PRIMED-LEXICAL DECISION: THE EFFECT OF VARYING THE STIMULUS-ONSET ASYNCHRONY OF PRIME AND TARGET *

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Accepted May 1985

Lexical decisions to word targets are usually faster when they are preceded by associatively related word primes than when they follow a neutral prime. Also, it has been shown that, under certain circumstances, lexical decisions to words preceded by unassociated word primes are slower than those to words following a neutral prime. The present study explores the influence of the stimulus-onset asynchrony (SOA) of prime and target on these priming effects. Eleven SOAs were investigated ranging from 100 msec to 1240 msec. The facilitatory effect of related primes was reliable in all SOA conditions. The inhibitory effect of unrelated primes was reliable in all but one SOA condition. Furthermore, it was found that, up to the longest SOA, facilitation increases with SOA, whereas inhibition remains virtually constant. In the longest SOA condition both facilitation and inhibition decrease. Yet another finding was that pseudowords following non-neutral primes were processed faster than those preceded by neutral primes, except with the two shortest SOAs. It appears that the SOA data cannot be satisfactorily interpreted in terms of actual priming processes, that is, processes that prepare subsequent word recognition, and that some experimental artifacts may partly have been responsible for the observed pattern of results.

Introduction

When two words are presented in close succession, the first (the prime) influences performance on the second (the target) in a number of tasks. One such task is lexical decision, in which the subjects decide whether

* This research was supported by the Netherlands Organization for the Advancement of Pure Research (ZWO).

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the letter strings presented as targets are words or nonwords. Lexical decisions to word targets associatively related to the preceding word prime are typically made faster than those to words that follow a 'neutral prime', i.e., a prime that, ideally, does not set off processes that influence subsequent target processing. Moreover, it has been shown that, under certain circumstances, lexical decisions to words preceded by unrelated word primes take longer than those following a neutral prime. The experiment reported below explores the influence of the stimulus-onset asynchrony (SOA) of prime and target on these facilitatory and inhibitory effects in lexical decision.

At least three processes have been proposed to underlie the above effects. Two of them, automatic spreading activation in semantic memory and a process that we will call 'prime-induced attentional processing', constitute the two components of the 'two-process theory of priming effects', which is based on a theory of attention developed by Posner and Snyder (1975). The third process that presumably underlies priming effects in lexical decision is meaning integration. The influence of the SOA of prime and target and of a number of other temporal factors on priming effects (see below) cannot really be understood without reference to these three processes. Therefore, before discussing more specifically the role of timing factors in priming, a description will be presented of their workings and of some of their relevant properties.

Automatic spreading activation in semantic memory comes about when a word, say the prime word, is being recognized and its corresponding memory representation is activated in the course of this process. This activation is assumed to spread automatically along the paths of the memory network to nearby word representations. According to a well-known model of semantic memory (Collins and Loftus 1975) the set of representations neighbouring the source of activation includes those of words associatively related to the word that originally stimulated its memory representation, i.e., the prime word. If a target word is presented that corresponds to one of the neighbouring representations, it will be recognized fast as compared to a target word with a representation that did not receive pre-activation from the prime word's representation. This only holds, however, between certain temporal boundaries. On the one hand, by the time the target is presented the activation in the prime word's representation must have had sufficient time to spread to neighbouring representations, and on the other, the
activation received by the latter must not yet have died out completely. Automatic spreading activation is said to occur without intention and conscious awareness, to be fast-acting, and to leave unaffected the processing of words represented along memory pathways not encountered by the activation wave (Posner and Snyder 1975).

Prime-induced attentional processing implies that the subjects use the prime word to direct their attention to the memory representations of one or more words (in other words, to think of one or more words) before the target appears. If one of these ‘expected’ words is subsequently presented as target, its recognition will be relatively fast, because, e.g., the expectation allows less complete or more efficient stimulus processing. But if the target is not among the expected words, its processing will be inhibited. It is not altogether clear how this inhibition comes about (see Discussion). The identity of the expected word(s) depends upon the experimental materials surrounding the critical prime-target pair and upon the way the subjects are instructed. If many of the prime-target pairs in the set of experimental materials consist of associatively related words, and if the subjects are not explicitly instructed to direct their attention to certain other words (e.g., Neely 1977), they will typically anticipate word associates of the prime.

