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Tests of a Theory of Priming Interference Involving Competitive Lateral Inhibition Between Nodes in Semantic Memory

by

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Abstract

Four experiments tested the predictions of a theory of priming proposed by McLeod and Walley (1989) which attributes interference effects in priming to processes of competitive lateral inhibition between nodes representing concepts in semantic memory. The more highly activated a node is, the more it will tend to inhibit other nodes. In all experiments masking procedures were used to vary activation levels of the prime and/or target nodes and interference effects were predicted based on the theory. A cost benefit paradigm was used in which the prime was either a strong associate of the target, an unrelated word or a neutral prime. Facilitation and interference effects were calculated by subtracting scores for word prime trials from scores for neutral prime trials. The task was a lexical decision. In Experiment 1, the prediction that interference normally found in a high cue validity condition at long SOAs would be considerably increased when the brief target was masked was confirmed in the first block of trials. In the second block, no increase was found suggesting that repetition of unrelated target words in the second block had compensated for the masking procedure. In Experiments 2 and 3, at short prime target SOAs when the prime mask SOA varied randomly, interference occurred only in the high cue validity condition and when the prime mask SOA was longer than the target mask SOA. In Experiment 4, however, when prime mask SOA was blocked in increasing or decreasing

order, interference occurred when prime and target mask SOAs were equal, suggesting that with prime mask SOA blocked, subjects could develop strategies for using the prime even when it was perceptually available for only 50 ms. Again, repetition of unrelated target words appeared to compensate for masking procedures such that interference did not occur in the second and third blocks. Data are consistent with the McLeod and Walley theory, and can be accounted for only in part by the Posner and Snyder theory. More generally, the data also support a systems view of attention in which many attentional mechanisms are working in parallel.

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I. INTRODUCTION

A. The Priming Phenomenon

A prime is a word or other stimulus presented at the same time or at some interval before another stimulus, the target, on which the subject is required to perform a task. Typically, it has been found that the nature of the prime can influence the speed and accuracy of the task performed on the target. It is common, for example, to find that a word target is processed more quickly and with fewer errors when the prime is a word related to the target than when it is unrelated (e.g. Meyer & Schvaneveldt, 1971; Neely, 1976).

B. The Cost Benefit Paradigm

Posner and Snyder (1975) developed an experimental paradigm that made it possible to distinguish the facilitatory effects of a related prime from the interference effects of an unrelated prime. In this paradigm, a neutral prime is used, often a string of x's which is thought to be equivalent to the word prime in alerting function and processing requirements, but to lack semantic content. The benefit obtained with a related prime is measured by subtracting the reaction time or error rate when the target is preceded by the related prime from reaction times or error rates when it is preceded by the neutral prime. Similarly, the cost of an unrelated prime is measured by subtracting unrelated prime reaction times or error rates from those obtained with the neutral prime. In order to chart the time course of facilitation and interference, the duration of the interval between the onset of the prime and the onset of the target (SOA) is varied. As well, some method is used to manipulate the amount of attention paid to the prime in order to assess the effect of attention on priming effects. Jonides and Mack (1984) have discussed the pitfalls of this cost benefit paradigm, and have pointed out the difficulty of ever knowing whether the neutral prime used does have the same alerting function and processing characteristics. The cost benefit paradigm remains, however, the only way of separating out facilitatory and inhibitory processes in a priming task.

C. The Posner and Snyder Two Process Theory of Priming

Posner and Snyder (1975) propose that there are two independent processes involved in the priming phenomenon: automatic spreading activation and deliberate, consciously directed attention. In their theory, as in Collins and Loftus (1975), semantic memory is thought of as a network of linked nodes, the nodes corresponding to concepts in memory and the length of the various links connecting them corresponding to their strength of association. Related concepts, are, therefore, thought of as being closer together and unrelated concepts, farther apart (Posner, 1978; Neely, 1976, 1977). When a node in memory is activated, that activation is thought of as quickly and automatically spreading outward to other related nodes through these associative links. Activation is released from the node at a fixed rate as long as the concept is activated. Through a mechanism which is not specified, the level of activation gradually decreases as activation spreads outward from the original activated node first to nodes that are closely related and then to nodes that are less and less closely related.

In a priming task, Posner and Snyder propose that even if the prime is not consciously attended to, it automatically activates the node in memory corresponding to its physical form, name and semantic content. Activation then spreads automatically to other related concepts in semantic memory. As a result of this spreading activation, related target words can be processed more quickly and accurately because common pathways in memory have already been activated. This process of automatic spreading activation is thought to occur without intention, without awareness and without interference with other mental activity. It quickly facilitates the processing of related targets, but has no inhibiting effect on the processing of unrelated targets.

In contrast, the mechanisms of consciously guided attention are seen as slow, deliberate and serial. Conscious attention has a limited capacity, and commitment to one mental activity interferes with another. The conscious attentional mechanism is thought of as being like a spotlight which moves through memory sequentially accessing concepts, which are stored at different locations. This shifting of the attentional mechanism from one memory location to another takes time. The more unrelated the concepts are, the farther the shift required, and the more time it takes to accomplish. Thus, the processing of a new stimulus that is unrelated to the original stimulus will take longer than the processing of a related stimulus, which does not require such a long shift.

Posner and Snyder's theory predicts, therefore, that when the subject is not paying attention to the prime, or at early stages of processing before conscious attention has had time to develop, there should be evidence of facilitation due to automatic spreading activation, but no evidence of interference. At later stages of processing when the subject is attending to the prime, both processes should be operational, and, therefore, both facilitation and interference effects should be found.

