accessing semantic memory (Bentin & McCarthy, 1994; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), whereas others have emphasized the role of contextual integration during sentence comprehension in eliciting this component (Brown & Hagoort, 1993; Osterhout & Holcomb, 1993). The present results do not resolve the question of lexical versus nonlexical interpretations of the N400, but they do indicate that it reflects attentional rather than automatic components of semantic priming. Moreover, the semantic activation produced by words in the attended channel, which was verified by the N400 amplitude modulation, resulted in those words being more accessible to direct recognition.

To summarize, the indirect tests used in the present study indicate that allocation of attention is not required for activation of semantic memory. However, it appears that attention at study is needed to achieve subsequent recognition in direct testing. It seems reasonable to propose that the same attentional mechanism enables both the modulation of the N400 component by semantic priming and the semantic elaboration of stimuli that makes them available to consciousness.

References

Ambler, B. A., Fisicaro, S. A., & Proctor, R. W. (1976). Temporal characteristics of primary-secondary message interference in a dichotic listening task. *Memory and Cognition, 4,* 709–716.

Anisfeld, M., & Knapp, M. E. (1968). Association, synonymity, and directionality in false recognition. *Journal of Experimental Psychology, 77,* 171–179.

Antos, S. J. (1979). Processing facilitation in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 527–545.

Bentin, S. (1987). Event-related potentials, semantic processes and expectancy factors in word recognition. *Brain and Language, 31,* 308–327.

Bentin, S. (1989). Electrophysiology of word perception lexical organization and semantic priming: A tutorial review. *Language & Speech, 32,* 205–220.

Bentin, S. (in press). Semantic processing of ignored stimuli: The role of attention in memory. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance* (Vol. 15). Cambridge, MA: MIT Press.

Bentin, S., Kutas, M., & Hillyard, S. A. (1993). Electrophysiological evidence for task effects on semantic priming in auditory word processing. *Psychophysiology, 30,* 161–169.

Bentin, S., & McCarthy, G. (1994). The effect of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 130–149.

Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision, and semantic priming. *Journal of Electroencephalography and Clinical Neurophysiology, 60,* 343–355.

Bentin, S., & Moscovitch, M. (1990). Psychophysiological indices of implicit memory performance. *Bulletin of the Psychonomic Society, 28,* 346–352.

Bentin, S., Moscovitch, M., & Heth, Y. (1992). Memory with and without awareness: Performance and electrophysiological evidence of savings. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1270–1283.

Bentin, S., & Peled, B. (1990). The contribution of stimulus-related and task-related factors to the repetition effect at short and at long lags: Electrophysiological evidence. *Memory and Cognition, 18,* 359–366.

Besson, M., & Macar, F. (1987). An event-related potential analysis of incongruity in music and other non-linguistic contexts. *Psychophysiology, 24,* 14–25.

Bradshaw, J. L. (1974). Peripherally presented and unreported words may bias the perceived meaning of a centrally fixated homograph. *Journal of Experimental Psychology, 103,* 1200–1202.

Broadbent, D. E. (1971). *Decision and stress.* San Diego, CA: Academic Press.

Broadbent, D. E., & Gathercole, E. S. (1990). The processing of nontarget words: Semantic or not? *Quarterly Journal of Experimental Psychology, 42A,* 3–37.

Brown, C., & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Science, 5,* 34–44.

Carr, T. H. (1992) Automaticity and cognitive anatomy: Is word recognition automatic? *American Journal of Psychology, 105,* 201–238.

Corteen, R. S., & Dunn, D. (1974). Shock-associated words in a nonattended message: A tests for momentary awareness. *Journal of Experimental Psychology, 102,* 1143–1144.

Corteen, R. S., & Wood, B. (1972). Autonomic responses to shock-associated words in an unattended channel. *Journal of Experimental Psychology, 94,* 308–313.

Craik, F. I. M., & Lockhart, R. S. (1972). Depth of processing and the retention of words in episodic memory. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

Dallas, M., & Merikle, P. M. (1976). Semantic processing of non-attended visual information. *Canadian Journal of Psychology, 30,* 15–21.

Dark, V. J., Johnston, W. A., Myles-Worsley, M., & Farah, M. J. (1985). Levels of selection and capacity limits. *Journal of Experimental Psychology: General, 114,* 472–497.

Dawson, M. E., & Schell, A. M. (1982). Electrodermal responses to attended and nonattended significant stimuli during dichotic listening. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 315–324.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70,* 80–90.

Dunn, J. C., & Kirsner, K. (1989). Implicit memory: Task or process? In S. Lewandowsky, J. C. Dunn, & K. Kirsner (Eds.), *Implicit memory: Theoretical issues* (pp. 17–32). Hillsdale, NJ: Erlbaum.

Fishler, I. (1977). Semantic facilitation without association in a lexical decision task. *Memory and Cognition, 5,* 335–339.

Fishler, I., & Bloom, P. A. (1979). Automatic and attentional processes in the effects of semantic context on word recognition. *Journal of Verbal Learning and Verbal Behavior, 18,* 1–20.