Whether or not prime-induced attentional processing will be performed by the subjects when they are not explicitly asked to do so, will depend upon the profitability of that strategy. This, in turn, will depend upon such factors as the proportion of related prime-target pairs in the set of materials, the degree of associative strength between prime and target in the related pairs, and the SOA between prime and target. If this SOA is always too short for the subjects to direct their attention to certain word representations prior to target presentation, and they discover that this is so, they may decide not to engage in this process any longer. One of the properties of the present process has already been mentioned, namely, that it not only facilitates responding to attended targets, but that it also inhibits responding to unattended targets. Two further alleged properties are that it is a relatively time-consuming process and, consequently, only effective with relatively long SOAs and that, as is suggested by its name, it requires the commitment of attention.

The third process that has been proposed to underlie the above priming effects, meaning integration, involves the subjects’ tendency to search for a relation between the meanings of pairwise presented words,
in the present case between those of prime word and target word, after both have been recognized. It appears that a positive output of this process of meaning integration (in case of a related target) biases the 'decision maker' (Forster 1979) to a 'yes' or 'word' response, thereby shortening the post-access processing stage involved in lexical decision and, thus, the lexical-decision RT. In this processing stage recognition or non-recognition are translated into a 'yes' or a 'no' response, respectively. A negative output of meaning integration (in case of an unrelated target), biases the decision maker to a 'no' or 'nonword' response, thereby lengthening the post-access processing stage and lexical-decision RT. Of course, meaning integration can only affect lexical-decision RT if it delivers its output before response selection and execution have taken place. For a detailed description of the working of this process the reader is referred to De Groot (1985), Forster (1981) and West and Stanovich (1982). In view of the purpose of the present paper one property of meaning integration is particularly interesting, namely, that its effectiveness is presumably relatively independent of the SOA of prime and target, since this process only starts to operate after both the prime word and the target word have been recognized, in other words, after the time interval between prime onset and target onset, however long, has elapsed. Meaning integration may thus explain how priming effects can occur even when the prime is presented after the target (Kiger and Glass 1983). De Groot and Thomassen (1984) mention a number of other plausible but less well-documented properties of meaning integration.

As pointed out in the description of automatic spreading activation and prime-induced attentional processing above, the effectiveness of these two processes largely depends, and more so than that of meaning integration, upon the time interval between the onsets of prime and target. The time course of the effects caused by one or both of these processes has been investigated by varying this SOA (Antos 1979; Fischler and Goodman 1978; Neely 1976, 1977; Warren 1977). Some of the relevant findings are that facilitation resulting from automatic spreading activation occurs earlier than facilitation and inhibition due to prime-induced attentional processing (Neely 1977). Neely's data also suggest that the effect of automatic spreading activation starts to diminish at SOAs as short as 250 msec, and that prime-induced attentional processing results in an inhibitory effect on unattended
target words at SOAs shorter than those under which it causes the processing of attended targets to be facilitated.

In addition to the physical duration of SOA of prime and target there are a number of other temporal factors that determine the amount of time available for automatic activation to spread in semantic memory and for attention to be directed to the memory representations of certain words; These factors may, therefore, also influence the size of facilitation and inhibition. In general, priming effects increase with the available processing time between recognition of the prime word and the target word (see Mitchell (1982: 108–118) for a detailed discussion of this finding). For instance, Fischler and Goodman (1978) found larger priming effects for targets following ‘fast’ word primes than for targets preceded by ‘slow’ word primes. Fast and slow word primes were those that had been classified as words rapidly and slowly, respectively, in an unprimed lexical-decision experiment. Also, Stanovich and West (1979, 1981) showed that the visual quality of the target and its difficulty (as determined by language frequency and length in letters) influence the size of the priming effects (see also Fischler and Goodman 1978). Degraded and difficult target words, which take relatively long to be recognized, showed the largest effects. Since in the various SOA studies mentioned above different primes and targets have been used that presumably vary in recognition time, the time courses of facilitation and inhibition may be expected to differ across these studies. Also, some variance may have been introduced by the fact that the focussing of attention to certain word representations was probably not equally time-consuming in these studies. Indeed it is likely that it takes less time to attend to word associations (horse) of the prime word (pony; e.g., Neely 1976), or to the name of the category (fruit) of which the prime (apple) names an exemplar (Antos 1979), than – following the instructions – to attend to words (building) that have no ‘automated’, well-learned, relation with the prime word (body; Neely 1977). All in all, it seems unfeasible to combine the data from the above SOA studies in order to obtain a reasonably complete picture of how varying the SOA of prime and target influences priming effects. Moreover, none of these SOA studies separately is capable of providing such a picture, since either the number or the range of SOAs for which data were collected was quite small. The purpose of the present study is to provide this picture by presenting the same set of experimental materials in 11 different SOA conditions ranging from 100 msec to 1240 msec.
Method

