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Auditory and visual semantic priming using different stimulus onset asynchronies: An event-related brain potential study

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Abstract

Semantic priming effects (behavioral and electrophysiological) were compared in the visual and auditory modalities across three stimulus onset asynchronies (SOAs; 0, 200, and 800 ms). When both prime and target were presented in the visual modality (the prime just to the left of a fixation point and the target to the right), there were N400 priming effects present across the three SOAs. However, the N400 in the 0-ms SOA condition extended longer in time (800 vs. 500 ms) than in the other SOAs. When both the prime and target were presented in the auditory modality (the prime to the right ear and the target to the left), the largest priming effects were found for the 800-ms SOA. Moreover, there was a relatively early priming effect present in the 0- and 800-ms SOA conditions but not in the 200-ms condition. The results are discussed in terms of modality differences in the time course of word comprehension processes.

Descriptors: N400, Semantic priming, Auditory word processing, Visual word processing, ERP

An interesting but seldom investigated aspect of word recognition is the extent to which similar processes and/or representations are used during reading and listening. Although a word that is written or spoken usually conveys the same meaning, there is the possibility that some of the processes leading up to full comprehension may be different for the two modalities. This seems particularly likely for early sensory and perceptual processes (i.e., those processes usually included under the rubric of *encoding)* given that spoken and written words, like all auditory and visual stimuli, initially engage different neural systems in modality-specific brain regions.

Evidence supporting at least a partial modality-specific view of auditory and visual language processing comes from the many obvious and intuitive differences in the physical properties of spoken and written language. Probably the most salient are differences in the temporal dynamics: spoken words unfold over time, whereas printed words are available all at once, usually in a single eye fixation. However, from a processing perspective this difference could turn out to be relatively meaningless if, for example, the component parts of spoken words are buffered (i.e., recognition does not begin until the entire word has been spoken) or if written words are converted into a temporally extended representation (e.g., as might happen in phonological recoding). A number of studies have indirectly addressed this issue. For example, Marslen-Wilson and colleagues have shown that, at least in some circumstances, spoken words are not buffered but rather appear to be processed "on-line" as they unfold in real time (e.g., Marslen-Wilson, 1987). Recently, Radeau, Morais, Mousty, Saerens, and Bertelson (1992) demonstrated that written word processing does not appear to have a strong temporal component analogous to spoken words. These two groups of studies would seem to suggest that the two modalities utilize temporal information somewhat differently. However, it should be pointed out that these studies used relatively "off-line" dependent variables such as reaction time and therefore leave some doubt about similarities and differences in the relative time course of written and spoken word comprehension.

The broad goal of the current experiments was to compare more directly the time course of written and spoken word recognition and determine if there are differences that reflect the temporal constraints placed on recognition processes by the two modalities. These experiments utilized a word pair semantic priming paradigm in which it has been shown that words are recognized faster when they are preceded by a semantically related word than when they are preceded by a semantically unrelated word (e.g., Meyer & Schvaneveldt, 1971; Neely, 1977). This demonstration of the role of context on word recognition is known as the semantic priming effect and has been reported in numerous studies for both written and spoken words. The rationale for using this procedure is that it has been shown to be sensitive to word recognition processes that extend across a number of levels (e.g., lexical, postlexical; see Neely, 1991, for a review of visual semantic priming) and therefore might reasonably be

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expected to yield interesting information about differences and similarities in the comprehension of written and spoken words. Semantic priming is also reflected in the N400 component of the event-related potential (ERP) during processing of word pairs and sentences (see Kutas & Van Petten, 1988; Osterhout & Holcomb, in press). In general, greater degrees of semantic discrepancy elicit larger amplitude negativities, which peak at about 400 ms after the onset of the target word. One interpretation of such effects is that they reflect the process whereby semantic information is integrated into a higher level discourse representation (e.g., Holcomb, 1993).

N400 effects have been found in studies using visual presentation of stimuli (e.g., Bentin, McCarthy, & Wood, 1985; Holcomb, 1988, 1993; Holcomb & Neville, 1990; Kutas & Hillyard, 1980, 1984) and auditory presentation (Bentin, Kutas, & Hillyard, 1993; Connolly, Stewart, & Phillips, 1990; Holcomb & Neville, 1990, 1991; McCallum, Farmer, & Pocock, 1984; Osterhout & Holcomb, 1993). However, only one of these studies has directly compared the N400 between the modalities. In their study, Holcomb and Neville (1990) reasoned that if similar mechanisms for semantic priming are operating for the two modalities, then there should be a similar pattern of behavioral and electrophysiological findings. However, a different pattern of results between the two modalities would indicate that different mechanisms underlie semantic priming during listening and reading. They presented subjects with word pairs (a prime followed 1,150 ms later by a target) that were either semantically related, semantically unrelated, or word/nonword pairs and required subjects to make a lexical decision for each target item (the second member of each pair). In one block of trials, items were spoken pairs, and in a second block they were written. In both modalities, a robust semantic priming effect was foundthe amplitude of the N400 was smaller when a target word was preceded by a semantically related prime word than when that same word was preceded by an unrelated word. However, differences between the two modalities were found in the scalp distribution and time course of the N400 effect. In particular, written words, as in several previous studies (e.g., Kutas & Hillyard, 1980, 1984), tended to elicit a slightly larger N400 effect over the right hemisphere, whereas spoken words produced a more bilaterally symmetrical response. In addition, for spoken words the effect began earlier (200 vs. 300 ms) and lasted longer (800 vs. 600 ms) than it did for written words. Holcomb and Neville (1990) interpreted the relatively early onset of the N400 effect for spoken words, which was earlier than the duration of even the shortest words presented, as supporting MarslenWilson's hypothesis that spoken word recognition (in context) can occur on-line, prior to the arrival of all of a word's acoustic information (cf. the Cohort model, e.g., Marslen-Wilson, 1987; Marslen-Wilson & Tyler, 1980).

One complication in the Holcomb and Neville (1990) study was that the time interval between the onset of the prime and the onset of the target (stimulus onset asynchrony; SOA) was 1,150 ms. This relatively long interval might have allowed subjects to use different strategies for processing the spoken and written words (see Neely, 1991, for a discussion of strategic processes involved in lexical decision). The use of different strategies could account for differences in N400 distribution and time course across the modalities.

The purpose of the present study was to extend the findings of Holcomb and Neville (1990) by comparing visual and auditory semantic priming effects using several different SOAs. Previous research has shown that the temporal delay between the prime and target presentation can be used to determine if there are differences in the amount of time needed for the prime to become a source of context (e.g., Neely, 1977). One interpretation of the earlier onset of the N400 for spoken words in the Holcomb and Neville (1990) study is that it reflects the earlier availability of semantic information for auditory than for visual words. If this hypothesis is correct, then at short prime-target intervals, spoken word primes should produce larger and earlier differences than should analogous written word primes, which should translate into larger N400 and reaction time (RT) semantic priming effects for spoken than for written word targets at short SOAs.

The manipulation of SOA has also been used in the behavioral literature to differentiate so-called automatic and controlled processes in word recognition (e.g., Neely, 1977). When the prime-target interval is short (usually less than 400 ms), automatic spreading activation, which presumably occurs without attention, is believed to be the primary source of priming effects. However, when the interval is long (greater than 400 ms), then enough time is allowed for controlled or attentional processing, in which various strategies can contribute to the priming effect. It has recently been suggested that the N400 component may be more sensitive to postlexical integrative factors (Brown & Hagoort, 1993; Holcomb, 1993; Rugg, 1990), which are usually equated with controlled processing. However, there is also evidence that although the N400 may be most responsive to controlled processes, it may also be sensitive to more automatic processes (Besson, Kutas, & Van Petten, 1992; Holcomb, 1988; Kutas & Hillyard, 1989). The comparison of priming effects at short and long SOAs should also be revealing about the sensitivity of the N400 to automatic versus controlled processing. However, if N400 effects are found at both short and long SOAs, it would suggest that the N400 is sensitive to both types of processing. Specifically, if N400 priming effects are found only at the long SOA, this would suggest that the N400 is primarily sensitive to controlled but not automatic processing. Examination of the pattern of effects will be particularly important for comparisons in the auditory modality because no ERP or RT studies have addressed the issue of automatic and controlled processing with spoken words. Modality differences might suggest differences in the roles of controlled and automatic processes during listening and reading.

