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The facilitation of lexical decisions by a prime occurring after the target

JOHN I. KIGER
American Bell, Inc., Holmdel, New Jersey 07733

and

ARNOLD L. GLASS
Rutgers University, New Brunswick, New Jersey 08903

Three experiments are reported that investigate priming effects in a lexical decision task when the prime was presented after the target. In Experiment 1, the lexical decision target was presented for 50 msec, followed 80 msec later by the prime. No significant facilitation of responses was observed in the related prime condition. In Experiment 2, the target was presented for 30 msec, followed 35 msec later by the prime. Targets followed by related primes were responded to significantly faster than targets with unrelated primes. Experiment 3 replicated the result of Experiment 2. The data are interpreted as supporting parallel processing of the prime and target in semantic priming experiments. The theoretical implications of the "backward" priming effect are discussed.

Since the first Meyer and Schvaneveldt (1971) report, numerous studies have shown that semantic context influences the course of lexical access (e.g., Fischler, 1977a, 1977b; Meyer, Schvaneveldt, & Ruddy, 1975; Neely, 1976, 1977; Schvaneveldt & Meyer, 1973). In the Meyer and Schvaneveldt (1971) experiment, subjects were to decide whether or not two simultaneously presented letter strings were words. They found that subjects' RTs were significantly faster when the two letter strings were associatively related words (e.g., nurse-doctor) than when they were unrelated words (e.g, nurse-bread). Subsequent studies, including those cited above, showed similar effects when the two words were presented in succession, even when requiring decisions only to the second member of each pair (e.g., Neely, 1976, 1977). This effect of semantic context on lexical decision RTs has been termed the semantic facilitation or semantic priming effect.

Explanations of the facilitation effect have generally included one or both of two independent processes (Fischler, 1977a; Posner & Snyder, 1975; Tweedy, Lapinski, & Schvaneveldt, 1977). One process, spreading activation, is assumed to be an automatic consequence of encoding a lexical stimulus (Collins & Loftus, 1975; Schvaneveldt & Meyer, 1973). On this account, encoding a word activates the feature detectors in lexical memory that represent words with features similar or equivalent to those of the stimulus (Morton, 1969). When activation occurs at any memory location, activation spreads from that location to others nearby. Assuming that lexical memory is organized by semantic or associative relatedness, nearby locations will be words related to the stimulus. The activation that spreads to those related words facilitates subsequent processing of the words.

The other process is assumed to reflect the conscious activities of the subject. According to Posner and Snyder (1975), if given sufficient time, the subject will consciously attend to the prime and related words. By attending to a restricted set of words in memory, the subject is able to respond quickly when the target is a member of that set. Of the two processes, spreading activation and conscious attention, the experiments reported here focus primarily on the former. This focus is controlled in the experiments by restricting the interval between the onset of the prime and the onset of the target, generally referred to as the stimulus onset asynchrony (SOA). According to Neely's (1977) analysis, semantic facilitation at SOAs of less than 250 msec should reflect only the spreading activation process. Neely's data suggest that the attentional process cannot respond quickly enough to influence RTs at very short SOAs (i.e., <250 msec).

The major issue addressed in this paper concerns the question of serial vs. parallel processing of the prime and stimulus in semantic priming experiments. In the typical semantic priming experiment, the first letter string (called the prime) is seen as providing the semantic context for the lexical decision to the subsequent target. Does the context manipulation (i.e., related vs. unrelated prime) affect the lexical decision RT through processes occurring during processing of the prime (e.g.,

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spreading activation), but prior to target processing (a serial model) or do these processes overlap processing of the target (a parallel model)? Clearly, if sufficient time intervenes between the presentation of the prime and target, the facilitation can be attributed to processes occurring prior to the presentation of the target. Indeed, this is precisely what one might expect of facilitation resulting from Posner and Snyder's (1975) attentional process. However, the problem becomes more interesting at very short SOAs. For instance, Fischler and Goodman (1978) report significant facilitation for lexical decisions at SOAs of 90 and 40 msec. In one of the Fischler and Goodman experiments, the prime was presented for 40 msec immediately prior to presentation of the lexical decision target. Responses in the related prime condition averaged 41 msec faster than responses with unrelated primes. Warren (1977) reports a similar priming effect with SOAs of 75, 112.5, 150, and 225 msec. These findings strongly suggest that prime and target processing may overlap at short SOAs.

The proceeding discussion suggests that priming effects may be found with serial or parallel processing of the prime and target. An interesting problem in this serial/parallel dichotomy is in the characterization of priming at very short SOAs. Below, we suggest several alternative explanations of such priming effects, using Fischler and Goodman's (1978) study as an example.

Consider the case of serial prime-target processing. The first hypothesis is that the presentation of the target terminates the encoding of the prime, but after 40 msec the prime has already been processed sufficiently to facilitate the processing of the target. Figure 1 illustrates the time course of events described by this hypothesis. To entertain seriously this hypothesis, one must be willing to accept the assumption that enough information can be extracted from a lexical stimulus in 40 msec to activate the stimulus' logogen and other related logogens.