D. Experimental Evidence

The strongest support for the Posner and Snyder theory has come from an experiment done by Neely (1977) and replicated by Favreau and Segalowitz (1983) in which he used a cost benefit paradigm with a lexical decision task while manipulating conscious attention by explicitly directing the expectations of the subject. Primes were category names with category exemplars for targets. SOAs were 250, 400 and 2000 ms. Results showed facilitation occurring at all SOAs but interference only with the 400 and 2000 ms SOAs in conditions where the subject's attention was misdirected. In other research, however, interference has been found at short SOAs (Antos, 1979; Myers & Lorch, 1980; Neely, Fisk & Ross, 1983), contrary to the Posner and Snyder model. More recently, McLeod and Walley (1989) in several experiments found significant interference occurring at a 200 ms SOA when targets were brief and masked. Posner (1978) has interpreted evidence of early interference as indicative of an early commitment of conscious attention, thus giving up the distinction between fast, automatic processes and slow, consciously guided processes. Because he has, however, defined consciously guided processes as those in which interference occurs, his reasoning runs the risk of becoming circular. Fischler and Bloom (1979), furthermore, found that in a lexical decision task primed by sentence contexts, subjects were not able to eliminate interference when instructed to ignore context implications. A strict division between fast, inhibitionless obligatory processes and slow, consciously guided processes involving inhibition does not seem to be supported.

E. An Alternative Theory

McLeod and Walley (1989) have offered an alternative model of the mechanisms involved in a priming task, based on a neuropsychological theory of selective attention proposed by Walley and Weiden (1973). Walley and Weiden proposed that the accessing of a concept in semantic memory corresponds to the activation of a particular set of cells in cortex. This set of cells could be fairly widely distributed across cortex, but, for convenience, the term 'node' will be used to represent the set of neurons in question. When a node in memory is activated, it will tend to lower the thresholds for activation of nodes representing related concepts in proportion to the strength of synaptic connections between the two concepts. (The word 'threshold' as used here signifies the amount of activation required to bring about the firing of the node in question.) Related concepts are not necessarily close together in memory, but they have strong synaptic connections. (It is also possible that concepts related through similarity rather than association may share neurons.) Whether activation can spread automatically beyond one set of synaptic connections remains an empirical question (See Balota & Lorch, 1986; de Groot, 1983).

At the same time as it lowers thresholds of related nodes, activation of a concept in memory will tend to inhibit other nodes in memory through a process of lateral inhibition brought about by inhibitory interneurons. The more highly activated the node in question becomes, the more strongly it will inhibit activation of other nodes, raising their thresholds. Nodes in memory can therefore be thought of as competing with each other for access to attention and to response mechanisms (McLeod & Walley, 1989). In this competition, the most highly activated node will win out, since lateral inhibition increases as a function of activation level.

In a priming task, at short SOAs facilitation of a target that is related to a prime is attributed to strong excitatory connections between the node corresponding to the prime and the node corresponding to the target. Activation of the prime node inhibits all other nodes, including the related target, but when strong excitatory links are present between prime and target nodes, these more than compensate for such inhibition. The threshold of the related target node is thus automatically lowered, and less perceptual input is required for recognition of a related target. Reaction times are, therfore, faster, and responses more accurate.

At longer SOAs, beyond 400 ms (Neely, 1977), facilitation is attributed to the generation of an expectancy concerning the identity of the target. When the subject knows that there is a high probability that the target is a strong associate of the prime, the node corresponding to the expected target will be activated. If the expected target is then presented, again, little perceptual input will be required to recognize it, and responses will be faster and more accurate. If the prime is a cue to a range of possible targets, as with a category prime, nodes corresponding to appropriate category exemplars will be activated, thus facilitating responses to expected targets.

Interference in a priming task, as stated earlier, is attributed to competitive interactions between nodes. If the target node is more strongly activated than the node competing with it, no interference will result, because the target node easily wins the competition. If, however, the two (or more) nodes competing for access to response mechanisms are both activated to a similar level, real competition will occur, resulting in errors and slowed reaction times.

At a short SOA, competition for response mechanisms exists between the node corresponding to the prime and the node corresponding to the target. Normally, the target node is more highly activated and no interference results, because, by the time the target is presented, activation of the prime node has already begun to decay. McLeod and Walley, however, found strong interference at a short 200 ms SOA when targets were brief and masked. They suggest that activation of the target node is considerably reduced in this condition, thus making it more susceptible to interference from the prime.

At long SOAs, competition is primarily between the target node and the node(s) corresponding to the expected target. It has typically been found that at long SOAs when a target is presented that is contrary to the subject's expectation, interference does result (e.g. Neely, 1977). McLeod and Walley suggest that this implies that the top down activation of the expected target node generated by expectancy may be stronger than that resulting from automatic activation of the node corresponding to the prime at short SOAs. Furthermore, the expected target node may be fully activated at the time of presentation of the target, and thus presents real competition to the node activated by bottom up processes of word recognition.

F. The Purpose of These Experiments

The proposed experiments tested some predictions of the model of priming proposed by McLeod and Walley. In four different experiments, attempts were made to manipulate activation levels of the target node and/or the prime node through masking procedures. Predictions were made from the model about the relative amounts of interference to be expected in different conditions. Experiment 1 was a primed lexical decision task with an SOA of 800 ms, in which a brief target was masked either in the first or second block of trials. Cue validity was either high or low, with 75% or 25% of targets highly related to primes. With high cue validity, it is expected that subjects will attend to the prime, using it as a cue for the generation of expected targets (den Heyer, Briand, & Dannenbring, 1983; Tweedy, Lapinski, & Schvaneveldt, 1977). McLeod and Walley have found large interference effects at a short SOA with brief masked targets. The model we propose predicts that the interference effects normally found at long SOAs in a high cue validity condition would be much larger if the target were brief and masked. In this case, with the activation level of the target node considerably reduced, the activation of the expected target node would be even more strongly competitive, resulting in even longer reaction times and a higher error rate. Such a prediction is supported by evidence from other research where, at long SOAs, the target was degraded in some way. Meyer, Schvaneveldt, & Ruddy (1975) used targets that were either clearly visible or degraded by the superimposition of a grid of dots. In both a lexical decision and a pronunciation task, they found greater amounts of interference with degraded targets. Becker and Killion (1977) varied stimulus intensity in a lexical decision and a pronunciation task, In both experiments, they found greater interference from an unrelated prime when stimulus intensity was low. Increased interference has also been found in priming studies using a sentence context when the target was degraded by reducing target background contrast (Stanovich & West, 1983).

In the low cue validity condition, where only 25% of primes and targets are strongly related, it was expected that subjects would not generate an expectation regarding the identity of the target based on the prime. There should, therefore, be no interference at long SOAs in the low cue validity condition either with or without a masked target.