Materials

The test materials consisted of 240 prime-target pairs, viz., 120 with a word as target (word-target pairs) and 120 with a pseudoword (i.e., a nonword that is a permissible Dutch letter sequence) as target (pseudoword-target pairs). The primes in 80 of the word-target pairs were all nouns that occur as stimulus words in a set of Dutch word association norms (De Groot 1980) and that have a strong primary word association. Sixty of these stimulus-word-primary-association combinations appeared as related word-target pairs in the experiment reported here. Each of the 20 remaining stimulus words selected from the association norms was combined with a word that neither occurred as an associate to this stimulus word in the norms, nor was related to it in any other obvious way. These 20 word pairs served as unrelated word-target pairs in the present experiment. In the 40 remaining word-target pairs the prime was always the Dutch equivalent of the word blank (blanco). These pairs served as neutral word-target pairs intended to provide a baseline from which facilitation (for related pairs) and inhibition (for unrelated pairs) were to be determined. All targets in the 120 word-target pairs were nouns.

Of the 60 related word-target pairs, only 20 were regarded as critical. Similarly, of the 40 neutral word-target pairs only 20 were considered critical. All 20 unrelated word-target pairs were regarded critical. The remaining 40 related and 20 neutral word-target pairs were regarded as fillers and were not included in the analyses below. Other than the critical targets, the targets in these filler pairs were not balanced on language frequency and length (see below). The 40 related filler pairs were included in order to obtain a relatively high proportion of related pairs so that prime-induced attentional processing may be assumed to be a reasonably profitable strategy for the subjects to use. Thus, out of each four non-neutral word-target pairs three were related and one was unrelated. The 20 neutral filler pairs were added to the set of critical materials, because an earlier experiment (De Groot et al. 1982) suggests that the processing of neutral word-target pairs is inhibited when there are relatively few of them among the experimental materials.

The mean association frequency of the targets to the primes in the 20 critical related word-target pairs was 65.7%, with a standard error of 2.8. The overall mean association frequency of the targets to the primes in all 60 related pairs was 56.9%.

Across the three groups of critical word-target pairs, the targets were balanced on language frequency (Uit den Boogaart 1975), length in letters and in number of syllables. The mean language frequencies were 75.3 (per 600,000 words) for the targets in the critical related pairs, 75.2 for those in the unrelated pairs, and 75.7 for the critical targets following the neutral prime blank. The corresponding standard errors were 17.5, 17.4, and 18.3, respectively. A complete list of all critical word-target pairs is presented elsewhere (De Groot 1984).

Forty of the 120 pseudoword-target pairs had the word blank as prime. All of these neutral pseudoword-target pairs were considered critical. The remaining 80 pseudoword-target pairs all had a different noun as prime. Only 40 of these non-neutral pseudoword-target pairs were regarded as critical, the other forty were regarded as
fillers, and they were left out of the analysis. The targets in all 120 pseudoword target pairs were derived from nouns by changing, adding or deleting one or two letters.

The presentation of the test materials was preceded by that of 86 practice prime-target pairs, viz., 43 word-target pairs and 43 pseudoword-target pairs. Among the practice materials, all types of prime-target pairs appeared in about the same proportion as among the subsequent test materials. With the exception of the word blank, all the words in the complete set of materials, practice and test sets combined, occurred only once, either as a prime or as a word target. Furthermore, the pseudoword targets were derived from nouns different from those used as primes or word targets in the practice and test sessions.

Subjects and apparatus

In the experiment 176 students from the University of Nijmegen participated as Ss. They were paid 6.50 guilders. Each S was assigned to one of eleven groups. A group consisted of 16 Ss, all of whom were tested under the same SOA condition (see Procedure section).

The Ss were tested in a group-experiment room that simultaneously allowed up to four individual, independent sessions, under control of a multiprogramming computer system. Stimuli were presented in upper-case letters (white on grey) on individual TV monitors under program control. Individual stimulus presentation, response time (RT) recording and feedback were performed by a program called LEXSYS (Hudson et al. n.d.).