An alternative serial hypothesis is that the processing of the prime delays processing of the target. This delay would allow the prime to be sufficiently processed to facilitate the processing of the target. Figure 2 illustrates this hypothesis. This hypothesis also assumes

Figure 1

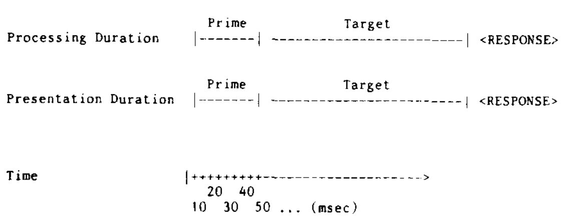

Figure 1. The figure shows the sequence of events if the presentation of a target is in the same location as the prime and the target terminates processing of the prime.

Figure 2

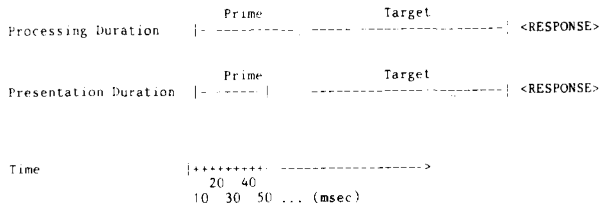

Figure 2. The figure shows the sequence of events if the brief presentation of a prime delays the processing of a subsequent target in the same location.

that serial processing of first the prime and then the target takes place.

The third hypothesis is that the processing of the prime continues after the target is presented and that the prime and target are processed in parallel. Figure 3 illustrates this hypothesis. If parallel processing of the prime and target is assumed, then this raises the following question. At what point has the prime been processed sufficiently to facilitate responses to the target? It might be the case that, as shown by the arrow labeled "A" in Figure 3, only when the prime itself has been identified as a word would it facilitate processing of the target. Or, it might be, as indicated by arrow "B," that the prime would begin to facilitate the identification of the target even before the prime itself were identified. If this were the case, then as indicated in Figure 3, a word's "facilitation time," that is, the time at which it would begin to facilitate lexical decisions for related words, would be shorter than its own lexical decision time. In fact, there is some evidence that facilitation time is shorter than lexical decision RT. Fischler and Goodman (1978, Experiment 2) found that even though their primes facilitated lexical decisions for the subsequent targets, subjects were usually unable to recall the primes even immediately after the lexical decision. Similarly, Marcel and Patterson (1978) and McCauley, Parmalee, Sperber, and Carr (1980) report semantic priming effects in lexical decisions and picture-naming tasks with prime presentation conditions that precluded identification of the prime.

If facilitation time is shorter than lexical decision time, then a prime should facilitate the processing of a target even when the prime is presented shortly after the target. Figure 4 demonstrates this hypothesis. Hence, if the lexical decision for a target were facilitated by the presentation of a prime shortly after the target, it would be evidenced (1) that the prime and target were processed in parallel and (2) that the processing time before the prime began to facilitate the target was shorter than the lexical decision time for the target. In contrast, consider the predictions of the serial hypotheses described above. Since, according to these hypotheses, words are processed one at a time in the order that they are presented, they predict that the prime would have no effect

Figure 3

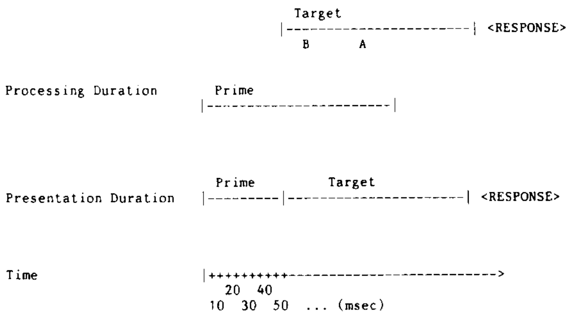

Figure 3. The figure shows the sequence of events if there is parallel processing of the prime and target. Does the prime influence the target only when it has itself been processed sufficiently for a lexical decision (A), or does it begin to influence the target at some earlier point in its own processing (B)?

Figure 4

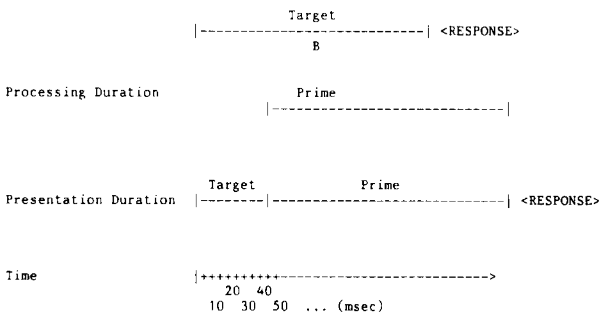

Figure 4. If the target and prime are processed in parallel, then the prime should influence the target (at B) even if the target is presented first.

on the decision time for the target. Hence, a positive effect of the prime would make it possible to reject the serial hypotheses and accept the parallel hypothesis.

There is some evidence concerning the viability of the parallel processing model of backward priming. Eriksen and Schultz (1979) found a type of backward priming in a letter discrimination task. Subjects in the Eriksen and Schultz study were to move a lever to the right if one of two letters appeared and move the lever to the left if either of two other letters was presented. On each trial, the target stimulus was preceded by, followed by, or presented with two letters that were identical to the target, were from the same response set as the target, or were from the other response set as the target, or no additional letters were presented. The two letters that accompanied the target were two instances of a single letter that were presented 750, 500, 250, or 100 msec after the target, were presented simultaneously with the target, or appeared 50, 100, or 200 msec after the target. These last three SOAs are analogous to the backward priming effect of interest here. Eriksen and Schultz found that when a pair of letters from the response set opposite that of the target was presented 50 or 100 msec after the target, subjects were slower to make the left-right response than when no letters were presented or when letters from the same response set were presented.