Durgunoglu (1988) found in a priming task with prime target SOA of 700 ms, that significant interference occurred when a target of 30 ms duration was masked at a target mask SOA of 60 ms, but found no interference when targets were clearly displayed for 1000 ms. However, in her experiment, although subjects were instructed to silently read the prime, it appears that the proportion of related primes and targets was not high (50%). It was unlikely, therefore, that subjects had developed a consistent strategy of using the prime to generate an expectancy regarding the identity of the target. The fact that the usual interference effect was not found with clearly discernible targets supports this conjecture. The interference found with a masked target in her experiment, may have occurred because some proportion of subjects did use the prime as a cue to the target either consistently or on some trials. Her experiment, therefore, does not clearly address the issue in question here.

Experiments 2, 3 and 4 tested the prediction that if activation of the prime is reduced through masking, interference found at short SOAs when targets are brief and masked will not occur. McLeod and Walley suggest that when targets were brief and masked, activation in the target node was considerably reduced, and therefore more susceptible to inhibition generated by the prime node. If, however, the prime is itself brief and masked, activation of the prime node should be reduced as well, and thus, with activation of the prime node already decaying by the time the target is presented, the target should win out easily with the prime node posing no serious competition. In Experiments 2, 3 and 4, varying prime mask SOAs were used with a brief masked target and it was predicted that interference would occur only when the prime mask SOA was equal to or longer than the target mask SOA. In Experiment 2, a low cue validity condition was used and prime mask and target mask SOAs were varied orthogonally. In Experiments 3 and 4, in order to assess the role of attention in interference effects at short SOAs, a cue validity condition was used with a wider range of prime mask SOAs and a fixed target mask SOA of 50 ms. In Experiment 4, prime mask SOA was blocked in order to clarify the roles of attention and prime mask SOA in interference effects.

II. EXPERIMENT 1

A. Subjects

Subjects were 80 undergraduate psychology students from the University of Alberta, 23 males and 57 females, who volunteered for participation as an option for course credit. All participants were native English speakers.

B. Experimental Design

There were 2 between subject variables and 3 within subject variables in the experiment. Between subject variables were order of conditions and cue validity. The brief targets were masked either in the first or the second blocks of trials. Cue validity was either high, with 75% of prime target pairs related , or low, with 25% of prime target pairs related. Within subject variables were prime type (whether the prime was a word or a string of x's), prime relatedness (if the prime was a word, whether was is a strong associate of the target or not associated) and target condition (masked or not masked). SOA in all cases was 800 ms and target duration was 66.7 ms.

C. Apparatus and Procedure

General instructions were presented to each subject prior to the experiment. Subjects were informed of the proportion of prime target pairs that were highly related.

Stimuli were presented by an Apple II plus microcomputer to each subject individually on a monitor in a small sound attenuating room. The monitor was an Electrohome model ESM-914 with a P4 phosphor. Brightness of the monitor screen measured approximately 12 candela per square meter in the center where stimuli were presented. The distance from the subject's eyes to the screen was approximately 70 cm.

Before each trial, the word "READY" appeared on the monitor. The subject then pressed the center button of a pad of three to begin the trial. First a cross appeared in the middle of the screen as a fixation point. This fixation point remained visible throughout the trial. The prime, which was either a word or a string of 5 x's, then appeared directly above the cross for 200 ms. At an SOA of 800 ms, the target appeared directly below the fixation point for 66.7 ms. On 25% of trials the target was a pronounceable nonword. In either the first or second block of trials, the target was immediately followed by a mask of 8 #'s of a 33.3 ms duration.

Subjects were instructed to press the button to the left of the central button if the target was a word, and the button to the right of the central button if the target was a nonword. The index finger of the right hand was used for all button presses. A 2-s response time was allowed.

The 192 trials were given in 2 blocks of 96 trials. As stated earlier, in either the first or second block of trials, the target was masked. Order of conditions was randomly assigned to subjects. Before each block the subject was given a block of 48 practice trials, using a different word list from those used in the experimental trials. A one minute break was given after the practice trials, and a 5 minute break after the first block of experimental trials.

D. Stimulus Materials

Four lists of 12 word pairs were selected from an atlas of normative free association data (Shapiro & Palermo, 1968) to serve as primes and targets in the strongly associated priming condition. The probability of the target being a primary associate of the prime was at least .40, with a mean probability of .58. The stimulus materials are presented in Appendix 1. The lists were matched as well as possible for mean word frequency using the Kucera and Francis norms (1967). Median word frequencies for the four lists were 90, 89, 74 and 71.5. The four lists were also matched for strength of association. Mean probability of the target being the primary associate of the prime was .58, .58, .58, and .57 in the four lists.

Subjects were divided randomly into 4 groups of 20. For each of these groups, the data of experimental interest were from trials using one of the four lists of associates. The purpose of using four groups was to ensure that all items appear equally often in all conditions.

In each block of 96 trials, there were 48 experimental trials, 24 filler trials and 24 nonword trials. Since related and unrelated targets were paired with the same prime, separate neutral conditions were used as controls for related and unrelated targets. For each cue validity condition, there were in each block: 12 trials in which prime and target were related pairs from the experimental list, 12 trials of neutral primes consisting of 5 x's paired with the same targets, 12 trials of the same primes from the experimental list paired with unrelated targets from other lists, and 12 trials of a neutral prime of 5 x's paired with each of these unrelated targets. All primes and targets from the experimental list thus appeared equally often, 4 times across the experiment. In each block, excluding filler trials, each prime from the experimental list appeared twice, once with the related target and once with a different target from other lists. Targets from the experimental list also appeared twice in each block: once with the related prime and once with the neutral prime. Targets from other lists appeared as unrelated targets 2 times each, once with a word prime from the experimental list and once with a neutral prime.

In the first block, primes and targets from the experimental list appeared twice each. Unrelated targets from another list also appeared twice. Filler trials included primes and targets from two lists not used for unrelated experimental targets. In filler trials each prime and target appeared once. In the second block, again each experimental prime and target appeared twice for a total of four times across the experiment. Unrelated targets in experimental trials were taken from a list that had previously appeared in filler trials in the first block. This meant that block 2 unrelated experimental targets appeared three times across the experiment. Again, in the second block, primes and targets in filler trials came from lists not used in block 2 experimental trials, and each prime and target in filler trials appeared once.