Procedure

The Ss were tested in groups of one to four in a normally lit room, separated from one another by screens. They sat at a comfortable reading distance in front of a monitor. They were told that pairs of letter strings were going to be presented on the monitor, one string after the other, and that they had to decide, as quickly and as accurately as possible, whether or not the second letter string of each pair was a Dutch word. They were also told that the first letter string would be either the word blank or any other word, and they were asked neither to respond overtly to this string nor to ignore it. If the second string was a word they were to press, with their right forefinger, the positive response key on the right-hand side of the keyboard in front of them. If this string was not a word, they were to press the negative response key on the left-hand side of the keyboard with their left forefinger.

Prior to every first letter string of a pair (the prime), a fixation star appeared for one second, slightly above and to the left of the place at which the prime would appear. The prime replaced the fixation star immediately. Prime duration was different for each group of Ss and depended upon the particular SOA condition under which a group was tested. There were 11 SOA conditions: 100, 160, 240, 300, 400, 540, 680, 800, 920, 1040 and 1240 msec [1]. In all these SOA conditions, the prime duration was 40 msec shorter

[1] The data of three of these SOA conditions, namely, 240, 540, and 1040 msec, have also been reported in a related study (De Groot 1984).
than the total SOA. Following prime offset and prior to the presentation of the second
target string (the target), the screen was empty for 40 msec. Subsequently, the target
appeared slightly below the position where the prime had been, and remained on the
screen until the S pressed one of the two response keys. Latencies and errors were
recorded on-line. After every trial, feedback was given to the S: one of the words
correct or wrong appeared on the monitor. Moreover, the word slow occurred whenever
a response was correct, but exceeded a pre-set 900-msec deadline. When the S failed to
respond within 2400 msec from target onset, the message too late was shown, and an
error was recorded. When an S had made three errors, the following message was
displayed: You are making too many errors. You have made three up to now. This
message was repeated and updated with every other further error. The test materials
were presented in ten blocks of 24 prime-target pairs each. After each block the mean
RT and the number of errors for that block were presented on the screen. After a
forced rest of minimally 10 sec the S initiated the presentation of a new block by
pressing one of the response keys. Prior to the test materials the practice materials were
presented in three blocks of 24 prime-target pairs each and one last block of 14 pairs
only.

Results

Word-target data

Table 1 presents the mean RTs of correct responses, the Ss' mean standard deviations
(collapsed across items) and the error rates for the groups of critical word-target pairs
in all 11 SOA conditions. Furthermore, for each SOA condition the facilitatory,
inhibitory and overall priming effects are shown in this table. These effects are defined
as the differences between RTs in the neutral and related, the unrelated and neutral,
and the unrelated and related conditions, respectively. All RTs longer than 1400 msec
(these occurred on less than 0.5% of the trials) were excluded from the RT data and
were scored as errors. The RT data are also depicted in fig. 1.

On the Ss' mean RTs of correct responses to the targets in the three critical sets of
20 word-target pairs under all 11 SOA conditions, a 3 (prime type; related, neutral and
unrelated) by 11 (SOA) by 16 (Ss) ANOVA was performed, treating prime type as a
within-Ss factor and SOA as a between-Ss factor. Also, a 3 (prime type) by 11 (SOA)
by 20 (critical items) ANOVA was run on the item means collapsed across Ss, treating
prime type as a between-items factor and SOA as a within-items factor.

The main effect of prime type was highly reliable on both analyses [$F_1(2,330) =
514.99, \ p < 0.001; \ F_2(2,57) = 51.81, \ p < 0.001]$. MinF' combining both F-values (Clark
1973) was also significant [$minF' (2,68) = 47.07, \ p < 0.001]$. The overall means for the
three different prime-type conditions were 470, 525 and 557 msec for the related,
neutral and unrelated pairs, respectively. Newman-Keuls tests showed that all three
differences between these means were statistically reliable on both the S and the item
analyses [$p < 0.01$ in all cases]. Furthermore, Newman-Keuls tests were performed on
the difference scores of the prime-type means of the separate SOA conditions. The
Table 1
Mean response times (in msec), standard deviations and error rates (in percentages) for the different types of word-target pairs in all SOA conditions.