Eriksen and Schultz (1979) suggested a response competition account of the inhibition effect that occurred when letters from the opposite response set were presented shortly after the target. Although there was no evidence of response facilitation with compatible response set letters accompanying the target, the implications for the parallel processing model presented in Figure 4 are the same. Taylor (1977) reports an effect similar to that of Eriksen and Schultz at an SOA of 50 msec. The results of Eriksen and Schultz (1979) and Taylor (1977) suggest response competition effects resulting from parallel processing of target and noise stimuli.

Using a different paradigm, Jacobson (1973) showed that a word backward masked by an associated word is more easily recognized than the same word masked by an unrelated word. Arguing that this effect is not due to guessing, Jacobson offers a "neuropsychological" account that amounts to backward priming in a "neuronal matrix" underlying the cognitive representations of the words. Accepting the evidence Jacobson offers against a guessing account of his data, the facilitation of word recognition responses he reports is consistent with the spreading activation account of backward priming presented above.

The following experiments were designed to investigate whether the parallel/serial distinction in prime and target may overlap in time and whether semantic facilitation occurs during this period of processing overlap. The paradigm employed to address these issues was essentially a reversal of the typical semantic priming experiment in which the priming stimulus was presented to the subject prior to presentation of the lexical decision target. In the three experiments reported below, the order of prime and target presentation was reversed from that of the typical priming experiment. The first stimulus presented to the subject was the lexical decision target, followed by the prime. The interval from the onset of the target to the onset of the prime was the SOA. The semantic context of the lexical decision was manipulated by presenting a related or unrelated letter string following target presentation. By employing very brief SOAs (e.g., $<$150 msec) and brief target presentation durations, it was attempted to provide the semantic context manipulation before target processing was complete. If prime and target processing proceed in parallel at similarly brief SOAs in the typical "forward" priming experiment, we should also expect parallel processing in this "backward" priming paradigm. Consequently, a parallel model of prime and target processing predicts that semantic facilitation will occur in the backward priming experiments as well. This contrasts with the expected predictions of a serial model. A serial model, not allowing processing overlap, should require processing of the first stimulus to terminate before processing of the second begins. Hence, the prime should not affect lexical decision RTs in the backward priming task.

EXPERIMENT 1

In the first experiment, subjects were presented a letter string for 50 msec, followed 80 msec later by a second letter string (SOA = 130 msec). Subjects were instructed to respond as quickly as possible, indicating whether or not the first letter string was a word. On each trial, the second letter string appeared on each side of where the lexical decision target had been. The second letter string was related to the target, unrelated, or simply a string of four Xs. This procedure is simply a variant of the typical priming experiment with the prime and stimulus reversed. Based on independent estimates that lexical access (not lexical decision) requires 150-200 msec (Sabol & DeRosa, 1976), we expected that a 130-msec SOA would permit processing of the context word before the lexical decision to the target was complete. If processing of the target and prime overlap, then related primes should facilitate responses. However, if processing is strictly serial, then no such facilitation should occur.

Method

Materials. Each of two test lists contained 192 target prime pairs. First, List 1 will be described, and then List 2. Of the 192 test pairs in List 1, half contained word targets and half nonword targets. The 96 targets in both the word and nonword conditions were paired with one of three types of primes: One-third were paired with related words (e.g., sour-sweet, cunoe-boat), one-third were paired with unrelated words (e.g., king-robin, cremp-glass), and one-third were paired with a neutral prime consisting of a pattern of four Xs (e.g., piano-XXXX, sweap-XXXX). Hence, there were 32 examples of each of the six kinds of target-prime pairs: word-related, word-unrelated, word-neutral, nonword-related, nonword-unrelated, and nonword-neutral.

The different kinds of target-prime pairs were constructed in a variety of ways. For the word target/related prime condition, two kinds of related primes were used. Fifteen pairs were taken from the Palermo and Jenkins (1964) free associative norms. In each case, the target was the word given as a response to the prime when the prime served as a free association stimulus in the Palermo and Jenkins study. Seventeen additional pairs were chosen from the Battig and Montague (1969) category instance norms, the instance serving as the target and the category as the prime. The 32 unrelated pairs were constructed by scrambling the primes from an additional set of related word pairs, also chosen from the Battig and Montague (1969) and Palermo and Jenkins (1964) norms. Nineteen of these were from the Palermo and Jenkins study, and 13 were from the Battig and Montague norms. For the word target/neutral prime condition, an additional 32 words were taken from the Kučera and Francis (1967) word frequency data, matched as closely as possible for word length and frequency with the 64 target words in the related and unrelated prime conditions. The 32 nonword target/related prime pairs were constructed by selecting 32 new pairs from the free association norms. The nonword in each pair was made by replacing one or two letters in the free association response, thereby misspelling the word while retaining many of its original features. Unrelated and neutral pairs were taken from the Kučera and Francis (1967) norms and were matched for frequency and word length with those in the related condition. Again, nonwords were made by misspelling the original word. Misspellings were obtained by adding or deleting letters, or by switching the positions of two letters such that the resulting letter string was orthographically and/or phonemically similar to the word from which it was made.