In both experiments reported on here, a lexical decision task was used in which subjects were presented with pairs of words that were related, unrelated, or word-nonword pairs. As in previous semantic priming experiments, related targets were expected to yield quicker and more accurate responses (button presses) and smaller N400 amplitudes than unrelated targets. The SOA of the prime and target was also manipulated across three levels: simultaneous presentation (0 ms), 200 ms, and 800 ms. In Experiment 1, the stimuli were presented in the visual modality; in Experiment 2 the same stimulus lists were presented in the auditory modality but to a different group of subjects.[1]

EXPERIMENT 1: VISUAL PRESENTATION

In the first experiment, the time course of visual semantic priming across three prime-target intervals was examined. There has

[1]Although it would have been ideal to present both modalities to the same group of subjects, the number of related stimulus pairs (720) needed for a within-subjects design would have been prohibitive.

been one other word pair ERP study in the visual modality in which SOA was manipulated. Boddy (1986) presented word pairs to subjects in a visual lexical decision task using three SOAs (blocked): 200, 600, and 1,000 ms. Although he did not find a significant difference in the N400 effect across SOAs, his results should be viewed with caution for several reasons. First, to overcome the overlap of components elicited by the prime and target in the 200-ms SOA condition, he subtracted the waveform for the 1,000-ms SOA prime from the 200-ms SOA condition under the questionable assumption of additivity of prime and target processing. Second, he included pseudowords in the statistical analyses, assuming that semantic association decreased progressively from related pairs to word/pseudoword pairs. This assumption is questionable because pseudowords are fundamentally different from words in that they do not specifically have meaning, and it is not known exactly what processes underlie pseudoword effects (see, for example, Rugg & Nagy, 1987). In the current study, direct comparisons were made between related and unrelated words, and the prime ERP was not subtracted from the overlapping target ERPs.

Method

Subjects

Twelve right-handed Tufts University undergraduates (four women, eight men), with a mean (SD) age of 19.08 (1.16) years, received partial course credit for their participation. All were native speakers of English with normal or corrected-to-normal vision.

Stimuli and Procedure

Each subject was presented with a total of 360 stimulus pairs. Each third was made up of semantically related, semantically unrelated, or word/pseudoword pairs. This condition represents the target type variable. Examples of pairs for each of the three target type conditions are *salt pepper, more-truck,* and *nickel-plone.* Unrelated pairs were formed by rearranging the related pairs so that the primes and targets did not have any semantic relationship. Pseudowords were constructed from legal words by altering one letter (phoneme) in such a way that it did not violate the orthographic or phonologic rules of English. None of the pseudowords were pseudohomophones. All visual stimuli were two to seven letters.

Related and unrelated word pairs were selected from six similarly constructed lists of 40 related word pairs. The pairs of words and pseudowords were selected from three similarly constructed lists of 40 word/pseudoword pairs. The word pairs were counterbalanced so that across subjects, target words appeared in both related and unrelated conditions and in each of three SOA conditions. However, within subjects each list (therefore each stimulus) was presented once.

A second within-subject variable was the onset asynchrony between items in each pair. One third of the stimulus pairs in each of the three target type conditions (related, unrelated, pseudoword) were presented with an SOA of 0 ms, another one third were presented with an SOA of 200 ms, and the remaining one third were presented with an SOA of 800 ms. Thus, each subject was presented with a total of 360 pairs of words (in a pseudorandom order) that were either related, unrelated, or word/pseudoword pairs and had an SOA of either 0, 200, or 800 ms, resulting in a total of 40 stimulus pairs in each of nine conditions (3 SOAs x 3 target types).

Stimuli were presented on a 20-in. monitor (NEC 5D) controlled by a PC-compatible computer. Stimuli were displayed as black lowercase letters on a white background. Each word subtended from 0.5° to 1.8° of horizontal and 0.4° of vertical visual angle.

Each trial began with a fixation point (a red dot) in the middle of the screen. Five hundred milliseconds later, the prime was presented to the left of the fixation point for 400 ms. The target was presented to the right of the fixation point also for 400 ms. This left-prime/right-target arrangement was chosen because it is similar to normal reading positions. For the 0 SOA condition, the target was presented simultaneously with the prime; for the other two SOAs, the target was presented either 200 or 800 ms after the onset of the prime. The fixation point remained on the screen during the presentation of the prime and target and for 1,500 ms after target offset. The screen was then blank for an additional 1,500 ms until the next trial began with the fixation point.

Subjects were instructed to keep their eyes on the fixation point and to decide if the stimulus to the right was a real word or not. They were told to respond as quickly and accurately as possible by pressing a button labeled yes with one thumb if the stimulus was a real word or a button labeled *no* with their other thumb if it was not a real word. The hand used for each response was counterbalanced across subjects. They were told to try to pay attention to the prime but not to make an overt response. Subjects were asked not to blink or move their eyes while the fixation point and letter strings were being presented.

Recording Procedure

The subject sat in a comfortable chair in a sound-attenuating chamber. An elastic cap (Electrode-Cap International) with tin electrodes was placed on the subject's head. Scalp locations included standard International 10-20 system locations over the left and right hemispheres at frontal (F7 and 1^{7}8) and occipital (O1 and 02) sites and three locations on the midline: frontal (Fz), central (Cz), and parietal (Pz). In addition, six electrodes were placed at the following nonstandard locations previously found to be sensitive to language manipulations (e.g., Holcomb, Coffey, & Neville, 1992; Holcomb & Neville, 1990, 1991): left and right temporal-parietal (Wernicke's area and its right hemisphere homologue [WL and WR): 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz); left and right temporal (TL and TR: 33% of the interaural distance lateral to Cz); and left and right anterior-temporal (ATL and ATR: 50% of the distance between T3/4 and F7/8). To monitor for eye blinks, one electrode was placed below the left eye; to monitor for horizontal eye movement, electrodes were placed lateral to each eye (bipolar recording). All electrodes (except for the bipolar horizontal channels) were referenced to the left mastoid, and the right mastoid was recorded from actively to determine if there were different experimental contributions to these two presumably neutral sites.[2]

The electroencephalogram (EEG) was amplified by a Grass Model 12 amplifier system using a bandpass of 0.01-100 Hz (3 dB cutoff). The EEG was sampled continuously throughout the experiment (200 Hz), and off-line, separate ERPs were aver-

[2] All comparisons of independent variables at the right mastoid site yielded no differences.

Table 1. *Reaction Times (RT) and Percentage of Errors (PE) in Visual Presentation Experiment*

SOA (ms)	Related words	Unrelated words	Nonwords	Priming effect[a]
0				
RT (ms)	773 (106)	826 (123)	948 (122)	53
PE (%)	1.46 (1.67)	2.50 (1.85)	6.88 (3.04)	1.04
200				
RT (ms)	715 (148)	747 (137)	881 (134)	32
PE (%)	0.62 (1.13)	1.67 (1.95)	4.17 (3.90)	1.05
800				
RT (ms)	736 (121)	755 (107)	883 (126)	19
PE (%)	0.42 (0.97)	1.67 (1.95)	3.96 (3.61)	1.25

Note: Values are means (*SD*).
[a]Unrelated minus related targets.

aged (using a pretarget baseline[3] of 100 ms) for each subject at each electrode site for the three targets types (related, unrelated, pseudoword) at each of the three SOAs. Only correct response trials that were free of eye and muscle artifact were included. In addition, difference waves were formed by subtracting the ERPs of the related from the ERPs of the unrelated condition.

Data Analysis

Mean RTs for correct responses between 200 and 2,000 ms[4] and percentage of errors were calculated for each subject. ERPs for targets were quantified by measuring the mean amplitude in three latency windows: 150-300 ms, 300-550 ms, and 550800 ms. The 300-550-ms window was chosen because it contains the area of the waveform typically associated with the N400; the other windows were included because they have revealed interesting differences in several prior studies using a similar design (e.g., Holcomb & Anderson, 1993). To more closely examine the time course of priming effects, the mean amplitude measures of 100-ms epochs were also taken starting 100 ms posttarget and extending to 900 ms.[5]

Repeated measures analyses of variance (ANOVAs) were performed on the above dependent measures. Variables included target type (related, unrelated-the pseudoword condition was not included in any of the analyses to be reported here) and SOA (0, 200, 800). For ERP analyses, midline and lateral sites were analyzed separately. In addition to target type and SOA, for the midline analyses there was an electrode site variable (frontal [Fz], central [Cz], parietal [Pz]), and at lateral sites there was an electrode site variable (frontal, anterior temporal, temporal, Wernicke's, occipital) and a hemisphere variable (left, right). Significant Target Type x SOA interactions were followed up with simple effects tests to help elucidate the source of the interaction and involved analyzing the effects of target type separately for each SOA. The Geisser-Greenhouse (1959) correction was applied to analyses with more than one degree of freedom in the numerator; the epsilon correction factor is provided.