<table>
<thead>
<tr>
<th>SOA</th>
<th>Prime type</th>
<th>Related</th>
<th>Neutral</th>
<th>Unrelated</th>
<th>Priming effect</th>
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<td></td>
<td></td>
<td>RT</td>
<td>SD</td>
<td>ER</td>
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<tr>
<td>100</td>
<td>Related</td>
<td>525</td>
<td>95</td>
<td>2.5</td>
<td>23</td>
</tr>
<tr>
<td>160</td>
<td>Related</td>
<td>482</td>
<td>97</td>
<td>0.6</td>
<td>36</td>
</tr>
<tr>
<td>240</td>
<td>Related</td>
<td>487</td>
<td>98</td>
<td>0.9</td>
<td>60</td>
</tr>
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<td>300</td>
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<td>474</td>
<td>86</td>
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<td>44</td>
</tr>
<tr>
<td>400</td>
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<td>458</td>
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<td>540</td>
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<td>0.6</td>
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<td>680</td>
<td>Related</td>
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<td>95</td>
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<td>58</td>
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<td>452</td>
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<td>0.3</td>
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<td>920</td>
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<td>1040</td>
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<td>60</td>
<td>14</td>
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<tr>
<td>300</td>
<td>Related</td>
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<td>504</td>
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<tr>
<td>540</td>
<td>Related</td>
<td>499</td>
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<td>2.2</td>
<td>58</td>
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</tr>
<tr>
<td>800</td>
<td>Related</td>
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<td>1.9</td>
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<td>3.1</td>
<td>49</td>
<td>26</td>
<td>75</td>
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</table>

Note: Priming effects without superscript are significant at the one-percent level on both the subject and the item analysis.

* Significant at the one-percent level on the subject analysis and not significant on the item analysis.

** Significant at the one-percent level on the subject analysis and at the five-percent level on the item analysis.

*** Significant at the five-percent level on both the subject and the item analysis.

**** Not significant on both the subject and the item analysis.
Fig. 1. Mean reaction times (in msec) for correct responses to word targets as a function of stimulus-onset asynchrony.
significance levels of the priming effects that were obtained from these tests are presented in table 1.

The main effect of SOA was only significant on the item analysis [$F_1(10,165) = 1.50$, $p > 0.10$; $F_2(10,570) = 23.72$, $p < 0.001$]. The mean RTs for the 11 SOA conditions collapsed across the three types of word-target pairs are shown in table 1. They tend to decrease when SOA increases from 100 msec to 400 msec, and to increase again from the SOA of 680 msec onwards.

The interaction between prime type and SOA was significant on both the S and the item analysis [$F_1(20,330) = 3.73$, $p < 0.001$; $F_2(20,570) = 5.31$, $p < 0.001$; $\text{minF}'(20,744) = 2.19$, $p < 0.01$]. The interaction data are seen most clearly in fig. 1. Apart from the irregularities in the SOA = 240 msec condition, the RTs to the targets in all word-target conditions decrease gradually between SOA = 100 and SOA = 400 msec. Beyond the latter SOA, the curves for the unrelated and neutral word-target pairs follow approximately the same course, showing a gradual slowing down up to SOA = 1040 msec. The RTs to the targets in the related word-target pairs deviate from those to the neutral and unrelated word-target pairs. Over a wide range of intermediate SOAs (from 400 to 1040 msec) they remain constant at about 450 msec, following which they suddenly increase. As a consequence of the way in which the three functions behave over SOAs, the inhibitory effect appears to change little over SOAs, whereas the facilitatory effect is much more affected by the duration of SOA. These observations are confirmed in the following analyses.

A 2 (prime type) by 11 (SOA) by 16 (Ss) ANOVA and a 2 (prime type) by 11 (SOA) by 20 (items) ANOVA performed on the RTs in the related and neutral conditions only, leaving out the data of the unrelated condition, showed that varying SOA indeed affects the magnitude of facilitation: The interaction between SOA and prime type was statistically reliable [$F_1(10,165) = 4.67$, $p < 0.001$; $F_2(10,380) = 6.41$, $p < 0.001$; $\text{minF}'(10,400) = 2.70$, $p < 0.01$]. In contrast, when these same analyses were performed on the RTs in the neutral and unrelated conditions only, leaving out the data for the related condition, the interaction between SOA and prime type was insignificant [$F_1(10,165) < 1$; $F_2(10,380) = 1.35$, $p > 0.10$], indicating that the inhibitory effect remains constant when varying SOA.