List 2 was constructed in a similar manner. The 32 words in the unrelated prime condition of List 1 were re-paired with their original related primes to form the related prime condition in List 2. The related word pairs from List 1 were used to form the unrelated prime condition in List 2 by scrambling the 32 primes to form unrelated pairs. All other items of List 2 were identical to those in List 1.

Procedure. A PDP-11/40 computer controlled all displays and recorded the responses. Each subject was seated in front of a 9-in. Panasonic video monitor with a two-choice response panel (two microswitches labeled "yes" and "no"). Target stimuli were presented in the center of the bottom line of the video screen.

On each trial, the subjects saw three stimuli. The first was a warning stimulus, the word "READY," which served to prepare the subject for the upcoming target. The "READY" was present for 1 sec, followed by a 500-msec blank screen interval. After this 500-msec interval, the target was presented for 50 msec, in the same position as the "READY." Eighty milliseconds after the offset of the target, the target was replaced by the prime. The prime appeared on each side of the target's location. The nearest letter of the prime was displaced two spaces to either side of the position where the prime had been located. The prime was present until the subject responded to the target. All stimuli were presented in uppercase letters. Each letter was 7 mm in height and slightly more than 2 mm wide. As such, a six-letter word (nonword) was approximately 7 mm tall and 13 mm wide, subtending a (vertical) visual angle of .7 deg. The letter-background contrast was quite high, as letters were presented in black against a white background in a darkened room. A blank screen intervened for 1.5 sec between each response and the subsequent "READY."

In each session, one of the two lists was presented. In each list, 18 practice items preceded the first 96 test items, after which there was a short rest. Following the 2-min rest period, 18 additional practice items preceded the final 96 test pairs. Practice items were constructed using the same rules used for the test items. The frequencies (distributions) of word and nonword targets and related vs. unrelated primes were the same for the test and practice item sets.

Subjects were given verbal instructions at the beginning of the session. The task procedure was explained in detail. They were informed that half of the trials contained word targets and half, nonword targets. Subjects were instructed to respond as quickly as possible, but with a minimum of errors, when they knew whether or not the target was a word. They were also told that on some occasions they would find that the prime was related to the target. Subjects were told that the prime served only as a distractor, but that it might at times be useful when making a response. No further information concerning the intent of the experiment was provided.

Twenty students from an introductory psychology course volunteered for the experiment. Ten subjects received List 1, and 10 saw List 2. They received extra credit for their participation.

Results

Analyses were performed treating subjects as a random effect.[1] Alpha was set to .05 for all statistical tests. Table 1 shows the results of Experiment 1. As can be seen from the table, responses to word targets were sig-

Table 1
Mean RTs and Error Rates for Word and Nonword Decisions in Experiment 1

	Word	
	RT	PE
Related Prime	463	4.4
Unrelated Prime	481	5.0
Neutral Prime	497	8.1

Note—PE = percent error.

nificantly faster [F(1,19) = 32.54] and more accurate [F(1,19) = 35.97] than responses to nonword targets. Although prime type (related, unrelated, or neutral) had no overall effect, prime did interact with target type (word vs. nonword) for RT and error rate [F(2,38) = 13.32 for RTs; F(2,38) = 5.93 for errors]. Table 1 shows that this interaction reflects a significant effect of prime type on responses to word targets [F(2,32) = 6.06 for RTs; F(2,32) = 4.09 for errors]. The effect was due to word responses in the neutral prime condition being significantly slower and less accurate than response in the related prime condition (Scheffé's orthogonal contrasts, p<.05). For nonwords, responses were least accurate with the related primes. In this case, the related and unrelated conditions were significantly different and the difference for the related and neutral conditions also approached significance. Word responses in the neutral prime condition were less accurate than responses with word primes (Scheffé's orthogonal contrast, p<.05). There were no other significant differences in RT for responses to words or nonwords.

As can be seen in Table 1, responses to words followed by related primes were 18 msec faster than responses to words followed by unrelated primes. This difference was 23 msec for the associative primes and only 12 msec for categorical primes, but neither the main effect of prime relatedness nor its interaction with prime type (associative vs. categorical) was significant. The items used as related pairs are presented in Appendix A, classified as associative or categorical according to prime type. Perusal of this appendix will show that the associative and categorical classifications are not without some overlap.

Discussion

As predicted by the parallel processing hypothesis, responses were faster for words followed by related primes than for words followed by unrelated primes, but this difference was not significant. Possibly, this was because the primes appeared too late to influence the processing of most of the target words. If this were true, the related primes influenced the processing of just enough targets to produce a nonsignificant difference in the expected direction. This explanation predicts that a shorter SOA should produce a significant result.

Before proceeding to Experiment 2, we should consider the effect of the neutral primes on word responses. The finding of somewhat slower RTs for responses in the neutral condition suggests that there may have been some effect of the prime manipulation. The cause of slower RTs with the neutral prime is not clear. Word primes may have biased responses toward word responses, or the words in the neutral prime condition may simply have been more difficult to identify.

EXPERIMENT 2

The second experiment was an attempt to provide a more sensitive test of the serial-parallel distinction. The SOA used in Experiment 2 was 65 msec, one-half of the duration of the SOA in Experiment 1. We expected that the shorter SOA would lead to a higher probability that prime activation would facilitate responses to the target. In the second experiment, the prime appeared 65 msec after the onset of the target. The duration of the target presentation was 30 msec.