[3] Selection of an appropriate baseline is difficult in studies such as these. After careful examination of several possible alternatives (including subtractive procedures such as those used by Boddy, 1986), a pretarget baseline was chosen to maintain some consistency across SOA conditions with respect to the target. However, this baseline occurs at different points with respect to the prime for each SOA condition, but at this point in time (just prior to target presentation) there is no difference between the target type conditions within each SOA. Also, for the critical relatedness effects, the comparisons are made between conditions with the same pretarget stimulus characteristics.

[4]This window was chosen to exclude fast, premature button presses and long responses that may have been due to guessing. In both experiments, all responses fell within this window.

[5] Because there is a greater risk of Type I error when using multiple windows, this time course analysis was intended only as a supplementary measure.

Results

Behavioral Findings

Across SOA conditions, subjects responded more quickly to related targets than to unrelated targets (main effect target type: F [1,11] = 20.14, p < .001; see Table 1). There was also a main effect of SOA (F[2,22] = 13.61, p < .0001, e = 0.9927), with reaction time being slower in the 0 SOA condition than in the 200 and 800 SOA conditions. Furthermore, the priming effect varied across SOA (Target Type x SOA: F[2,22] = 3.57, p < .046, e = 0.9920). Simple effects analyses revealed that the priming effect was significant in all SOA conditions (0 SOA: 53-ms effect, F [1,11] = 28.91, p < .0002; 200 SOA: 32 ms effect, F [l, 1 1] = 5.69, p < .036; 800 SOA: 19-ms effect, F [1,11] = 6.04, p < .032). Comparisons of the effects at each SOA revealed that the 800 SOA priming effect was significantly smaller than the 0 SOA effect (F [1,11] = 7.36, p < .02).

Error rates are presented in Table 1. Because there were many cases in which there were 0% errors, these data were transformed using the arcsine procedure recommended by Myer (1979). Across SOA conditions, subjects made more errors with the unrelated targets (F [1,11] = 5.25, p < .043). The SOA variable approached significance (F[2,22] = 3.20, p < .068, e = 0.8838), with errors tending to decrease as SOA became longer. The interaction between target type and SOA was not significant (p > .95). Subjects were both slower and less accurate in their responses to the unrelated targets (i.e., there was no indication of a speed/accuracy trade-off).

Electrophysiological Findings

The grand mean ERPs for the targets are plotted in Figure 1. Approximately 7[0]1o of the trials were rejected because of eye blinks, horizontal eye movement, or amplifier blocking. Because of the differential overlap of stimuli, the waveforms appear

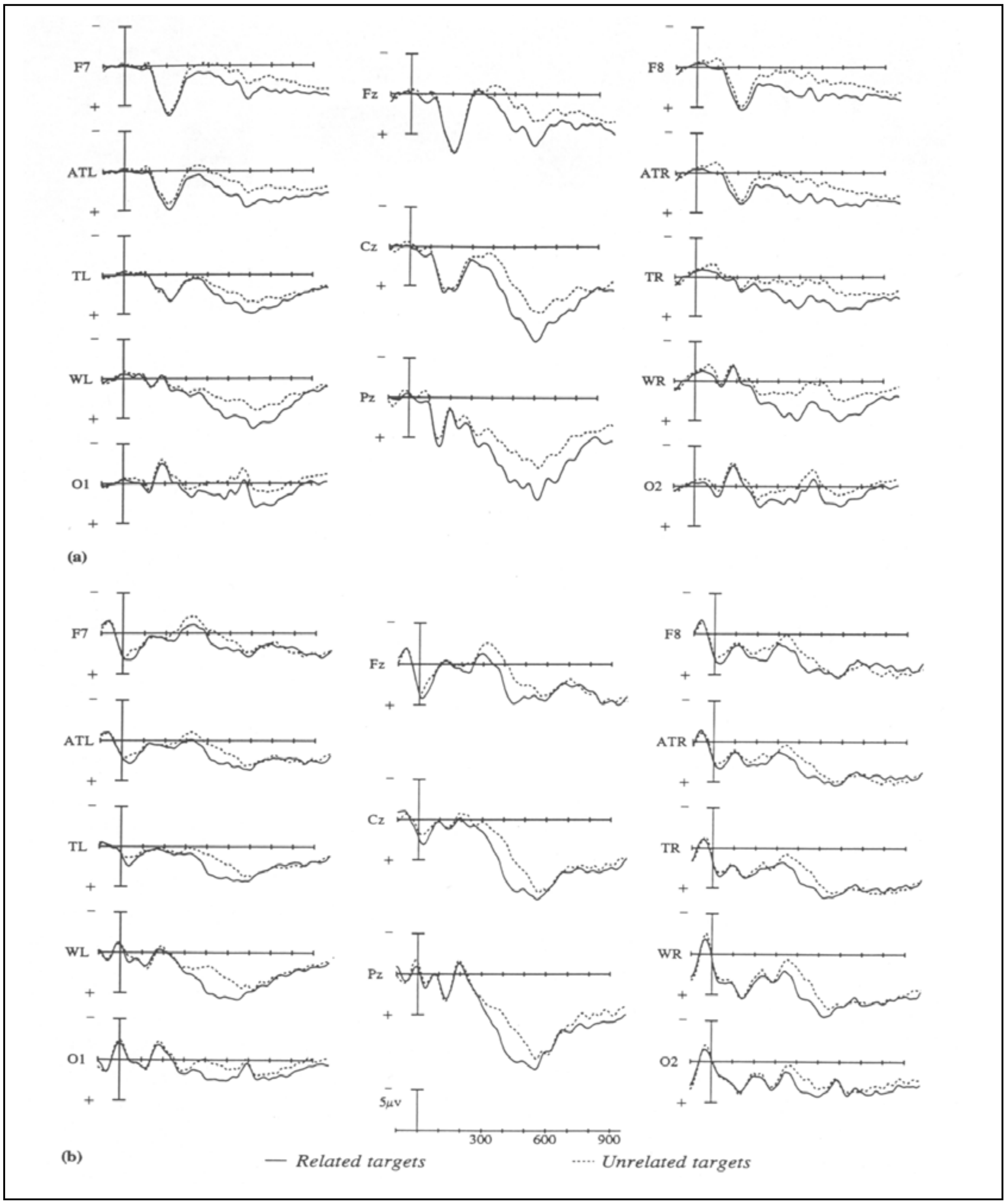


Figure *1*. Grand mean ERPs (n = 12) for related and unrelated target words in Experiment 1 (visual presentation). a. 0 SOA condition. b. 200 SOA condition. ERPs in the left column are from electrodes placed over left hemisphere sites, the middle column is from midline sites, and the right column is from right hemisphere sites. Time is in milliseconds, each tic mark representing 100 ms. Stimulus onset (target) is at the vertical calibration bar. Figure continued on next page.

somewhat different at the three SOAs. One of the first visible components is an anterior negativity peaking around 100 ms (N1), which is especially apparent in the 800 SOA condition. Following the N1, an anterior positivity peaking around 200 ms was elicited (P2). Over the posterior sites, a positivity around 100 ms (P1) and a negativity around 175 ms (posterior N1) can be seen. These early components were also elicited to a lesser extent by the offset of the stimulus and can be seen especially at the more posterior sites (i.e., 01 and 02).

Several later components were also visible in the waveforms. After the P2, there was a negative-going wave that peaked at about 400 ms (N400) and had a broad scalp distribution. The N400 was followed by a posteriorly distributed positive-going wave, peaking around 600 ms (the P3 or late positive component).