The 24 filler trials were composed of primes and targets from two other lists. The purpose of these filler trials was to provide enough extra trials to make up the two cue validity conditions. In the high cue validity condition, all of the 24 filler trials consisted of related primes and targets. In the low cue validity condition, all 24 filler trials consisted of unrelated prime and target pairs.

Pronounceable nonwords were constructed for the nonword trials, matched to unrelated experimental target words in length and digram frequency using frequencies reported by Mayzner and Tresselt (1965). Twenty-five percent of trials were nonword trials. Proportions of word primes and neutral primes used with nonwords were the same as for words. Word primes for nonword trials were drawn from other lists not used in experimental trials. Because nonwords were matched to unrelated experimental targets, different nonwords were used in each block of trials. Within each block, nonwords occurred twice, once with a word prime and once with a neutral prime. Fewer repetitions of nonword targets than word targets, therefore, occurred across the experiment.

Within each block, trials were presented in a different random order for each subject, with the restriction that at least three trials intervene between any repetition of a prime or a target word.

A separate list of 18 word pairs, with probability of the target being the first associate of the prime at least .30 was selected from the Shapiro and Palermo norms (1968) for use in the 96 practice trials. In the high cue validity condition, in each block of 48 trials, 18 consisted of related pairs, 6 consisted of primes paired with unrelated targets from the same list, 12 consisted of targets preceded by a neutral prime of 5 x's, and 12 were nonword trials. In the low cue validity condition, 6 were related primes and targets, 18 consisted of primes paired with unrelated targets from the same list, 12 consisted of targets paired with a neutral prime of 5 x's and 12 were nonword trials.

E. Results

Reaction Time Data

An analysis of variance was carried out on reaction time data with variables: cue validity, order of masking (mask in first or second block of trials), prime type (word or x's), prime relatedness and blocks. Data analysed were means averaged over errorless trials. Facilitation and interference in all figures and tables have been calculated by subtracting scores for word prime trials from scores for neutral prime control trials. Positive scores obtained in this way indicate facilitation, while negative scores indicate interference.

Mean reaction time for the experiment was 623 ms. As shown in Table 1 and Figure 1, interference, as predicted, was considerably increased in the high cue validity condition when the target was masked in the first block of trials. However, in the second block of trials, no difference in interference was found between masked and unmasked target conditions. As predicted, no significant interference occurred in the low cue validity condition with either masked or unmasked targets.

The analysis showed that reaction times were faster in the second block (581 vs. 666 ms) regardless of which block was masked $\underline{F}(1,76) = 76.59$, $\underline{p}<.001$, EMS = 15251. Furthermore, the increase in reaction time with the masked target was much greater when the first block was masked than when the second block was masked (98 ms vs 25 ms) $\underline{F}(1,76) = 39.76$, $\underline{p}<.001$, EMS = 15251.

Related prime trials and their controls were, on average, faster than unrelated prime trials and their controls, $\underline{F}(1,76) = 94.16$, $\underline{p}<.001$, EMS = 4164.4. This difference was greater when targets were masked, $\underline{F} = 14.90$, $\underline{p}<.001$, EMS = 2862.6. Word prime trials were faster than neutral prime trials, $\underline{F}(1,76) = 16.98$, $\underline{p}<.001$, EMS = 2239.9. Across the experiment, there was a mean facilitation on related prime trials of 53 ms and a mean interference on unrelated prime trials of -22 ms. This interaction of prime type (word or x's) and prime relatedness was significant $F(1,76) = 71.32$, $p<.001$, EMS = 3099.3. Both facilitation and interference were greater in the high cue validity condition, $F(1,76) = 7.77$, $p<.01$, EMS = 3099.3, and when targets were masked, $F(1,76) = 12.91$, $p<.001$, EMS = 1561.5. In the high cue validity condition, both facilitation and interference were greater in the first block of trials, but in the low cue validity condition facilitation was only slightly greater in the first block of trials and no significant interference occured in either block $F(1,76) = 4.12$, $p<.05$, EMS = 1561.5.

Although the interaction of cue validity, prime type, prime relatedness, order of masking and blocks was not significant, Figure 1 shows that by far the greatest amount of interference occurred in the high cue validity condition when the target was masked in the first block of trials. As shown in Table 1, this interference amounted to 86 ms which was significant using a planned two tailed t-test using the corresponding error term from the analysis of variance, $t(76) = 6.96$, $p<.001$. Interference was not significant in the low cue validity condition nor was it significant in the high cue validity condition when the target was not masked, either in the first or second block of trials, $t(76) = 1.92$, nor when the target was masked in the second block, $t(76) = 1.76$.

Error Data

An analysis of error data was carried out with the same variables as for reaction time data. There was a mean error rate across the experiment of 3.1%. As shown in Table 2, in the high cue validity condition, interference was considerably increased when the target was masked in the first block of trials, but not when then the target was masked in the second block of trials. This pattern of interference is similar to reaction time data. However, significant interference was also found in errors in the low cue validity condition when the target was masked in the second block of trials.

A greater number of errors occurred across all conditions when the target was masked in the first block of trials, $F(1,76) = 7.08$, $p<.01$, EMS = 1.671. More errors occurred overall in the first block of trials, $F(1,76) = 14.60$, $p<.001$, EMS = 1.007. By far the greatest number of errors, 7.1%, occurred in the first block of trials when the target was masked, $F(1,76) = 25.03$, $p<.001$, EMS = 1.007.

Across the experiment, related prime trials and their controls had fewer errors than did unrelated prime trials and their controls, $F(1,76) = 20.58$, $p <.001$, EMS = .549. This difference was greater in the first block of trials, $F(1,76) = 5.88$, $p<.05$, EMS = .364. Unrelated prime trials and their controls had the greatest number of errors in the first block of trials when that block was masked, $F(1,76) = 32.51$, $p<.001$, EMS = .364. When targets were masked in the first block of trials, there was a tendency for more errors with word prime trials than with neutral prime trials in the high cue validity condition, but in the low cue validity condition errors were approximately equal on word prime and neutral prime trials. However, when targets were masked in the second block of trials, errors were approximately equal in word prime and neutral prime trials in the high cue validity condition but in the low cue validity condition more errors occured in word prime trials than on neutral prime trials. This interaction of cue validity, order of masking and prime type was significant, $\underline{F}(1,76) = 4.01$, $\underline{p}<.05$, EMS = .328.