Forster, P. M., & Govier, E. (1978). Discrimination without awareness? *Quarterly Journal of Experimental Psychology, 30,* 289–295.

Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston: Houghton Mifflin.

Frost, R., & Bentin, S. (1992). Processing phonological and semantic ambiguity: Evidence from semantic priming at different SOAs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 58–68.

Graf, P., & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning and Verbal Behavior, 23,* 553–568.

Graf, P., Mandler, G., & Haden, P. (1982). Simulating amnesic symptoms in normal subjects. *Science, 218,* 1243–1244.

Hamann, S. B. (1990). Levels-of-processing effects in conceptually driven implicit tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 970–977.

Hawley, K. J., & Johnston, W. A. (1991). Long-term perceptual memory for briefly exposed words as a function of awareness and attention. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 807–815.

Henik, A., Friedrich, F. J., & Kellogg, W. A. (1983). The dependence of semantic relatedness effects upon prime processing. *Memory and Cognition, 11,* 366–373.

Holcomb, P. J. (1988). Automatic and attentional processing: An event related brain potential analysis of semantic processing. *Brain and Language, 35,* 66–85.

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology, 30,* 283–290.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using evoked potentials. *Language and Cognitive Processes, 5,* 281–312.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *The Behavioral and Brain Sciences, 9,* 1–66.

Inhoff, A. W. (1989). Parafoveal processing of words and saccade computation during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 544–555.

Inhoff, A. W., & Rayner, K. (1986). Parafoveal word processing during eye fixation in reading: Effects of word frequency. *Perception & Psychophysics, 40,* 431–440.

Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 21–38.

Jacoby, L. L., & Craik, F. I. M. (1979). Effects of elaboration of processing at encoding and retrieval: Trace distinctiveness and recovery of initial context. In L. Cermak, & F. I. M. Craik (Eds.), *Levels of processing in human memory* (pp. 1–21). Hillsdale, NJ: Erlbaum.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

Jacoby, L. L., & Witherspoon, D. (1982). Remembering without awareness. *Canadian Journal of Psychology, 32,* 300–324.

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Reviews in Psychology, 17,* 3–75.

Johnston, W. A., Dark, V. J., & Jacoby, L. L. (1985). Perceptual fluency and recognition judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 3–11.

Johnston, W. A., & Hasher, L. (1987). Human learning and memory. *Annual Reviews of Psychology, 38,* 631–668.

Johnston, W. A., & Wilson, J. (1980). Perceptual processing of nontargets in an attention task. *Memory and Cognition, 8,* 372–377.

Kahaneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davis (Eds.), *Varieties of attention* (pp. 29–61). San Diego, CA: Academic Press.

Kahaneman, D., Treisman, A., & Burkell, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 510–522.

Karanaydis, F., Andrews, S., Ward, P. B., & McConaghi, N. (1991). Effects of interilem lag on word repetition: An event-related potential study. *Psychophysiology, 28,* 307–318.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207,* 203–205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307,* 161–163.

Kutas, M., Lindamood, T. E., & Hillyard, S. A. (1984). Word expectancy and event-related potentials during sentence processing. In S. Kornblum and J. Requin (Eds.), *Preparatory states and processes* (pp. 217–234). London: LEA.

Kutas, M., & Van Petten, C. (1988). Event-related potential studies of language. In P. K. Ackles, J. R. Jennings, & M. G. H. Coles (Eds.), *Advances in psychophysiology* (pp. 285–314). Greenwich, CT: JAI Press.

Lambert, A. J., Beard, C. T., & Thompson, R. J. (1988). Selective attention, visual laterality, awareness, and perceiving the meaning of paraphoveally presented words. *Quarterly Journal of Experimental Psychology, 40A,* 171–186.

Lewis, J. L. (1970). Semantic processing of unattended messages using dichotic listening. *Journal of Experimental Psychology, 85,* 225–228.

Lockhart, R. S., Craik, F. I. M., & Jacoby, L. (1976). Depth of processing, recognition and recall. In J. Brown (Ed.), *Recall and recognition* (pp. 456–468). New York: Wiley.

Mackay, D. G. (1973). Aspects of theory of comprehension, memory, and attention. *Quarterly Journal of Experimental Psychology, 25,* 22–40.

McCarthy, G., & Nobre, A. C. (1993). Modulation of semantic processing by spatial selective attention. *Electroencephalography and Clinical Neurophysiology, 88,* 210–219.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62,* 203–208.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior, 16,* 519–533.

Morton, J. (1970). A functional model for memory. In D. A. Norman (Ed.), *Models of human memory* (pp. 203–260). San Diego, CA: Academic Press.

Morton, J. (1982). Disintegrating the lexicon: An information processing approach. In J. Mehler, E. C. T. Walker, & M. Garret (Eds.), *Perspectives on mental representation* (pp. 89–110). Hillsdale, NJ: Erlbaum.