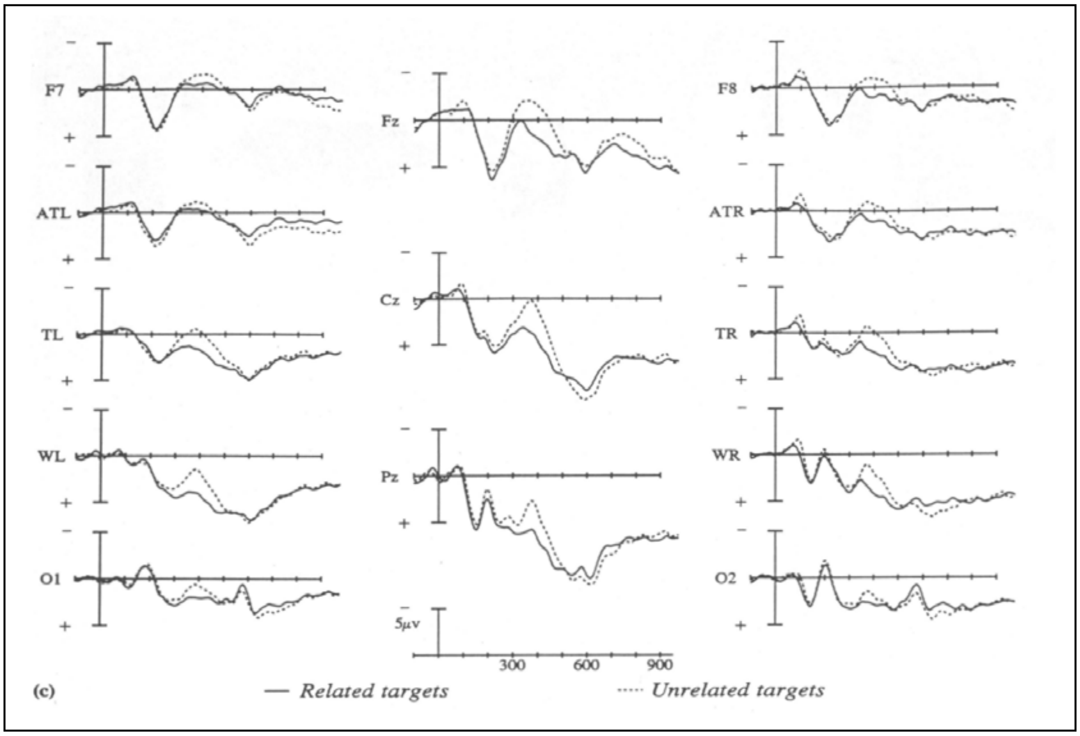


Figure 1 continued. c. 800 SOA condition.

Effects of Target Type

Traditional Measures

150-300. At 150-300 ms, there were no effects of target type (midline: p > .18; lateral: p > .23).

300-550. Unrelated targets were significantly more negativegoing than related targets at 300-500 ms (midline: F [1,11] = 11.66, p < .006; lateral: F [1,11] = 8.41, p < .014), and this priming effect did not interact with SOA (midline: p > .56; lateral: p > .47), electrode site, or hemisphere.

550-800. Across SOAs, at 550-800 ms the main effect of target type did not reach significance (p > .081; lateral: p > .10), although there was a significant SOA x Target Type interaction (midline: F[2,22] = 5.45, p < .016, e = 0.8749; lateral: F[2,22] = 6.81, p < .01, e = 0.7890). To further examine the source of this interaction, separate analyses were performed at each SOA. Only the 0 SOA condition revealed a significant effect of target type (0 SOA: midline: F[1,111 = 8.72,p < .013; lateral: F [1,11] = 10.76, p < .007; for the 200 and 800 SOAs, both Fs < 1). There was also an interaction of SOA x Target Type x Electrode Site at the midline (F[4,44] =4.32, p < .018, e = 0.6089), indicating that the effect was larger over Cz and Pz at the 0 and 200 SOAs but was larger over Fz at the 800 SOA.

100-ms Epochs

To examine the time course of the priming effect, the waveform was divided into 100-ms epochs beginning with 100 ms and extending to 900 ms. The differences in mean amplitude during each epoch are listed in Table 2.

The main effect of target type began during the 300-400-ms epoch and continued into the 400-500-ms epoch. However from 500 to 800 ms, the effect of target type was reliable only for the 0 SOA condition (Target Type x SOA interaction).

Discussion

To summarize the results, semantic priming effects (behavioral and ERP) were found across all three SOA conditions. Related targets were responded to more quickly and accurately across all three SOAs, but the RT effect was largest at the 0 SOA. In addition, at the 0 SOA, subjects were slower in responding to both related and unrelated targets than they were at the other two SOAs (69 and 54 ms slower than for the 200 and 800 SOAs, respectively). Furthermore, although the percentage of errors only approached significance across SOAs, the direction of the effect (more errors at the 0 SOA) was consistent with the RT effects. This overall decrement in performance at the 0 SOA may have been due to the additional attention demands required in processing two stimuli simultaneously.

The ERP measures provided additional information concerning the time course of semantic priming. An ERP semantic priming effect (i.e., N400 effect) was elicited in all three SOA conditions, but the morphology and time course of this component differed across the SOAs. In the 0 SOA condition, the effect was more temporally extended, lasting into the 500800-ms epoch. Furthermore, the 0 SOA effect appeared to begin a little later over several scalp locations (frontal midline, left temporal, and Wernicke's sites) than did the 200 and 800 SOA effects. As with the delayed RTs, this delay in onset of the N400 could have been due to differences in the attention mechanisms mentioned above. Kutas (1987) found delays in the onset of the N400 of anomalous final words in sentences when the presentation rate (visual) was very rapid (10 words/s) as compared with a slower rate (1 word/700 ms).

Table 2. *Semantic Priming Effects (u V) in the Visual Experiment*

Epoch (ms)	0	*SOA (ms)a* 200	800	TT	p *TT x SOA*
100-					
Midline	-0.26	-0.19	-0.51	n.s.	n.s.
Lateral	-0.40	-0.16	-0.13	n.s.	n.s.
200-					
Midline	-0.46	-0.60	-0.95	n.s.	n.s.
Lateral	-0.56	-0.45	-0.15	n.s.	n.s.
300-					
Midline	-1.27	-2.32**	-2.51**	.006	n.s.
Lateral	-1.06	-1.17+	-1.19*	.014	n.s.
400-					
Midline	-3.15**	-3.21**	-2.03*	.006	n.s.
Lateral	-1.96**	-1.83*	-1.05	.014	n.s.
500-					
Midline	-3.29**	-1.10	0.34	.048	.005
Lateral	-1.94**	-0.76	0.12	.064	.013
600-					
Midline	-2.74*	-0.12	0.47	n.s.	.012
Lateral	-1.88**	-0.03	0.47	n. s.	.008
700-					
Midline	-2.14*	-0.49	-0.36	.042	n.s.
Lateral	-1.50**	0.04	0.11	.073	.039
800-					
Midline	-0.97	-0.56	-0.62	n.s.	n.s.
Lateral	-0.704+	0.01	0.05	n.s.	n.s.

Note: TT = target type.

'Significance of separate analyses at each *SOA*: + $p < .1$, *$p < .05$, **$p < .01$.

During the simultaneous presentation (0 SOA), the N400 effect had a prolonged duration and there was also a larger RT difference between related and unrelated words. There are several possible explanations for this pattern. This pattern may reflect automatic spreading activation from the prime, resulting in quicker responses to the related targets because of their partial activation. Because there was no delay between the onset of the prime and target, activation from the prime may have spread to related lexical/semantic nodes and may not have decayed before the target was processed. This may have occurred to a greater extent for the 0 SOA than for the 200 SOA condition (where automatic priming effects would also be expected), because the activation presumably would have decayed to a lesser degree before the target was processed. Furthermore, the later onset of the RTs in the 0 SOA condition (and delayed N400 at some sites) may have resulted in an increase in the priming effect (cf. Meyer, Schvaneveldt, & Ruddy, 1975). It is also possible that when both prime and target were simultaneously presented, backward priming occurred along with the more typical forward priming. That is, the target could have primed the prime, which in turn further activated the target. This process would occur because of the temporal overlap in the processing of the two stimuli. Kiger and Glass (1983) found significant associative priming effects when the SOA of targets and primes was 50 or 65 ms but not when it was as long as 130 ms. Their findings suggest that temporal overlap of processing can occur only when there is a very small amount of time between stimuli. The simultaneous presentation condition (0 SOA) would fall within this time window.

EXPERIMENT 2: AUDITORY PRESENTATION

The second experiment was conducted using the same stimulus lists and procedure but in the auditory modality. If similar processes are operating early on in both modalities, then the same pattern of priming effects should be seen, especially at the two short SOAs. However, different patterns would indicate differences in the temporal dynamics of visual and auditory language. In particular, based on the early N400 effects reported by Holcomb and Neville (1990) for spoken words, it was predicted that at short prime-target intervals (0 and 200 ms SOA), auditory words would produce a larger priming effect than would the same items presented in the visual modality.

Method

Subjects

Twelve right-handed Tufts University undergraduates (seven women, five men), with a mean (SD) age of 20.83 (4.26) years, received partial course credit or $10.00 for their participation. All were native speakers of English who reported having normal hearing. None of the subjects had participated in Experiment 1.

Stimuli and Procedure

The same lists of stimuli and procedure that were used in Experiment 1 were used in Experiment 2, except that the modality of presentation was auditory. Another minor difference was that the fixation point was an "X" instead of a period.