With respect to the error data, table 1 shows that, on the whole, more errors were made in the neutral condition than in the related condition, and that most errors were made in the unrelated condition. Therefore, the RT-differences between these three types of word-target pairs appear not to be caused by a trade-off between speed and accuracy. Since only very few errors were made on the word-target pairs (3.1% overall), they were not analyzed further.

**Pseudoword-target data**

Table 2 shows the mean RTs of correct responses, the Ss' mean standard deviations (collapsed across items) and the error rates (incorrect responses and responses slower than 1400 msec combined) for the groups of critical pseudoword-target pairs in all SOA conditions. Also, for each SOA condition the priming effect (the difference between the two prime-type conditions) is presented in this table. The RT data are also depicted in fig. 2.
Table 2
Mean response times (in msec), standard deviations and error rates (in percentages) for the groups of critical pseudoword-target pairs in all SOA conditions.

<table>
<thead>
<tr>
<th>SOA</th>
<th>Prime type</th>
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<td></td>
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<td>SD</td>
<td>ER</td>
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Note: Priming effects without superscript are significant at the one-percent level on both the subject and the item analysis.

b and d See explanation at the bottom of table 1.

e Significant at the five-percent level on the subject analysis and not significant on the item analysis.

Overall, the RTs to the targets in the pseudoword-target pairs are longer than those to the targets in the word-target pairs. On the Ss’ mean RTs to the 40 critical non-neutral pseudoword-target pairs and the 40 neutral pseudoword-target pairs a 2 (prime type) by 11 (SOA) by 16 (Ss) ANOVA was performed, treating prime type as a within-Ss factor and SOA as a between-Ss factor. Also, a 2 (prime type) by 11 (SOA) by 40 (items) ANOVA was performed on the item means collapsed across Ss, treating prime type as a between-items factor and SOA as a within-items factor. Incorrect responses and responses slower than 1400 msec were excluded from both analyses.

The main effect of prime type was statistically reliable on both analyses \[ F_{1(1,165)} = 133.53, \, p < 0.001; \, F_{1(1,78)} = 9.43, \, p < 0.001; \, \text{minF'} (1,89) = 8.80, \, p < 0.011. \] The overall mean RT to the 40 critical non-neutral pseudoword-target pairs was 581 msec, which was 22 msec shorter than the mean RT to the 40 neutral pseudoword-target pairs (603 msec). Newman-Keuls tests were performed on the prime-type means of the separate SOA conditions. The significance levels of the differences between these means obtained from these tests are shown in table 2.

The main effect of SOA was also significant on both analyses \[ F_{1(10,165)} = 2.00, \, p < 0.05; \, F_{2(10,780)} = 48.05, \, p < 0.001; \, \text{minF'}(10,178) = 1.92, \, p < 0.05. \] The mean RTs for the 11 SOA conditions collapsed across the two pseudoword conditions are
Fig. 2. Mean reaction times (in msec) for correct responses to pseudoword targets as a function of stimulus-onset asynchrony.
shown in table 2. As in the word-target data they tend to decrease gradually between the SOAs of 100 and 400 msec, and to increase again from the SOA of 680 msec onwards.

The interaction between prime type and SOA was statistically reliable $[F_1(10,165) = 3.42, \ p < 0.01; \ F_2(10,780) = 4.28, \ p < 0.01; \ minF'(10,470) = 1.90, \ p < 0.05]$. A comparison of figs. 1 and 2 shows that the SOA conditions that produce small effects of prime type on the pseudoword-target trials tend to synchronize with those that produce small effects of prime type on the word-target trials. The curves for the two types of pseudoword-target pairs are very much alike, and they have a shape similar to those for the word-target pairs.

With respect to the error data, table 2 shows that, on the whole, more errors were made in the neutral pseudoword-target condition than in the non-neutral pseudoword-target condition. Therefore, the difference in RTs between these two types of pseudoword-target pairs appears not to be caused by a trade-off between speed and accuracy. Since also few errors were made on the pseudoword-target pairs (2.9% overall), they were not analyzed further.

Discussion

On the whole the data confirm the findings from previous primed lexical-decision experiments: (1) Relative to word targets following a neutral prime, word associates of a preceding word prime are facilitated and word targets unrelated to the word prime are inhibited; (2) Pseudoword targets following a non-neutral prime are processed faster than those following a neutral prime; (3) RTs to word targets are shorter than those to pseudoword targets.