Across the experiment, there was a mean facilitation with a related prime of .5% fewer errors and a mean interference with an an unrelated prime of 1.2% more errors, $\underline{F}(1,76) = 5.57$, $\underline{p}<.05$, EMS = .343.

The interaction of cue validity, prime type, prime relatedness, order of masking and blocks was again not significant, but, as shown in Table 2, interference was greatest, (3.7%) in the high cue validity condition when the target was masked in the first block of trials and in the low cue validity condition when the target was masked in the second block of trials. This interference was significant, $\underline{t}(76) = 2.95$, $\underline{p}<.001$, in both cases.

Nonword Data

Analyses of reaction times and error rates was carried out for nonword data with variables: cue validity, order of masking, prime type and blocks. Reaction time data analysed were means averaged over errorless trials.

Mean reaction time for nonwords was 845 ms. As shown in Table 3, nonword data showed effects that were consistent with word data except that masking nonword targets still had considerable effect in the second block of trials. Nonword reaction times were faster in the second block of trials, $\underline{F}(1,76) = 19.23$, $\underline{p}<.001$, EMS = 26172. Reaction times were slower for masked nonword targets compared to unmasked nonword targets in both blocks of trials, but this difference was greater when the nonwords were masked in the first block of trials, $\underline{F}(1,76) = 74.21$, $\underline{p}<.001$, EMS = 6354.6. No other main effects or interactions were significant in nonword reaction time data.

The mean error rate for nonword trials was 26.8%. More errors occurred in both blocks of trials when nonword targets were masked, but this difference was less when nonword target were masked in the first block of trials, $\underline{F}(1,76) = 91.23$, $\underline{p}<.001$, EMS = 756. No other main effect or interaction was significant.

F. Discussion

It was predicted that with a long 800 ms prime target SOA, as in previous research, interference would occur only in the high cue validity condition where subjects learn that using the prime as a cue to the target improves performance. In the low cue validity condition, it was assumed that subjects would not generate an expectancy about the identity of the target, since on most trials the prime would be a misleading cue.

Reaction time data showed, as predicted, that significant interference did not occur in the low cue validity condition. Significant interference did occur, however, in error data in the low cue validity condition when the target was masked in the second block. This evidence suggests that the difficulty involved in identifying the target when it was masked may have induced some subjects to use the prime as a cue even in the low cue validity condition.

Significant interference did not occur in the high cue validity condition when the target was not masked. At 24 ms, however, the interference found was close to significance, and consistent with other research. Neely (1977) found 62 ms interference at an SOA of 700 ms in an experiment where subjects were explicitly instructed and trained to develop an expectation for the category type of the target based on the prime. With the usual cue validity manipulation explicit instructions are not given to subjects but attention to the prime is manipulated by varying the proportion of related prime target pairs. Typically the proportion effect is relatively small (den Heyer, 1986). Den Heyer, Briand and Dannenbring (1983), for example, with an SOA of 1000 ms, found 32 ms interference in a high cue validity condition as compared to 5 ms interference in a low cue validity condition. De Groot (1984) with an SOA of 1040 ms, found 40 ms interference in a high cue validity condition as compared to 20 ms interference in a low cue validity condition.

Interference, as predicted, was much greater (86 ms) when the target was masked, but only when it was masked in the first block of trials. In previous research in this laboratory (McLeod & Walley, 1989, Experiment 2) 84 ms interference was found with a long 800 ms SOA and a 66.7 ms masked target. This evidence supports our contention that when the target was masked in the first block of trials activation of the target node was reduced enough to make it susceptible to inhibition generated by the node in memory corresponding to the expected target.

Why, then, did masking the target in the first block produce increased interference while masking the target in the second block did not? Because nonword targets were repeated less often than word targets across the experiment, the word/nonword decision required by the lexical decision task may have been easier in the second block. Balota and Chumbley (1984) have proposed that the lexical decision is based on a familiarity judgment. With word targets repeated more often than nonword targets, the original difference in familiarity between words and nonwords would become even greater across the experiment. In fact, reaction times for both words and nonwords were faster in the second block of trials. There is no reason, however, why an easier lexical decision task should affect the relative reaction times between word prime trials and neutral prime trials. It is unlikely that the decision could be made without lexical access in the second block, assuming lexical access had occurred in the first block for the same word targets.

A more likely possibility is that since targets in the second block had been repeated more than targets in the first block, this extra repetition compensated in some way for the masking procedure. Although primes were also repeated across blocks, each prime in experimental trials occurring four times in the experiment, it seems unlikely no matter what theory of priming one uses, that the repetition of primes could result in decreased interference across the experiment. On the other hand, although as discussed below, an interaction of stimulus quality, repetition and interference effects has not previously been found, there is good reason to believe it may have happened in this experiment.

In this experiment, in the unrelated prime trials, primes from the experimental list were paired with targets from other lists. In each block of trials, these unrelated targets came from a different list; for example, if the experimental list were List 1, unrelated targets in block 1 were from List 2 and in block 2 from List 3. The filler trials, however, were also drawn from lists other than the experimental list. If the experimental list were List 1, in the first block of trials the fillers were drawn from Lists 3 and 4, and in the second block of trials they were drawn from Lists 2 and 4.

Within experimental trials each unrelated target was presented twice, once with a word prime and once with a neutral prime. Because neutral and word primes occurred in random order, when an unrelated target appeared with a word prime, sometimes it had occurred before in experimental trials and sometimes it had not.

In the first block of trials, therefore, with unrelated targets from List 2 and filler trials from Lists 3 and 4, on unrelated prime trials it would be either the first or the second presentation of the target. In the second block of trials, however, when unrelated targets were taken from List 3, it would be either the second or the third presentation of the target since List 3 targets appeared in filler trials in the first block.

This additional repetition of targets in the second block may have been sufficient to compensate for masking procedures in the second block of trials, lowering the threshold of firing for the target word nodes such that less perceptual input was required for word identification. In this case, target node activation may have reached a level similar to the condition when targets were not [illegible] since the amounts of interference in these conditions i[illegible]r. In support of this interpretation, it can be noted [illegible] overall reaction times and error rates were influenced significantly more by the mask when it occurred in the [illegible] block of trials.