The stimuli were spoken in isolation by a female member of our research team and were digitized (16 kHz, 24 pole 7.9-kHz Butterworth filter) by a Data Translations analog-to-digital converter (12 bits resolution). Each stimulus was edited so that the time of its onset could be time locked with EEG digitization. Editing was done using sound editing software that allowed us to listen to a stimulus while visually positioning its waveform. The onset time was defined as the point where the acoustic energy consistently deviated from zero. At the time of the experiment, the stimuli were output through a digital-to-analog converter, then filtered (7.9 kHz) and sent to the subject's headphones. The average duration of primes was 562 ms (range, 375812 ms) and that of the targets was 568 ms (range, 300-862 ms).

The prime was presented to the right ear, and the target was presented to the left ear. One half of the subjects were instructed to try to attend to the prime (but not to make an overt response to it), and the other half were not given any explicit instructions about the prime stimulus.[6]

Results

Behavioral Findings

Across SOA conditions, subjects responded more quickly to related targets than to unrelated targets (main effect target

[6] Careful examination of the two groups of six subjects did not reveal any significant differences, so they were combined for all subsequent analyses.

Table 3. *Reaction Times (RT) and Percentage of Errors (PE) in the Auditory Presentation Experiment*

SOA (ms)	Related words	Unrelated words	Nonwords	Priming effect'
0				
RT (ms)	911 (79)	929 (56)	1,072 (77)	18
PE (⁰7o)	5.00 (3.54)	7.52 (5.57)	21.70 (8.46)	2.52
200				
RT (ms)	812 (74)	869 (53)	989 (72)	57
PE (%)	4.80 (4.06)	8.57 (5.92)	21.50 (9.18)	3.77
800				
RT (ms)	756 (86)	898 (82)	1,002 (75)	142
PE (⁰7o)	0.63 (1.13)	4.59 (4.25)	9.62 (5.88)	3.96

Note: Values are means (SD).
'Unrelated minus related targets.

type: *F[1,11]* = 160.91,p < .00005; see Table 3). There was also a main effect of SOA, with subjects responding more quickly as the SOA became longer (main effect of SOA: F[2,22] = 46.05, p < .00005, e = 0.6903). Furthermore, there was a significant difference in the size of the priming effect in the different SOA conditions (Target Type x SOA: F[2,22] = 40.14, p < .00005, e = 0.8010). Simple effects ANOVAs revealed that for the 0 SOA condition, the priming effect (18 ms) was not reliable (F [1,11] = 2.75, p > .12), but for the 200 and 800 SOAs the differences were significant (200 SOA: 57-ms effect, F [1,11] = 39.47,p <.0001; 800 SOA: 142-ms effect, *F[1,11]*=196.29,p < .00005).

Subjects made more errors with unrelated targets than with related targets (main effect of target type: F [1,11] = 8.78, p < .013, arcsine transformed; see Table 3). There was also a main effect of SOA, with fewer errors made in the 800 SOA condition (F[2,22] = 8.95, p < .002, e = 0.9754). The interaction between target type and SOA was not significant (p > .77). Subjects were both slower and less accurate in their responses to the unrelated targets (i.e., there was no indication of a speed/accuracy trade-off).

Electrophysiological Findings

The grand mean ERPs for each SOA are plotted in Figure 2. Approximately 10% of the trials were rejected because of eye blinks, horizontal eye movement, or amplifier blocking. Because the two auditory stimuli overlapped at different times depending on the SOA condition, the waveforms appear somewhat different at the three SOAs. At both the 0 and 800 SOA conditions, there is a large negativity peaking at approximately 100 ms (N1), which is largest at midline and more anterior sites and diminished at the most posterior lateral electrodes (01, 02). In the 0 SOA condition, the N1 component was larger, presumably because of the summated activity from the two stimuli presented simultaneously to the two ears. In the 200 SOA condition, this component, which appears much smaller, was presumably refractory because of the recent presentation of the prime.

The N1 component was followed by a positive-going wave that peaked at around 200 ms (P2). The P2 had a scalp distribution similar to that of the N1. Following the P2, there was a broad negativity that peaked between 300 and 550 ms, the window usually associated with the N400. This broad negativity extended to the end of the recording epoch at the frontal sites of the 0 SOA condition but returned to baseline at most of the other sites. For the 0 and 200 SOA conditions, the overall amplitude of this negativity (collapsing across both target types) tended to be larger over the right hemisphere especially anteriorly; for the 800 SOA it was more negative-going over the left hemisphere. At most sites, the ERP became positive-going at the end of the epoch, especially in the 200 and 800 SOA conditions (P3 or late positive component).

Effects of Target Type

Traditional Measures

150-300 ms. In this early 150-300-ms epoch, the unrelated targets elicited a significantly more negative-going ERP than did the related targets (midline: *F[1,11]* = 6.55, p < .026; lateral: F[1,11] = 7.04, p < .022). Furthermore, this target type effect interacted with SOA at the midline sites (F[2,22] = 4.51, p < .026, e = 0.9209) but not at the lateral sites (p > .17). Followup analyses of the midline sites revealed that the unrelated targets were significantly more negative than the related targets for the 0 SOA (F [1,11] = 5.66,p<.037) and 800 SOA (F [1,1 1] = 12.76 , p < .004) conditions but not for the 200 SOA condition (p > .8).

300-550 ms. The unrelated targets were also more negative-going at 300-550 ms (main effect of target type, midline: F [1,11] = 14.36, p < .003; lateral: F [1,11] = 18.22, p < .001), and this priming effect varied across the SOAs (Target Type x SOA interaction, midline: F[2,22] = 13.51, p < .0003, e = 0.9173; lateral: F[2,22] = 12.12, p < .0007, e = 0.8336) and across sites (Target Type x SOA x Electrode Site, lateral: F[8,88] = 4.01, p < .023, e = 0.3049). However, the priming effect did not differ significantly across the hemispheres. Separate follow-up analyses revealed that only the 800 SOA condition produced a significant effect (midline: F [1,11] = 32.77, p < .0001; lateral: F[1,11] = 28.95, p < .0002). Furthermore, at the lateral sites the effect interacted with electrode site (F[4,44] = 6.17, p < .015, e = 0.3713), with the largest differences over WL/R and TL/R.

550-800 ms. The target type effect continued into the 550-800-ms epoch (midline: F [1,11] = 13.85, p < .003; lateral: F [1,11] = 22.3, p < .0006) and at lateral sites interacted with SOA (F[2,22] = 4.16, p < .043, e = 0.7661). Follow-up analyses indicated that there were significant target type effects for