Three of the possible sources of the effects described under (1) have already been discussed at length in the introduction. The second of the above findings was also obtained, amongst others, by Neely (1976, 1977), and induced him to modify earlier views on how prime-induced attentional processing (see Introduction) causes inhibition of unrelated word targets. In Posner and Snyder's original model (1975), this inhibition was attributed to the fact that misdirected attention causes delay in a system of limited capacity. But, as noted by Neely, if the limited-capacity nature of attentional processing is responsible for the inhibition of unattended word targets, the responses to pseudowords following non-neutral primes should take longer than those to pseudowords following neutral primes, because only the former type of primes are assumed to direct the subjects' attention to certain word representa-
tions, and, consequently, deplete the resources of the limited-capacity attentional system. In contrast to this prediction, pseudowords following a neutral prime take longer to process. This led Neely to suggest that a 'predict-and-match' strategy, which can be regarded as an elaboration of prime-induced attentional processing (see Introduction), is responsible for the response pattern observed for pseudowords. This strategy also specifies how inhibition of unrelated word targets may come about: It implies that the subjects, when presented with a non-neutral prime, direct their attention to the memory representations of prime-related words and subsequently match these memory representations onto the actual target. If this target is a word that corresponds to one of the attended representations, the match will be successful and the subjects will be biased towards a 'yes' response. On the other hand, if a pseudoword is presented, or a word that does not correspond to one of the attended representations, there will be a mismatch, and the subjects will be biased towards a 'no' response. Such a strategy would facilitate both the appropriate 'no' response to pseudoword targets and the appropriate 'yes' response to word targets that correspond to attended representations. But it would inhibit the appropriate 'yes' response to unattended (unrelated) word targets.

As an alternative explanation for the different RTs to the targets in the two pseudoword conditions one might suggest that it is simply due to the subjects being more attentive to new stimuli (non-neutral primes) than to old stimuli (neutral primes). However, Kinoshita et al. (1985), in a series of lexical-decision experiments in which sentential contexts instead of word contexts served as non-neutral primes, provided yet another interpretation of the effect, that renders the previous one unlikely. They argued that the response pattern commonly observed for pseudowords reflects an overestimate of the lexical-decision RT to pseudowords following 'neutral' primes caused by mixed presentation of neutral and non-neutral stimuli. With blocked presentation of these stimuli equal RTs to pseudowords following non-neutral and neutral primes were obtained. On the basis of the above attentional explanation of the present effect, one would again have expected faster RTs for pseudowords following sentential primes, since both in Kinoshita et al.'s blocked presentation condition and in their mixed condition the neutral primes were 'old' stimuli (strings of Xs that were divided into chunks of word size). The source of the inhibitory effect on pseudowords following a neutral prime in the mixed-presentation condition
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(see Kinoshita et al. (1985) for a detailed description of the underlying process) also causes an inhibitory effect on word targets preceded by neutral primes, thus overestimating the facilitatory effect in the congruous (related) condition and underestimating the inhibitory effect in the incongruous (unrelated) condition: With blocked presentation of neutral and non-neutral stimuli, the facilitatory effect on congruous word targets decreased and the inhibitory effect on incongruous word targets increased.

Within search models of word recognition (e.g., Forster 1976), the third of the above findings is commonly attributed to a relatively time-consuming search through the mental lexicon in case the target is a pseudoword: A pseudoword decision can only be delivered if and when an exhaustive search of the mental lexicon has failed to locate a lexical entry with a visual description matching the target. In contrast, in case the target is a word, the search can be stopped and the process of selecting and executing the word decision can start as soon as the appropriate entry has been located. Direct-access models (e.g., Morton 1969) attribute the longer RTs for pseudoword targets to a deadline-mechanism: The recognition of a word comes about when its corresponding lexical entry (logogen) ‘fires’. If no such firing occurs within a certain amount of time it can be inferred that the presented target is not a word.

The fact that all primes were words may also have contributed to the effect of target type (words vs pseudowords), since it may have caused a bias towards word responses. Such bias would have to be overcome in the case of pseudoword targets. This can be tested by presenting both words and pseudowords as primes. If under those circumstances pseudowords following pseudowords turn out to be processed faster than those preceded by words, the present suggestion will be supported.