Experiment 2 did not include a neutral prime condition. Word and nonword targets were followed by either a related or an unrelated word. Experiment 2 also provides a more systematic investigation of associative and category prime responses. Word targets were divided into three categories: (1) those followed by associative primes (from Palermo & Jenkins, 1964), (2) high production frequency (PF) category instances followed by their immediate superordinate category (e.g., robin-bird), and (3) low-PF instances followed by their immediate superordinate (e.g., ostrich-bird). Categories and their instances were taken from the Battig and Montague (1969) category-instance production norms.

Method

Design and Materials. Two test lists were used in the experiment. Each contained 336 critical stimulus pairs and 72 practice pairs. Half (168) of the pairs were word target/word prime pairs, and half were nonword target/word prime pairs. Half of the primes were related to the target, and half were unrelated. Each list consisted of four sets of 18 practice items followed by 84 test items. A short rest followed each of the first three sets.

In List 1, one-third (56 pairs) of the pairs in the word (target) condition were taken from the Palermo and Jenkins (1964) study and served as the prime in this experiment. To construct the 56 pairs, 14 associatively related word pairs were drawn from the norms. Each of the lexical decision targets in these 14 pairs occurred twice with its related prime (i.e., 28 pairs). The remaining 28 pairs were made by pairing the same (14) primes used in the related prime condition with 14 unrelated words of similar length and frequency and presenting each of these 14 pairs twice (i.e.,28 related pairs, 28 unrelated pairs).

Fifty-six additional word pairs were chosen using categories (primes) and high-PF instances (targets) from the Battig and Montague (1969) norms. Instances from 28 different categories were paired once with a related prime (the category of which the instance was a member) and once with an unrelated prime (i.e., 28 related pairs, 28 unrelated pairs). High-PF instances were drawn from one of the five most frequently produced instances of each of the 28 categories.

The remaining 56 word pairs were low-PF instance-category pairs chosen from the same 28 categories as the high-PF pairs. Each of the 28 low-PF instances was primed once by a related category and once by an unrelated category. Low-PF instances were instances produced by fewer than 10% of the subjects in the Battig and Montague (1969) study.

List 1 also contained 168 nonword trials, consisting of a nonword target followed by a related word (e.g., cunoe-boat) or an unrelated word (e.g., cremp-glass). Related and unrelated pairs occurred equally often (i.e., 84 of each). The 84 nonword pairs containing related primes were made from 42 English words. Each of the 42 words was misspelled to form a nonword (e.g., canoe . . . cunoe) and was presented twice with the same related word (e.g., cunoe-boat). The 84 nonwords presented with unrelated primes were derived in the same manner from a different set of 42 English words. Primes for nonwords were judged to be related or unrelated on an intuitive basis.

An important feature of List 1 was the repetition of items, which was accomplished in the following manner. The first half of List 1 was constructed by a random arrangement of all test items described above, with no repetitions. The exception to this procedure was that only half of the category prime conditions appeared in the second half of the list. Adding 18 practice items at the beginning and after the 84th test pair produced a list of 168 test items and 36 practice pairs. The second half of the list was made by appending a copy of this list to the end of the original. Also, all category prime pairs (14 related high-PF and 14 related low-PF category pairs and 14 unrelated high- and low-PF pairs) were replaced with the 56 pairs excluded from the first half of the list. Consequently, the second half of the list was a replication of the first half with the exception of the category prime pairs.

List 2 was constructed by rearranging List 1. Recall that List 1 contained four sets of 84 test trials. List 2 was made by rearranging (inverting) Sets 1-4 into the order 4-3-2-1. Otherwise, all aspects of the two lists were identical.

Procedure. The procedure of Experiment 2 resembled that of Experiment 1. On each trial, the subject saw the word "READY" for 1 sec, a 500-msec blank field, and then the target and prime. However, several changes in the procedure were made. Target presentation duration was reduced from 50 msec (Experiment 1) to 30 msec, and the interval from the offset of the target to prime onset was reduced to 35 msec (from 80 msec), producing a 65-msec SOA. The target presentation was moved from the center of the bottom line of the video screen to the bottom left corner, and the prime appeared directly to the right of the target. Limitations of the computer's hardware required moving the targets to the left margin in order to gain any significant reduction in SOA. Instructions to the subjects were the same as those used in Experiment 1. Twenty-five subjects from an introductory psychology class participated in the experiment for extra credit. Eleven subjects saw List 1, and 14 saw List 2.

Results

Because each test list was made so that its two halves were nearly identical, initially we analyzed the two halves separately. By doing this, we could see whether or not repeating items in the second half of the list affected the outcome of the experiment. However, there were no interesting interactions involving repetition of list items. Consequently, the data are presented only for the overall analysis involving both halves of each test list. When two F ratios are reported for a single effect, the first is for the subject analysis and the second is for the item analysis. If only one F ratio is reported for an effect, it is the F ratio using subjects as the random effect.