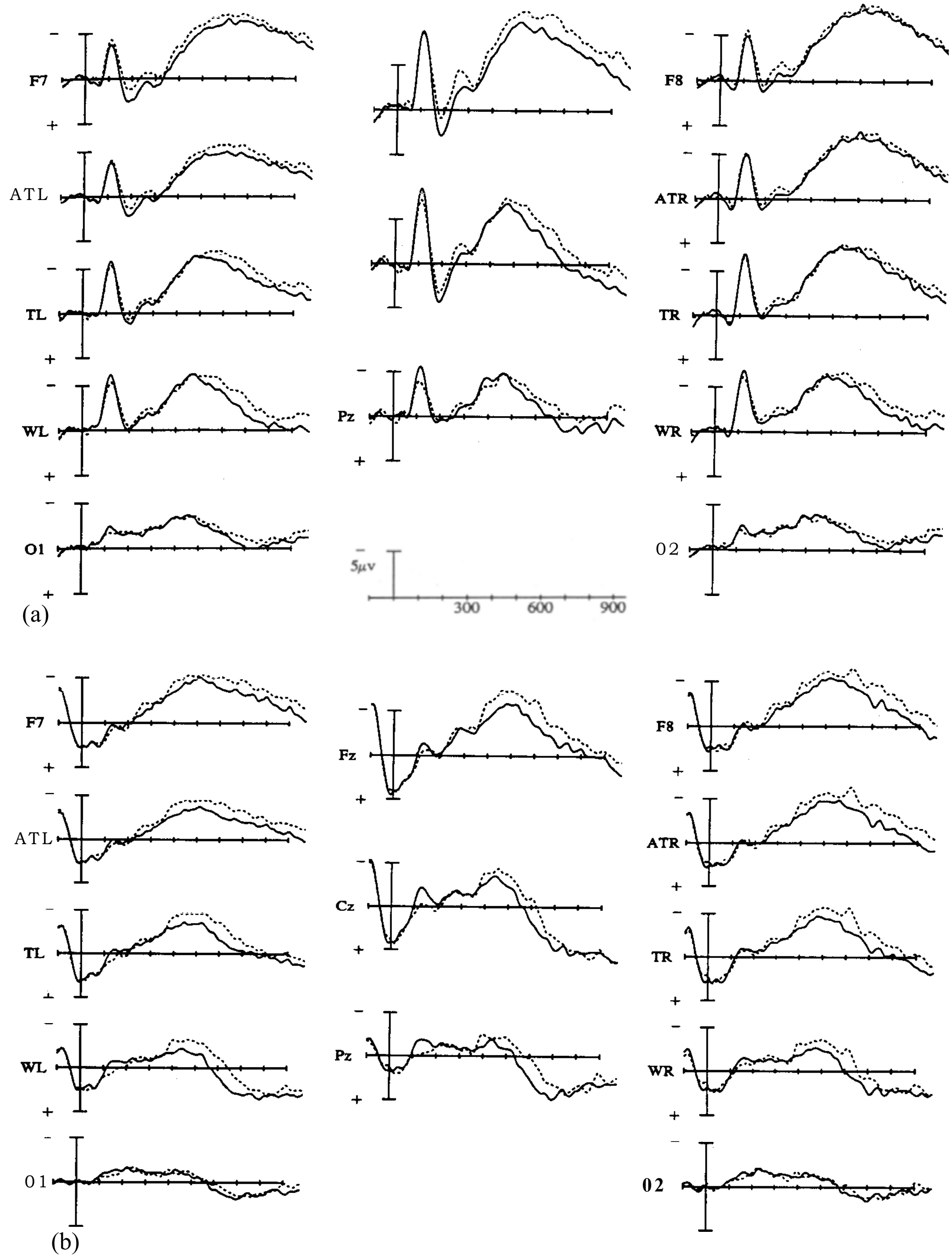
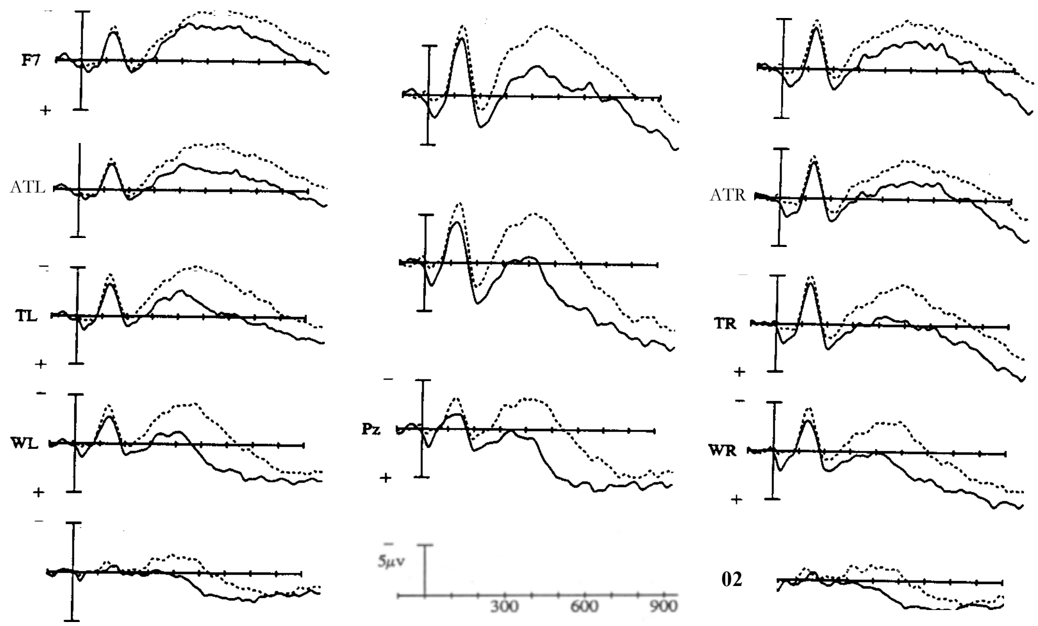


Figure 2. Grand mean ERPs (n = 12) for related and unrelated target words in Experiment 2 (auditory presentation). a. 0 SOA condition. b. 200 SOA condition. All else is as in Figure 1. Figure continued on next page.

the 800 SOA (lateral: *F [1,11]* = 48.9, p < .00005) and 0 SOA (lateral: F [1,11] = 7.5, p < .019) conditions, but for the 200 SOA condition the effect only approached significance (lateral: *F[1,11]* = 4.1, p < .068). Across SOAs, the target type effect did not differ significantly between hemispheres. Target type interacted with electrode site at the lateral sites (F[4,44] =4.63, p < .022, e = 0.4828;), with the effect being largest at WL/R and TL/R and smallest at 01/2.

100-ms Epochs

To examine the time course of the priming effect, the wave-forms were divided into 100-ms epochs beginning with 100 ms and extending to 900 ms. The differences in mean amplitude during each epoch are listed in Table 4. There were early effects at the 800 SOA starting in the 100-200-ms window, and at the 0 SOA the effects approached significance in the 200-300-ms window. The main effect of target type began during the 200-



(c) **▬** *Related targets* ---- *Unrelated targets*

Figure 2 continued. c. 800 SOA condition.

300-ms epoch and persisted through to the last epoch measured. The priming effect varied significantly across SOAs from the 200-300-ms epoch until the 500-600-ms epoch (except at the lateral sites during the 200-300-ms epoch). From 200 to 500 ms, the interactions reflected the large priming effects for the 800 SOA but nonsignificant effects for the 0 and 200 SOAs. Between 500 and 600 ms, a similar trend was found with the largest effects at the 800 SOA and smaller, yet significant, effects at the 0 and 200 SOAs. Finally, beyond the 600-700-ms epoch, there were no reliable differences in the effect size across the SOAs.

Discussion

When both prime and target were presented in the auditory modality, there were behavioral and electrophysiological priming effects that were not consistent across the SOA conditions. Subjects responded faster to related targets across SOA conditions, but the priming effect was significant only in the 200 and 800 SOA conditions. As in Experiment 1, subjects responded more slowly for both related and unrelated targets at the 0 SOA, again probably because of the higher attentional demands of attending to two stimuli at once. The overall higher errors rates at the 0 and 200 SOAs attest to the difficulty of the conditions in which the stimuli overlapped.

The ERP priming effects revealed both similarities and differences across the SOA conditions. At the 0 SOA, there was a small early effect between 150 and 300 ms at midline sites, then no effect between 300 and 550 ms (the traditional N400 epoch), and finally a significant effect from 550 to 800 ms (both midline and lateral). The distribution of the 0 SOA effect in the 150300-ms window was different from that of the typical N400. At the midline sites where the N400 usually has a centroparietal distribution, the effect was slightly larger at the frontal and central scalp electrodes and was virtually absent at the parietal site.

Occasional variations in the typical distribution of the N400 have been reported and are sometimes attributed to different task demands. For example, Bentin et al. (1993) reported a more frontal distribution for auditory presentation using a long SOA in a memory task.

At the 200 SOA, there were some visible differences between the related and unrelated waveforms beginning at about 375 ms. However, these differences only approached significance at the lateral sites in the [5]50-800-ms window. In the 100-ms epoch analyses, the related and unrelated waveforms reached significance in the 500-600- and 600-700-ms epochs.

Unlike the two shorter SOA conditions, the ERP priming effect at the 800 SOA was quite robust, beginning at about 200 ms and extending until the end of the measuring epoch. It had a wide scalp distribution and was largest over temporoparietal regions, as reported in previous auditory studies (e.g., Holcomb & Neville, 1990). The effect began well before the shortest word duration (300 ms); this result is further support (see Holcomb & Neville, 1990, 1991) for the hypothesis that with context, word recognition can occur prior to the arrival of all acoustic information (Mars len-Wilson, 1987).

To summarize, the differences seen across the SOAs tended to occur in the temporal epoch typically identified with the N400 component (300-550 ms), and similarities tended to occur later in the waveform (after 550 ms). The later similarities may be important because the auditory ERP priming effect generally extends over a broad time range (as in Bentin et al., 1993; Holcomb & Neville, 1990). However, the pattern of behavioral and earlier ERP priming effects across the SOAs was clearly not consistent with the hypothesis of rapid spoken word priming. Instead of larger priming effects for short prime-target intervals (0 and 200 ms SOA), these effects were smaller and more temporally restricted than those obtained at the longest interval (800 ms).