More interesting, for our present purposes, than the above effects is how they vary with SOA. Even though 11 different groups of subjects provided the data for the various SOA conditions, figs. 1 and 2 show remarkably smooth curves. Furthermore, The RT functions for all types of stimuli, word-target stimuli as well as pseudoword-target stimuli, are very similar. Apart from the anomalies in the 240-msec SOA condition, the RTs for all types of stimuli decrease between 100-msec SOA and 400-msec SOA and increase again with longer SOAs. The functions differ only with respect to the number of intermediate SOAs over which they remain flat. The shapes of the curves are reminiscent of those that
have been found in a large number of reaction-time experiments with variable foreperiods, and especially in those investigating the psychological refractory period. For instance, Posner and Boies (1971) found that the RTs were minimal when the subjects were given about 500 msec between a preparatory stimulus and a subsequent imperative stimulus. According to these authors, the SOA functions reflect the time necessary to encode the prime in a form that is optimal for processing the second stimulus. The relatively long RTs at the shorter SOAs presumably indicate that at these SOAs prime processing was not yet complete when the target arrived and that the subjects finished prime processing before attending to the target. The slowing down at the longer SOAs may have been due to relaxed attention.

In addition to these general features, one aspect of the SOA data is particularly interesting in view of the alleged sources of priming effects discussed in the Introduction: Prime-induced attentional processing and also its elaborated version, the predict-and-match strategy, are thought of as being time-consuming processes, and therefore should only become effective with relatively long SOAs. As a consequence, if this process is being operative, both the facilitatory effect on related word targets and the inhibitory effect on unrelated word targets should increase over SOAs. The present data indeed show an increase of the facilitatory effect over SOAs, but the inhibitory effect on unrelated word targets remained constant over SOAs.

Yet a second aspect of the SOA data may not be in agreement with the (predict-and-match) notion of prime-induced attentional processing. In addition to an increase of both the facilitatory effect on related words and the inhibitory effect on unrelated words, this process also predicts a growth of the facilitatory effect on pseudowords preceded by word primes. This is indeed obtained: At the two shortest SOAs the RTs for the two pseudoword conditions are equal, but beyond that SOA pseudowords following non-neutral primes are processed faster than those following neutral primes. However, the onset point for attentional-priming effects has previously been located at a longer SOA than one somewhere between 160 and 240 msec (De Groot 1985; Neely 1977).

Clearly, our views on the origin of priming effects must be altered to accommodate the above two findings. The most parsimonious solution is to dismiss prime-induced attentional processing as a source of priming effects in the present experiment; the profitability (see In-
troduction) of this process may just have been not large enough for the subjects to engage in it. Meaning integration may then be thought of as the sole cause of inhibition on unrelated word targets, and both meaning integration and automatic spreading activation may be regarded as the sources for the facilitatory effect on related word targets (but see Kinoshita et al. 1985). However, the relative independence of the effectiveness of meaning integration of the SOA of prime and target (see Introduction) will then require the additional assumption that the increase of the facilitatory effect on related word targets over SOAs must be due to automatic spreading activation becoming gradually more effective between SOAs of about 540 and 1040 msec. This would not be in agreement with Neely's (1977) observation that the effects of the latter process start to diminish beyond an SOA of 240 msec.

It may also be the case that the increase of the facilitatory effect over SOAs is not caused by any priming process, but simply reflects a ceiling effect in the related condition: Classifying letter strings as words or pseudowords under the present experimental conditions may minimally take about 450 msec, so that the function for related word targets cannot follow the common curve for the psychological refractory period (see above) as neatly as those for targets in the (slower) neutral and unrelated word-target conditions do.

Of course, if prime-induced attentional processing has indeed not been operative in the present experiment, it cannot have caused the priming effect on pseudowords either. This effect should then have to be attributed to some other source, e.g., the mixed presentation of non-neutral and neutral stimuli (see Kinoshita et al. 1985). However, this alternative source of the effect must then be specified such that it can explain the present finding that the priming effect on pseudowords varies over SOAs.

The above interpretations serve to illustrate our need for more detailed knowledge as to when the prerequisites for the effectiveness of the different priming processes are fulfilled and for a way to dissociate the effects of these processes. Also, they suggest that many effects that used to be regarded as evidencing the influence of contextual information on subsequent word recognition, may in fact be artifacts of the experimental conditions under which the data were collected. If we will eventually manage to get more control over our experiments, word recognition may turn out to be a much more autonomous process than many 'interactionists' have assumed for long.
References