For all subsequent tests, alpha equals .05 unless otherwise specified. An initial, global analysis indicated that responses were significantly faster when the targets were followed by related primes [$F(1,24) = 14.41$]. However, the interactions of prime type (associative, high-PF category, low-PF category) and prime relatedness indicate the prime relatedness effects were due to

Table 2
Mean RTs and Error Rates for the Different Prime Types in Experiment 2

	Associative Prime		High Related Category Prime		Low Related Category Prime	
	RT	PE	RT	PE	RT	PE
Related Prime	636	8.1	679	13.7	721	19.0
Unrelated Prime	690	16.6	688	14.0	716	23.1

Note–PE = percent error.

responses in the associative prime condition. This interaction was significant over subjects, but not items for RTs [$F(2,48) = 8.23$; $F(2,134) = 1.93$, $p > .05$] and errors [$F(2,48) = 5.65$; $F(2,134) = 1.1$, $p > .05$]. As can be seen in Table 2, responses with associative primes were significantly faster [$F(1,24) = 16.76$; $F(1,54) = 7.64$] and more accurate [$F(1,24) = 19.91$; $F(1,54) = 8.51$] in the related prime condition, but there was no priming effect for either of the category prime conditions. The items used as related pairs in the associative, high-PF category, and low-PF category prime conditions are presented in Appendix B. Mean RT for nonwords was 887 msec and mean error rate was 32.9%. None of the treatments significantly affected responses to the nonwords.

Discussion

Experiment 2 has shown that semantic priming effects can be obtained even when the priming stimulus is presented after the lexical decision target. While the overall analysis indicated a general effect of prime relatedness, subsequent analyses found that the priming effect was due only to those items chosen from the free association norms of Palermo and Jenkins (1964). No priming was observed for categorically related target-prime pairs. The interaction of prime relatedness with target-prime relationship (e.g., associative, categorical, etc.) is puzzling and unexpected, but it should not overshadow the particular result of interest (i.e., backward priming). Given this unexpected interaction and the relative weakness of the general priming effect (i.e., significant over subjects but not items), a third experiment was conducted as a replication of Experiment 2.

EXPERIMENT 3

The third experiment was designed primarily as a replication of Experiment 2. However, several design changes were made. The repetition of items that occurred in the second experiment was dropped. In addition, the use of high- and low-typicality categorically related target-prime pairs was dropped in favor of only highly typical pairs. The associative prime vs. categorical prime distinction was maintained, with several new items added to each condition. The SOA was also changed, and the offset of target to onset of prime interval was reduced to zero. An SOA of 50 msec was employed in the experiment.

Method

Design and Materials. Two test lists were used in the experiment. Each list contained 96 stimulus pairs. Half (48) of the pairs were word target/word prime pairs and half were nonword target/word prime pairs. Half (24) of the word targets were related to their word primes, and half were unrelated to the primes. Half (12) of the related word primes were associatively related to the target word, and half were categories of the target word. The associative and category primes were drawn from the same pool of items used in Experiment 2.

The word target/related word prime pairs of List 1 were scrambled to form the word target/unrelated word prime pairs of List 2, and vice versa. Each word and each prime appeared in each list only once.

Procedure. On each trial, the subject first saw the word "READY" for 1 sec, then a 500-msec blank field, then the target for 50 msec, and then the prime, which was presented to the right of the target. The presentation occurred in the center of the video screen. The experiment was controlled by an Apple II Plus computer. Its program was a PASCAL program written by John Kiger and Arnold Glass. Each session began with 24 practice trials, before the 96 test trials were administered. Half the subjects saw List 1, and half the subjects saw List 2. Both List 1 and List 2 were presented in one random order to half the subjects and in another random order to the other half.

A total of 26 subjects participated in the experiment. One subject was eliminated because of chance performance, and one was eliminated because of failure to understand the instructions. Of the remaining 24 subjects, half were faculty, officers, staff, and students of the Harvard University psychology department and half were employees of the Neuropsychology Unit of the Boston Veterans Administration Medical Center. The Boston VA subjects responded by pressing one of two microswitches. They responded with their left hands for words and their right hands for nonwords. Harvard subjects responded by pressing the response buttons on one of two T/G game paddles. They responded with their right hands for words and with their left hands for nonwords.

Results

Two analyses of variance were performed on the RT data, one in which subjects and one in which items served as the random effect. The factors in the analyses were hand (for word response) by list by order (or presentation) by association type by relatedness. The only significant effect was the effect of relatedness [$F(1,16) = 10.2$; $F(1,88) = 12.0$]. The results for words are shown in Table 3. For nonwords, the mean RT was 897 msec and the mean error rate was 24%.

Discussion

Experiment 3 replicated the main result of Experiment 2. Semantic priming effects were obtained even though the priming stimulus was presented after the lexical decision target. This time, the effect of the prime was significant across both subjects and items. Also, the interaction between the effect of the prime and whether it was categorically or associatively related to the target did not replicate. Since there was no reason to obtain this interaction in Experiment 2, its failure to replicate in Experiment 3 is reassuring. On the other hand, it should be noticed (see Table 3) that the effect of the prime is still slightly larger for associatively than for categorically related primes. It may be that there is some other factor unrelated to the category-associative distinction that reduced or eliminated the priming effect for those category items common to Experiments 1, 2, and 3.

Table 3
Mean RTs and Error Rates for the Different Prime Types in Experiment 3

	Associate Prime		Category Prime	
	RT	PE	RT	PE
Related Prime	671	6	734	6
Unrelated Prime	770	11	775	15

Note–PE = percent error.