Moscovitch, M., & Bentin, S. (1993). The fate of repetition effects when recognition approaches chance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 148–158.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: The role of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading—Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Nobre, A. C. (1993). *Linguistic processing in the human brain: Neurophysiological studies of neural organization and selective attention.* Unpublished doctoral dissertation, Yale University.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9,* 97–113.

Osterhout, L., & Holcomb, P. J. (1993). Semantic priming and the N400 component. *Neuropsychologia, 30,* 28–35.

Otten, L. J., Rugg, M. C., & Doyle, M. C. (in press). Modulation of event-related potentials by word repetition: The role of selective attention. *Psychophysiology.*

Paller, K. A. (1990). Recall and stem-completion priming have different electrophysiological correlates and are modified differently by directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 1021–1032.

Paller, K. A., McCarthy, G., & Wood, C. C. (1992). Event-related potentials elicited by deviant endings to melodies. *Psychophysiology, 23,* 202–206.

Posner, M. I., Sandson, J., Dhawan, M., & Shulman, G. L. (1989). Is word recognition automatic? A cognitive-anatomical approach. *Journal of Cognitive Neuroscience, 1,* 50–60.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Reviews of Psychology, 39,* 475–543.

Roediger, H. J. III., & Blaxton, T. (1987). Retrieval modes produce dissociations in memory for surface information. In D. Gorfein & R. R. Hoffman (Eds.), *Memory and cognitive processes: The Ebbinghaus cenntenial conference* (pp. 349–377). Hillsdale, NJ: Erlbaum.

Roediger, H. J. III., Weldon, M. S., & Challis, B. H. (1989). Explaining dissociations between implicit and explicit measures of retention: A processing account. In H. J. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honor of Endel Tulving* (pp. 3–41). Hillsdale, NJ: Erlbaum.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. *Memory and Cognition, 18,* 367–379.

Rugg, M. D., & Doyle, M. C. (in press). Event-related potentials and stimulus repetition in direct and indirect tests of memory. In H. Heinze, T. Munte, & G. R. Mangun (Eds.), *Cognitive electrophysiology.* Cambridge, MA: Birkhauser Boston.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.

Shaffer, W. O., & LaBerge, D. (1979). Automatic semantic processing of unattended words. *Journal of Verbal Learning and Verbal Behavior, 18,* 413–426.

Shiffrin, R. M. (1985). Attention. In R. C. Atkinson, R. J. Hernstein, G. Lindsey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology.* New York: Wiley.

Simpson, G. B., & Burgess, C. (1985). Activation and selection processes in the recognition of ambiguous words. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 28–39.

Smith, M. C., Theodor, L., & Franklin, P. E. (1983). The relationship between contextual facilitation and depth of processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 697–712.

Squire, L. R. (1987). *Memory and the brain.* New York: Oxford University Press.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12,* 205–219.

Treisman, A. (1986). Features and objects in visual processing. *Scientific American, 255,* 106–115.

Treisman, A., Squire, R., & Green, J. (1974). Semantic processing in dichotic listening? A replication. *Memory and Cognition, 2,* 641–646.

Tulving, E., & Schacter, D. L. (1990). Priming and human memory. *Science, 247,* 301–306.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 336–342.

Underwood, G. (1976) Semantic interference from unattended printed words. *British Journal of Psychology, 67,* 327–338.

Van Petten, C., Kutas, M., Kluender, R., Mitchiner, M., & McIsaac, H. (1991). Fractioning the word repetition effect with event-related potentials. *Journal of Cognitive Neurosciences, 3,* 131–150.

Whalen, D. H., Wiley, E. R., Rubin, P. E., & Cooper, F. S. (1990). The Haskins laboratories's pulse code modulation (PCM) system. *Behavior Research Methods, Instruments, & Computers, 22,* 550–559.

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P&C Board Appoints Editor for New Journal: *Psychological Methods*

The Publications and Communications Board of the American Psychological Association has appointed an editor for a new journal. In 1996, APA will begin publishing *Psychological Methods.* Mark I. Appelbaum, PhD, has been appointed as editor. Starting January 1, 1995, manuscripts should be directed to

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Psychological Methods will be devoted to the development and dissemination of methods for collecting, understanding, and interpreting psychological data. Its purpose is the dissemination of innovations in research design, measurement, methodology, and statistical analysis to the psychological community; its further purpose is to promote effective communication about related substantive and methodological issues. The audience is diverse and includes those who develop new procedures, those who are responsible for undergraduate and graduate training in design, measurement, and statistics, as well as those who employ those procedures in research. The journal solicits original theoretical, quantitative empirical, and methodological articles; reviews of important methodological issues; tutorials; articles illustrating innovative applications of new procedures to psychological problems; articles on the teaching of quantitative methods; and reviews of statistical software. Submissions should illustrate through concrete example how the procedures described or developed can enhance the quality of psychological research. The journal welcomes submissions that show the relevance to psychology of procedures developed in other fields. Empirical and theoretical articles on specific tests or test construction should have a broad thrust; otherwise, they may be more appropriate for *Psychological Assessment.*