Tulving and Schacter (1990), in a review of repetition priming effects, suggest that evidence supports the idea that repetition has its effect on a perceptual representation system that operates at a pre-semantic level. Repetition of the target word could, therefore, be thought of as priming a set of neurons corresponding to the visual representation of the target. With sufficient repetition priming, less perceptual input would be required to activate the visual representation of the target word when the target was masked. The above explanation, of course, is not consistent with Sternberg's additive factors logic (Sternberg, 1969) according to which an interaction of repetition, priming and masking should indicate that all three factors were affecting the same stage of processing. The Tulving and Schacter theory suggests that repetition and degradation should affect processing at the visual representation stage, but that semantic priming effects should be operative at a later stage of processing in semantic memory. The Sternberg model assumes that processing at each stage is independent of processing at previous stages (Pachella, 1969), and that output from a stage is all or none. In McClelland's cascade model (1979), however, components of an information processing system operate continuously passing information on as it becomes available, not in an all or none fashion. McClelland also suggests that degrading stimulus quality may affect asymptotic levels of activation right through to the final decision stage of processing.

If masking the briefly presented target results in a lower activation level or a less complete activation of the set of neurons corresponding to the visual representation of the target, this degraded processing could be passed on to the semantic level, resulting in a lower level of activation of the node corresponding to the meaning of the target node. This lower level of activation, as previously suggested, would make the target node more succeptible to interference generated by other activated semantic nodes.

Previous research that has attempted to determine whether priming effects, stimulus quality and repetition are additive or interactive effects has produced less than conclusive results. As previously mentioned, interactions between priming effects and target degradation have been found (Becker & Killion, 1977; McLeod & Walley, 1989; Meyer, Schvaneveldt, & Ruddy, 1975). Stimulus quality and repetition have also been found to interact (Besner & Swan, 1982; Norris, 1984). However, typically, no interaction between repetition and priming effects has been found (den Heyer, 1986; den Heyer, Goring, & Dannenbring, 1985; Durgunoglu, 1986; Wilding, 1986). Durgunoglu, in fact, used masked, otherwise degraded or clearly visible targets with a prime target SOA of 700 ms, and compared priming effects on the first and second presentation of target words. She found significant interference only on masked target trials, but no significant difference in interference between first and second presentations of the target.

Den Heyer and Benson (1988) did find an interaction of repetition, priming affects and stimulus clarity at an SOA of 750 ms when the time between repetitions was short (0-7 intervening trials), but found that priming and repetition effects were additive when the time between repetitions was relatively long. As with Durgunoglu's experiment, targets were repeated only once. Targets were degraded by lowering stimulus intensity. Den Heyer and Benson, however, used only related and neutral primes so their interaction is limited to priming effects that are facilitatory.

It seems likely that the presence of an interaction between stimulus quality, repetition and priming effects could be influenced by several factors including the method and degree of target degradation, the number of repetitions, and the time interval between repetitions.

In summary, the data from the first experiment do support the theory proposed, that interference effects in a priming task result from processes of competitive lateral inhibition between nodes representing concepts in semantic memory, and that when the target is brief and masked activation of the target node is reduced enough to make it more susceptible to inhibition generated by other activated nodes. At short SOAs we have proposed that competitive inhibition is generated by the prime node. In this experiment, with a long SOA, inhibition would be generated by the node corresponding to the expected target when the target presented is unrelated to the prime.

In Experiment 2, using the same stimulus materials as in Experiment 1 and an SOA of 200 ms, an attempt was made to manipulate the activation levels of both the prime and the target by masking both primes and targets and varying prime mask and target mask SOAs orthogonally. Prime mask and target mask SOAs were 50 ms, 83.3 ms or 116.7 ms. Prime and target duration were maintained at 50 ms. It was predicted that interference would be greatest when the prime mask SOA was longer than the target mask SOA, i.e. when the effective prime duration exceeded the effective target duration.

In previous research (McLeod & Walley, 1989), no effect of cue validity manipulation on priming effects was found at short SOAs. On the assumption, therefore, that attention to the prime was irrelevant to interference effects at short SOAs, a low cue validity condition was used for all subjects.

III. EXPERIMENT 2

A. Subjects

Subjects were 60 undergraduate psychology students at the University of Alberta, 30 males and 30 females, volunteering for participation as an option for course credit. All participants were native English speakers.

B. Experimental Design

There was 1 between subject variable and 3 within subject variables in the experiment. The between subject variable was target mask SOA. Target duration in all cases was 50 ms, with a target mask SOA of 50, 83.3 or 116.7 ms. Within subject variables were prime mask SOA, prime type (whether the prime is a word or a string of x's), and prime relatedness (if the prime is a word, whether it is a strong associate of the target or not related). Prime duration was maintained at 50 ms, with prime mask SOA 50, 83.3 or 116.7 ms. Prime mask SOA was randomized. Prime target SOA on all trials was 200 ms, and cue validity was low with 25% of prime target pairs strongly related.

C. Apparatus and Procedure

Apparatus was the same as that described for Experiment 1. Procedure was the same as for Experiment 1 except for the following: prime duration was 50 msec, the prime being followed by a 33.3 ms mask of 8 #'s at an SOA of either 50, 83.3 or 116.7 ms. Prime mask SOA was varied randomly. Target duration was also 50 ms, with a 33.3 ms mask of 8 #'s following at the appropriate SOA.

Subjects were first given a block of 72 practice trials, using a different word list from those in the experimental trials. During these practice trials, the target duration was gradually shortened until it was 50 ms as in experimental trials. In trials 1-18, the target duration was 100 ms; in trials 19-36, 83.3 ms; in trials 37-54, 66.7 ms; and in trials 55-72, 50 ms.

The 288 experimental trials were given in 3 blocks of 96 trials with one minute breaks between.

D. Stimulus Materials

Stimulus materials were the same as those used in Experiment 1. Each block of 96 trials consisted of 48 experimental trials, 24 filler trials and 24 nonword trials. Each related and unrelated prime target pair and its neutral prime control appeared once in each block, each time with a different prime mask SOA. Prime mask SOAs were also varied randomly for filler trials and nonword trials.