GENERAL DISCUSSION

The most important result of Experiments 2 and 3 is the finding that a prime presented after the lexical decision target can facilitate responses to that target. The facilitation may be interpreted as indicating that processing of a prime and target can proceed in parallel, even when attention appears to be focused on only one of the two stimuli. Also interesting was the finding that only the associative, but not the categorical, primes reduced RT in Experiment 2 and produced a somewhat greater priming effect in Experiment 3. Initially, one might ask if this reflects any fundamental characteristics of memory organization. For instance, semantic memory theorists (e.g., Glass & Holyoak, 1975; McCloskey & Glucksberg, 1979; Smith, Shoben, & Rips, 1974) have placed considerable significance on the role of category relations in semantic memory organization. If category relations are truly an important structural feature of memory, one would expect this to be reflected in a priming task. However, the present results suggest, inasmuch as priming can be used to index memory organization, that simple associative relations may be more important or fundamental than the category relations. The significance of this result will be discussed further at the conclusion of this report. But first, implications of these result for the parallel and serial priming models will be examined.

The most widely received view of lexical decisions derives from Morton's (1969) logogen model of word recognition. In Morton's original formulation and other related models (e.g., McClelland, 1979), the internal representation of a word (logogen) includes a system of feature detectors amd a response threshold associated with these detectors. If activation of these detectors exceeds this threshold, the word becomes available for conscious processing. In the typical priming experiment, it is generally assumed that presenting a semantically or associatively related word prior to the lexical decision target causes activation to spread from the internal representation of the prime to the (representation of the) target. This activation raises the activation level at the target logogen, decreasing the addition activation required to reach the response threshold.

The existence of backward priming is completely consistent with this model. In Experiments 2 and 3, when the related prime followed the target by at most 65 msec, presumably the additional activation it provided the target's logogen pushed the activation level over the response threshold. However, in Experiment 1, when the related prime followed the target by 130 msec, the additional activation it might have provided arrived at the target's logogen too late for any effect.

Consider the implications of these results for the serial and parallel models presented earlier. It appears that the parallel model can explain priming in both the forward (e.g., Fischler & Goodman, 1978) and backward paradigms. In Fischler and Goodman's (1978) second experiment, the SOA was 40 msec and the target overwrote the prime in the same position in the visual field. Consequently, the target should have masked the preceding prime. That masking actually did occur is shown by the fact that less than 3% of the primes were recallable, with prime recall immediately following each response. Nevertheless, according to the parallel hypothesis, the prime continued to be processed after the target was presented, and it activated its own and related logogens, including that of the succeeding target. That is why significant priming was found in their task. But why, then, was the prime so poorly remembered? According to a model recently proposed by Johnston and McClelland (1980), the activation from the succeeding target *inhibited* the response of the prime's logogen. However, this inhibition occurred after activation had begun spreading from the prime's logogen.

When the results of Fischler and Goodman (1978), Johnston and McClelland (1980), and the experiments reported here are all considered together, they lead to the following generalizations. If two words are successively presented in adjacent locations, they will be processed in parallel (unless processing of one is complete before the other is presented). Activation will flow from each word's logogen to related logogens. Hence, if they are presented closely enough together in time and are related, each word will prime the other (i.e., both forward and backward priming will occur). If two words are successively presented in the same position, they will again be processed in parallel. Activation will flow from each word's logogen to related logogens. If it occurs closely enough after the presentation of the first stimulus, the activation from the second word will inhibit the response of the first word's logogen. Parallel processing in this case is limited by the inhibitory effects of the second stimulus on the first. This inhibition will prevent identification of the first stimulus. Hence, forward priming will occur, but backward priming will not.

The phenomenon of backward priming provides strong support for the hypothesis that words may be processed in parallel. However, one might argue that it is not possible to determine whether processing in any given task was actually serial or parallel. This argument relies on the fact that it is possible to mimic the behavioral predictions of any parallel (serial) model with some possible serial (parallel) model (Anderson, 1976; Townsend, 1974). However, in the experiments reported above, one can rule out all serial models in which processing of the first of two stimuli must be completed before the processing of a second begins. To account for backward priming with a serial model, one would need to assume (for instance) that processing starts with the target, switches to the prime for processing sufficient to activate the target (via spreading activation), and then switches back to target processing for the final decision. Although this type of model represents a logical possibility, it is less plausible (parsimonious) than the simpler parallel processing model.

There may be other plausible parallel processing models consistent with the backward priming effect. For instance, one could argue that the facilitation occurs at the response stage, rather than during the identification stage (Neely, 1976, 1977). On this account, priming could occur as a result of output (activation) from the prime logogen biasing the response. Such an effect would be the complement of the Eriksen and Schultz (1979) response competition effect discussion in the introduction. It is interesting to note that they did not observe response facilitation as was observed in the present experiments. The response-bias account assumes that the target facilitates prime processing and the early identification of the prime as a word biases the response to the target. Whether the prime influences the response or lexical access is an empirical question. We have chosen the lexical access interpretation because of the extent to which our model fits in with current models of lexical priming.