Table 4. *Semantic Priming Effects (t~ V) in the Auditory Experiment*

	SOA (ms)a			P	
Epoch (ms)	0	200	800	TT	TT x SOA
100-200					
Midline	-0.44	0.96	-1.38*	n.s.	.038
Lateral	-0.33	0.37	-0.58+	n.s.	n.s.
200-300					
Midline	-1.13+	-0.05	-2.38**	.025	.019
Lateral	-0.64+	-0.27	-1.05**	.021	n.s.
300-400					
Midline	-0.12	-0.41	-3.42***	.034	.006
Lateral	-0.12	-0.31	-1.69**	.018	.011
400-500					
Midline	-0.54	-1.14	-4.96***	.001	.0002
Lateral	-0.19	-0.80+	-2.59***	.0003	.0008
500-600					
Midline	-1.27*	-1.66+	-4.99****	.0006	.0002
Lateral	-0.52	-0.98*	-2.80***	.001	.0001
600-700					
Midline	-1.81**	-1.92	-3.22***	.003	n. s.
Lateral	-0.80*	-1.37*	-2.15****	.0004	.075
700-800					
Midline	-1.56*	-0.74	-2.04**	.013	n.s.
Lateral	-0.74*	-0.88	-1.72***	.002	n. s.
800-900					
Midline	-1.32+	-0.24	-2.05*	.029	n.s.
Lateral	-0.55	-0.71	-1.74**	.0003	n.s.

Note: TT = target type.

'Significance of separate analyses at each SOA: + p < .1, *p < .05, **p < .01, ***p < .001, ****p < .00005.

COMPARISON OF VISUAL AND AUDITORY EXPERIMENTS

Behavioral Findings

An ANOVA with modality as a between-subjects variable and target type and SOA as within-subjects variables was done to examine the modality effects in these experiments (discussion will be limited to those effects involving modality). Visual target responses were 104 ms faster than the auditory responses (F[1,22] = 6.81, p < .016), although the semantic priming effect was greater in the auditory experiment than in the visual experiment (Modality x Target Type interaction: F[1,22] = 15.1, p < .0008). The pattern of priming effects for the SOAs was different for the auditory and the visual experiments (Modality x Target Type x SOA interaction: F[2,44] = 35.09, p < .00005, e = 0.9371). In the visual experiment, the priming effect decreased as the SOA became longer, whereas in the auditory experiment, the priming effect became greater as the SOA became longer.

The subjects in the auditory experiment were less accurate than those in the visual experiment (main effect of modality: F[1,22] = 35.17, p < .00005). The interaction of target type and modality approached significance (F[1,22] = 3.39, p < .079), indicating that the accuracy advantage for related words was slightly greater in the auditory experiment. The interaction of SOA and modality was significant (F[2,44] = 6.40, p < .004, e = 0.9874), indicating a larger modality difference present for the 0 and 200 SOAs than for the 800 SOA.

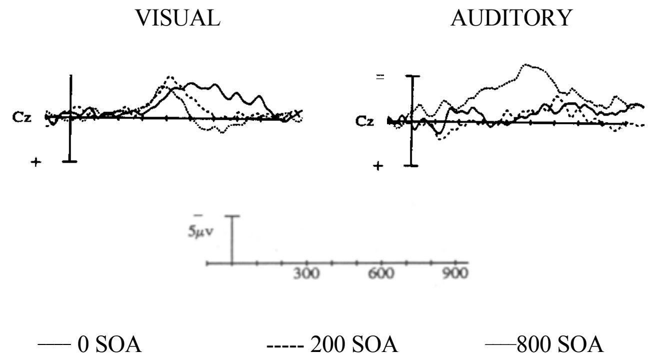


Figure 3. Difference waves at Cz (central midline) from Experiment 1 (visual) and Experiment 2 (auditory) calculated by subtracting related target ERPs from unrelated target ERPs at each of the three SOAs.

Electrophysiological Data

In the two experiments (regardless of target type), the overall auditory waveforms are more negative than the visual waveforms with respect to the baseline. This trend is especially notable at the more anterior sites. Of particular interest, however, is a comparison of the ERP priming effects in the two modalities. To facilitate this comparison, difference waves were formed by subtracting the related from the unrelated waveforms. Difference waves also provide a way to more easily visualize any differences in priming effects between SOAs. Figure 3 illustrates the ERP priming effects for the two experiments. In the visual experiment, the effect began at about the same time for the three SOAs, except that over several sites (Fz, Cz, TL, WL) the effect for the 0 SOA began slightly later than for the other two SOAs. The longer duration of the 0 SOA effect is also apparent in Figure 3. In the difference waves for the auditory experiment, the large priming effect for the 800 SOA dominates the figure. The early difference for the 0 SOA is visible (150-300 ms), as are the later effects for the other SOAs (500-700 ms).

A single latency window (200-700 ms) was used to quantify the difference waves. This epoch was chosen because it best encompassed the area of differences between the conditions in both modalities. There was no significant difference between experiments in the overall mean amplitude (midline: p > .58; lateral: p > .66), however, there was a significant interaction of SOA and modality (midline: F[2,44] = 9.05, p < .0006, e = 0.9847; lateral: F [2,44] = 9.82, p < .0004, e = 0.9618), reflecting the finding that in the visual experiment the effect did not vary significantly between SOAs but in the auditory experiment it was generally largest for the 800 SOA. There were no significant differences in the scalp distribution of the priming effect, although the interaction of modality, SOA, and electrode site approached significance at the midline (F[4,88] = 2.81, p < .06, e = 0.5913; lateral: p > .39). This interaction primarily reflects the slightly different midline distributions for the modalities at the 0 SOA; in the visual experiment the effect was maximal over Cz and Pz, but in the auditory experiment it was maximal at Fz and Cz.

GENERAL DISCUSSION

The purpose of this study was to investigate the time course of semantic processing within the visual and auditory modalities. More specifically, based on earlier work by Holcomb and Neville (1990), the hypothesis that spoken words are capable of eliciting priming effects at shorter prime-target intervals than written words was tested. Testing was accomplished by comparing semantic priming effects in the two modalities as the time interval between the onset of the prime and target (SOA) was manipulated. In the visual experiment, robust behavioral and ERP priming effects[7] were found across both short and long SOA conditions. However, in the auditory experiment the general pattern was one of large ERP priming effects in the 800 SOA condition and smaller, less consistent effects in the two shorter SOAs, especially prior to 500 ms. Furthermore, the RT effects revealed different patterns. In the visual modality the RT effect decreased as the SOA became longer, and in the auditory modality the RT effect increased as the SOA became longer. These differences in the time course of priming effects suggests that, as predicted, contextual cues (i.e., information from the prime) become available at different rates for the two modalities. However, the direction of this difference (visual > auditory) was exactly the opposite of that predicted based on the Holcomb and Neville (1990) study.

This finding is, however, consistent with a more recent study by Holcomb and Anderson (1993), in which stimuli were presented cross-modally (visual prime with auditory target and auditory prime with visual target). In that study, the same stimulus lists and basic procedure were used as in the present study. When the prime was visual and the target auditory, RT effects were found at all three SOAs, as were large N400 effects beginning by about 300 ms. When the prime was auditory and the target visual, an N400 effect was found at only the 200 and 800 SOAs. An interesting similarity between the within- and crossmodality experiments was the small or absent effects at short SOAs when the prime was auditory.

In the 800 SOA condition, the findings of the current study were similar to those of Holcomb and Neville (1990). Specifically, behavioral and ERP priming effects (i.e., the N400 effect) were found for both modalities. However, the effect in auditory modality had an earlier onset and longer duration than that in the visual modality. This finding, which has now been replicated in the current study, would seem to contradict the results for short SOA priming where visually presented stimuli produced more robust priming at short intervals than did auditorily presented stimuli.[8] That is, if auditory words can be primed faster than visual words, does this not imply that their semantic representation is usually activated faster than the visual counterpart? If this were so, then the faster activation of the semantic representation of the auditory prime should activate the semantic representation of a related auditory target word at shorter intervals than would a comparable written word. This was the logic behind the predictions of larger short-interval priming for spoken than for written words. It would appear however, that this hypothesis is incorrect.