E. Results

Reaction Time Data

An analysis of variance was carried out on reaction time data with variables: prime mask SOA, target mask SOA, prime type and prime relatedness. Data analyzed were means averaged over the errorless trials.

Mean reaction time for the experiment was 634 ms. As shown in Table 4 and Figure 2, significant interference did not occur as predicted when the prime mask SOA was equal to or greater than the target mask SOA. An unpredicted significant interference effect of 44 ms did occur when the target mask was 116.7 ms and the prime mask SOA was 83.3 ms, $t(114) = 3.18$, $p<.01$.

Related prime trials and their controls had significantly shorter reaction times than did unrelated primes and their controls (627 ms vs 640 ms), $F(1,57) = 7.27$, $p<.01$, EMS = 3783.9 Across the experiment, there was a mean facilitation of only 3 ms with a related prime and mean interference of -21 ms with an unrelated prime, $F(1,57) = 9.02$, $p<.01$, EMS = 3014.8. No other main effect or interaction was significant.

Error Data

Mean error rate across the experiment was 7.1% As shown in Figure 3 and Table 5, interference was not consistently greater when the prime mask SOA was equal to or greater than the target mask SOA. Fewer errors occurred in related prime trials and their controls than in unrelated prime trials and their controls (5.9% vs 8.3%), $F(1,57) = 10.32$, $p<.01$, EMS = 1.455. More errors occured on word prime trials than on neutral prime trials (7.9% vs 6.3%), $F(1,57) = 10.08$, $p<.01$, EMS = .675. Across the experiment, on average there were 3.0% more errors on unrelated prime trials than on their neutral prime control trials. No facilitation as indicated by fewer errors was shown with a related prime. On average, related prime trials showed .3% more errors than neutral prime trials. This interaction of prime type and prime relatedness was signifcant, $F(1,57) = 7.86$, $p<.01$, EMS =.594.

Fewer errors occurred as the target mask SOA became longer, $F(2,57) = 22.54$, $p<.001$, EMS = 5.038 Error rates at the 50, 83.3 and 116.7 ms target mask SOAs were 13.6%, 4.5 % and 3.1% respectively.

There was a tendency for fewer errors with the shortest prime mask SOA, $F(2,114) = 4.55$, $p<.05$, EMS = .750 Error rates at the 50, 83.3 and 116.7 ms prime mask SOAs were 6.0%, 8.0% and 7.2% respectively.

No other interaction was significant.

Nonword Data

Analyses of reaction times and errors on nonword trials was carried out with variables: prime mask SOA, target mask SOA and prime type. Reaction time data analysed were means averaged over the errorless trials. As shown in Table 6, these analyses showed effects that were consistent with results for word targets.

Mean reaction time for nonword trials was 872 ms. Nonword reaction times were faster for word prime trials than for neutral prime trials, $F(1,57) = 19.55$, $p<.001$, EMS = 7983.3. No other main effect or interaction was significant for onword trial reaction times.

Mean error rate for nonwords was 26.8%. The error rate decreased as target mask SOA increased, $F(2,57) = 11.85$, $p<.001$, EMS = 12.572. Error rates were higher for nonword trials when the prime was a word than when it was a neutral prime, $F(1,57) = 21.02$, $p<.001$, EMS = 1.872. No other main effect or interaction was significant for nonword error rates.

F. Discussion

In Experiment 2, an attempt was made to manipulate the amount of interference associated with an unrelated prime by varying orthogonally prime mask SOA and target mask SOA. It was hypothesized that when the prime mask SOA was longer than the target mask SOA, significant interference would occur because under these conditions, nodes in semantic memory corresponding to prime concepts would be activated more strongly than target concept nodes, and would, therefore, generate inhibition greater than that generated by the target node.

Data from Experiment 2 did not support this hypothesis. However, there are reasons why the activation of the prime node in this experiment may not have been strong enough to generate sufficient inhibition.

First, activation of the prime node may be presumed to decay as a function of prime target SOA (McLeod & Walley, 1989). By the time the target was presented, therefore, activation of the prime node may have decayed to a level which was not competitive with target node activation.

Second, in these experiments, the prime appeared immediately above a central fixation point, while the target appeared immediately below it. Both spatial and temporal cues were, therefore, available to subjects to assist them in distinguishing the target from the prime. The theory of priming proposed is fairly simple, and does not include an explanation of how these spatial and temporal cues could be integrated into a decision process. However, it is possible that these cues might result in greater activation of the target node, giving it a competitive edge.

Third, a low cue validity condition was used, with only 25% of prime words serving as valid cues to the target. It was expected, therefore, that subjects were not attending to the prime in a spatial sense nor were they consciously processing the prime at the semantic level. It is probable, however, that attention to a prime could affect the level of activation of the set of neurons corresponding to it, and therefore affect the amount of interference associated with an unrelated prime.

In earlier research (McLeod & Walley, 1989), no effect of a cue validity manipulation was found on priming effects at short prime target SOAs with a brief masked target. Significant interference occurred in all cue validity conditions: high, medium and low. We suggested that at short prime target SOAs there was not enough time for subjects to develop an expectation regarding the identity of the target based on the prime. Evidence from our Experiment 1 and from Neely (1977) suggests that it may take approximately 400 ms for such an expectation to develop. We, therefore, suggested that at short prime target SOAs, subjects were perhaps not attending to the prime in any cue validity condition, and that such attention may not be necessary for significant inhibition to occur.

This suggestion, however, may be incorrect. It is possible that subjects in all cue validity conditions were attending to the prime at short SOAs. Perhaps the unmasked prime of 200 ms duration used in those experiments produced sufficient activation to result in involuntary attention to the prime. An alternate explanation might be that subjects voluntarily attended to the prime because 25% cue validity is better than no cue validity at all.

Den Heyer, Briand and Dannenbring (1983) found no effect of cue validity with a 75 ms prime target SOA when both prime and target remained on the monitor screen until the subject's response. As previously found, however, (Tweedy & Lapinski, 1981; Tweedy, Lapinski & Schvaneveldt, 1977), priming effects were greater with a high cue validity than a low cue validity condition at longer prime target SOAs. Den Heyer et al. concluded that the proportion effect was mediated by attention driven factors not present at short SOAs.