Finally, the phenomenon of backward priming may provide an important new method of testing hypotheses about various stages of the word identification process. One such hypothesis that is directly addressed by the present data concerns differences in the processes that follow feature activation at target logogens. The basic model that we have assumed in this paper suggests that feature activation excites individual target logogens and that priming occurs because this activation reduces the activation that must be obtained from the target itself. An alternative, Becker's (1976, 1980) verification model proposes that the activation of individual logogens that are related to the prime leads to the formation of a semantic verification set. When the lexical decision target is presented, the subject searches the semantic verification set for the target. If the target is in the set, as it should be when the prime and target are related, a positive response occurs. If the target is not in the semantic set, the subject searches a sensory set that was constructed on the basis of target features (after the target was presented). Thus if the prime and target are not related, the response will occur when the target is found in the sensory set, after an unsuccessful search of the semantic set. If no prime is presented, verification occurs solely on the basis of information in the sensory set.

Since Becker's model has been employed to account for word identification in several contexts (e.g., Becker, 1976, 1979, 1980; Becker & Killion, 1977; Schvaneveldt & McDonald, 1981), it is interesting to note that his model predicts no effect of a related prime in the backward priming paradigm. Consider the following application of the verification model to the backward priming paradigm. In our experiments, presentation of the target stimulus precedes that of the prime. Consequently, formation of the sensory set, based solely on the target, should occur prior to the formation of a semantic set. On this account, lexical decisions should proceed as if no priming stimulus occurred at all, with responses based on information obtained from the sensory set. Since the stimulus for a semantic verification set occurs only after the sensory set is formed (or being formed), the properties of this semantic set should exert no effect on responses to the target.

However, one could argue that Becker's verification model applies only to priming effects at longer SOAs. While it is true that the model has only been applied to effects arising from priming with relatively long SOAs, it is incumbent upon the model to account for priming at all SOAs if it is to be taken as a general model of lexical processing. As such, there is no clear extension of the model to account for the present data other than to assume that the backward priming effect is a response-bias effect.

Other important aspects of word identification might also be revealed using this paradigm. For instance, by discovering the minimum SOAs at which visually and phonemically related primes influence processing of the target, it should be possible to estimate the time it takes to successively access a word's visual, phonemic, and semantic representations. Such research could be seen as an application or extension of the method of specific effects developed by Taylor (1977).

The potential sensitivity of the task is demonstrated by the fact that backward priming was more effective with the associative than the categorical primes. One possible explanation for this result is that associative relationships are different in kind from categorical relationships. However, categorically related instances and categories also seem to be associates (although only weak associates in many cases). Furthermore, it is difficult to imagine why activation should spread so much more rapidly between incidental associates than it should between categories and instances that are related so intimately in meaning. Another possible explanation is that it took longer to gain access to the semantic representations of the category primes (e.g., bird), and thus begin the spread of activation, than it did for the words used as associative primes. One might also argue that the associative and categorical stimuli differ on a number of unspecified dimensions that would have to be identified and scaled before a more definitive comparison could be made. Whatever the explanation, systematic investigation of the differences in forward and backward priming for different types of relations should have interesting implications about the structure of semantic memory and the course of semantic access.

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NOTE

1. No analyses treating items as random are reported, since there were no significant effects of interest and, hence, no concern about generalizability of results.

Appendix A
Related Pairs in the Categorical and Associative Prime Conditions for Experiment 1

Categorical Pairs		Associative Pairs	
color/red	sport/tennis	butter/bread	boy/girl
animal/horse	music/jazz	white/black	us/we
insect/fly	fruit/apple	light/dark	dog/cat
flower/rose	tree/oak	this/that	table/chair
bird/robin	weapon/knife	sour/sweet	him/her
fuel/oil	crime/murder	hotter/colder	slow/fast
money/dollar	tool/hammer	long/short	lamp/light
metal/copper	color/blue	king/queen	high/low
time/year	tool/saw	eagle/bird	he/she
weapon/gun	tree/maple	hard/soft	here/there
fruit/orange	animal/cow	sell/buy	green/grass
cloth/wool	fuel/gas	come/go	thirsty/water
crime/rape	money/dime	hammer/nail	in/out
music/rock	metal/iron	needle/thread	on/off
time/hour	insect/ant	short/tall	spider/web
		stem/flower	you/me
		eating/food	bitter/sweet

Note–The word to the left of the "/" served as the prime in the experiment.

Appendix B
Related Pairs in the High Related Category, Low Related Category, and Associative Prime Conditions in Experiment 2

High Related Category Primes		Low Related Category Primes		Associative Primes
relative/aunt	profession/teacher	relative/dad	profession/artist	boy/girl
fuel/coal	sport/soccer	fuel/alcohol	sport/racing	light/dark
distance/mile	clothing/shirt	distance/block	clothing/boots	this/that
tool/hammer	city/Chicago	tool/axe	city/Memphis	sour/sweet
cloth/wool	fish/trout	cloth/tweed	fish/whiting	loud/noise
crime/rape	disease/cancer	crime/suicide	disease/virus	hotter/colder
animal/cow	money/dime	animal/bull	money/check	slow/fast
country/France	flower/daisy	country/Peru	flower/poppy	long/short
color/yellow	music/fold	color/silver	music/swing	river/water
weapon/bomb	insect/ant	weapon/stone	insect/tick	spider/web
utensil/knife	bird/eagle	utensil/sink	bird/turkey	hardly/ever
fruit/apple	vegetable/corn	fruit/date	vegetable/turnip	bed/sleep
furniture/desk	vehicle/truck	furniture/cabinet	vehicle/cycle	lamp/light
metal/steel	toy/doll	metal/chrome	toy/tractor	where/there

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