One admittedly post hoc explanation for the unpredicted pattern of priming effects at short SOAs focuses on the temporal dynamics of information processing in the two modalities. With visual stimuli, information is available from the moment of presentation and throughout the duration of the stimulus. With auditory stimuli, the information is presented over time and the physical stimulus is rapidly replaced by silence or another word. The temporal unfolding of auditory stimuli apparently served as an advantage in processing the auditory targets in the 800 SOA condition, where the primes had been heard in their entirety prior to the onset of the target. There, the ERP priming effects for the auditory stimuli had an earlier onset than did the analogous visual condition (and were even earlier than the shortest duration of the spoken targets). However, at shorter SOAs the primes may not have been as effective in priming the targets because they had not been fully processed prior to the onset of the target. This could occur because the acoustic information from the prime may not yet have provided enough constraint to result in the selection of one lexical candidate. In support of this hypothesis is the finding that the priming effect at the 200 SOA began between 550 and 575 ms after the onset of the prime, whose average duration was 562 ms. In addition, the later priming at the 0 SOA also began near the average duration (between 500 and 550 ms). Therefore, although N400 effects occurred prior to the completion of target words at the 800 SOA, the findings suggest that partial information from the prime in the 0 and 200 conditions may not have been sufficient to result in robust early priming effects of the target. In other words, although auditory words can be primed prior to the arrival of all of their acoustic information, partial auditory words cannot serve as fully effective primes.

One theory of word recognition that might accommodate such a finding is Marslen-Wilson's cohort model (e.g., Marslen-Wilson, 1987). According to this model, word recognition is proposed to be a three-process operation. In the first process (lexical access), incoming acoustic information activates a large number of lexical items (the word initial cohort) consistent with the initial acoustic properties of the stimulus (e.g., the initial sounds in *trespass* activate *tree, train, trestle,* etc). As more information accumulates, more and more items drop out of the word initial cohort. The second process, selection, occurs when a single item remains in the cohort.[9] Once selection is complete, information (e.g., semantic) is integrated into a higher level discourse representation. The data from the current study suggest that selection must be complete before a spoken word can serve as a source of contextual (priming) information. However, Marslen-Wilson (1987) reported findings from a cross-modal lexical decision task that indicate that there is early access of the semantic codes of words in the cohort. Two probes (targets) for different members of the cohort were presented prior to the

[7] In many previous visual studies, the N400 effect has been slightly larger over the right hemisphere. This was not the case in the present experiment, although for the 0 SOA there was a slight (though nonsignificant) trend in that direction. However, because the effect was similar in other ways (e.g., latency, temporal-parietal maximum), we feel it is still a "traditional" N400. In previous auditory studies, there has not been a consistent pattern of asymmetry as with visual studies, but the N400 effects of the present study are very similar in latency and distribution to previous findings.

[8] There were some significant early effects in the 0 SOA that might suggest that partial information was not entirely insufficient to yield priming. However, this effect was small and was only reliable at more anterior midline sites, which is not the typical distribution of N400 effects (but see Bentin et al., 1993).

[9] Marslen-Wilson (1987) referred to this as the point of uniqueness. This is the point in the acoustic signal of a spoken word past which a word has no acoustic neighbors. According to Marslen-Wilson, most spoken words can be "selected" at this point.

point where the word could be differentiated and were responded to faster than unrelated probes were responded to; after the recognition point, only the probe related to the actual word was primed. Zwitserlood (1989) observed similar findings with words in context, also suggesting that partial information is sometimes able to prime related words. In future ERP studies, it will be important to more precisely control the amount of information contained in the primes prior to the onset of the target word.

A related explanation for the modality differences concerns the attentional demands in experiments such as these. Increased attentional demands from simultaneous (0 SOA) or temporally overlapping (200 SOA) stimuli may have interfered with or modified processing of both the prime and target more for auditory than for visual stimuli.[10] The higher errors rates and slower RTs at the short SOAs suggest that this might have been the case. While subjects were attempting to attend to the spoken target, there may have been interference from the prime that could have masked some of the target's acoustic information. Even though the visual stimuli also overlapped in time, this may not have been as important because they were spatially separated but were within a short distance of each other (cf. Broadbent & Gathercole, 1990). In future studies using dichotic presentation, it may be useful to provide additional cues that would help subjects separate the prime and target stimuli (e.g., male and female voices).

This study also sheds some light on the issue of whether the N400 component is sensitive to automatic processing, controlled processes, or both. In the visual modality, priming effects at short SOAs (less than about 400 ms) are believed to result primarily from the rapid but short-acting automatic spreading of activation to nearby related nodes (Collins & Loftus, 1975; Neely, 1977; Posner & Snyder, 1975). With a longer SOA though, subjects could engage in strategic or controlled processing such as predicting the target or (after processing both words) using a positive semantic match as an aid in the lexical decision (see Neely, 1991). According to these assumptions, the results of the visual experiment provide support for such a dual-process model of priming.[11] Furthermore, the findings are consistent with the idea that the N400 component reflects both automatic and controlled aspects of priming (see Besson et al., 1992; Holcomb, 1988; Kutas & Hillyard, 1989; but see Brown & Hagoort, 1993, for an alternative viewpoint). Although significant effects were found in the auditory experiment, priming was not as robust at the shorter SOAs. The presence of large effects at longer SOAs suggests that spoken word N400s are sensitive to controlled processing. However, the attenuation of such effects at short SOAs suggests that automatic spreading activation may not play the same role in spoken word processing as it does during reading. Alternatively, this modality difference in the time course of the N400 might reflect a delay in automatic spreading activation due to the protracted nature of the spoken signal. Resolution of this issue must await the results of future studies that more carefully

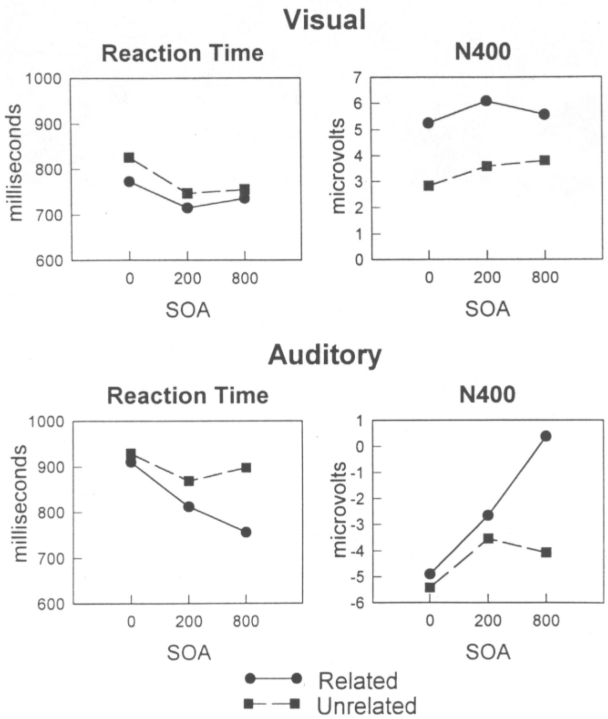


Figure 4. Reaction time and N400 priming effects (mean amplitude of the 300-550-ms epoch using an average of the three midline sites).

control the rate of information accrual in spoken prime and target words.

There were different patterns of effects in the RT and ERP data. In the visual experiment, the RT priming effect became smaller as the SOA became longer, but the ERP effects did not vary significantly across SOA during the traditional N400 epoch (300-550 ms; Figure 4, top). Moreover, a later ERP priming effect (550-800 ms) was only significant during the 0 SOA condition. One post hoc explanation for this pattern of effects assumes that a discrete measure such as RT might summate activity that extends across time in a more continuous measure such as ERPs. In other words, the larger RT effect in the 0 ms SOA condition may be reflecting the influence of processes extended across several ERP measurement windows (i.e., 300800 ms). Alternatively, because in most conditions the RTs occurred later than the ERP effects, it is possible that they were sensitive to processes that occurred after the ERP events of interest. This time lag would not be unusual; several other studies have demonstrated dissociations between RT and ERP effects (Brown & Hagoort, 1993; Holcomb, 1993; Kounios & Holcomb, 1992).

In the auditory experiment, the RT and ERP priming effects were more consistent, with the largest effects at the longest SOA (Figure 4, bottom). The difference in the pattern of effects in the visual and auditory modalities probably stems from the differences in the availability of information over time or the attentional influences. That is, in the visual experiment the stimulus information may have been more readily (and completely) available and less susceptible to interference from stimulus overlap, but in the auditory experiment the information may have been only partially available and more prone to attentional demands from the temporal overlap of stimuli.

[10]However, in the 200 SOA condition of the visual experiment, the offset of the prime occurred 200 ms into the presentation of the target. This may have resulted in a momentary shift of attention from the target to the prime, a shift that is not present in the other conditions.

[11]Several behavioral studies have included a neutral condition to assess the relative contribution of facilitation and inhibition to priming effects. In a previous study (Holcomb, 1988) that included a neutral condition, the N400 was more sensitive to facilitation than inhibition.

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