However, what is true of priming effects with a long target duration has been shown not to be true when targets are brief and masked. Possibly primes may be more useful or necessary as cues to the target when targets are difficult to distinguish, and therefore attention may be paid to the prime even in a low cue validity condition.

In consideration of the above factors, in Experiment 3 a wider range of prime mask SOAs were used. It was hoped that the longer prime mask SOA would compensate for the decay of prime activation over prime target SOA, and for the spatial and temporal cues available which may feed greater activation into the target node. In addition, an attempt was made to manipulate attention to the prime using a cue validity manipulation.

IV. EXPERIMENT 3

A. Subjects

Subjects were 40 undergraduate psychology students at the University of Alberta, 14 males and 26 females, who volunteered for participation as an option for course credit. All participants were native English speakers.

B. Experimental Design

There were 1 between subjects variable and 3 within subject variables in the experiment. The between subjects variable was cue validity. which was either high, with 75% of all prime target pairs strongly associated, or low, with only 25% of prime target pairs strongly related. As in Experiment 2, within subject variables were prime mask SOA, of which there were 3 levels, prime type and prime relatedness.

C. Apparatus and Procedure

Apparatus was the same as in Experiment 1 and 2. Procedure was the same as for Experiment 2 except for the following: Prime mask SOAs were either 50, 100 or 200 ms. Target mask SOA was invariably 50 ms. As in Experiment 2, prime and target duration were held constant at 50 ms. Subjects were informed of the proportion of word trials that would consist of related pairs. Cue validity in the practice trials was the same as in the main experiment.

D. Stimulus Materials

Stimulus materials were the same as those used in Experiment 2.

E. Results

Reaction Time Data

An analysis of variance was carried out on reaction time data with variables: cue validity, prime mask SOA, prime type and prime relatedness. Data analyzed were means averaged over the errorless trials. Approximately 6 subjects who made over 15 errors in the last 24 practice trials were excluded from the experiment. Data from approximately 8 subjects who made errors on two thirds or more nonword trials were discarded.

Mean reaction time for the experiment was 687 ms. As shown in Table 7 and Figure 4, interference was greatest in the high cue validity condition with the 200 ms prime mask SOA.

Related prime trials and their controls were, on average, 34 ms faster than trials involving unrelated primes and their controls (670 ms vs 704 ms), $F(1,38) = 23.55$, $p<.001$, EMS = 5871.3. Mean facilitation with a related prime was 24 ms and mean interference with an unrelated prime was -12 ms across the experiment, $F(1,38) = 14.29$, $p<.001$, EMS = 2800.3. Apparently, reaction times were shorter overall as prime mask SOA became longer, $F(2,76) = 4.20$, $p<.05$, EMS = 4313.1.

Priming effects were larger overall in the high cue validity condition, $F(1,38) = 5.12$, $p<.05$, EMS = 2800.3. where mean facilitation with a related prime was 28 ms and mean interference with an unrelated prime was -31 ms. In the low cue validity condition, mean facilitation with a related prime was 21 ms and unrelated prime trials showed a mean 'facilitation' of 7 ms. As can be seen in Table 7 and Figure 4, in the high cue validity condition, interference associated with an unrelated prime increased as prime mask SOA became longer. This interaction of cue validity with prime mask SOA, prime relatedness, and prime type was also significant, $F(2,76) = 3.95$, $p<.05$, EMS = 3166.2. By t-test, the 56 ms interference in the high cue validity condition with the 200 ms prime mask SOA was significant, $t(76) = 3.15$, $p<.01$. Interference was not significant in any other condition.

Data for low cue validity trials do not show significant interference with an unrelated prime at any prime mask SOA. Low cue validity data, however, seemed quite difficult to interpret, particularly priming effects in the 200 ms prime mask SOA condition which showed a mean 3 ms facilitation with a related prime, and a mean 37 ms facilitation with an unrelated prime.

Error Data

The mean error rate across the experiment was 7.9%. As shown in Table 7 and Figure 5, interference was greatest in the high cue validity condition at longer prime mask SOAs.

There were 5.7% errors on related prime trials and their controls as compared to 10.1% errors on unrelated prime trials and their controls, $\underline{F}(1,38) = 18.28$, $\underline{p}<.001$, EMS = 1.838. Overall mean facilitation with a related prime was .9% fewer errors and mean interference with an unrelated prime was 3.3% more errors, $\underline{F}(1,38) = 9.69$, $\underline{p}<.01$, EMS = .800. As in reaction time data, priming effects were greater in the high cue validity condition, $\underline{F}(1,38) = 5.75$, $\underline{p}<.05$, EMS = .800, where mean facilitation with a related prime was 1.8% fewer errors, and mean interference with an unrelated prime was 5.7% more errors. In the low cue validity condition, there was no facilitation with a related prime and mean interference with an unrelated prime was 1.0% more errors. An interaction of prime relatedness with prime mask SOA, $\underline{F}(2,76) = 4.31$, $p<.05$, EMS = .710, was difficult to interpret and may indicate a Type 1 error: unrelated prime trials and their controls consistently had more errors than related prime trials and their controls, but this difference was 2.0%, 6.5% and 4.7% with the 50, 100 and 200 ms prime mask SOAs respectively.

At the 50 ms prime mask SOA, neutral prime trials had 1.2% more errors than word trials, but at the 100 ms and 200 ms prime mask SOAs word trials had 2.2% and 2.7% more errors respectively than neutral prime trials, indicating an increase in interference with increasing prime mask SOA, $\underline{F}(2,76) = 4.56$, $\underline{p}<.05$, EMS = .533.

The interaction of cue validity with prime mask SOA, prime relatedness and prime type was not significant. However, as shown in Table 7, at longer prime mask SOAs, there was greater interference in the high cue validity condition than in the low cue validity condition. In the high cue validity condition, interference was significant at the 100 ms prime mask SOA, $\underline{t}(76) = 4.02$, $\underline{p}<.001$, and at the 200 ms prime mask SOA, $\underline{t}(76) = 3.81$, $\underline{p}<.001$. Interference was not significant in any other condition.

Nonword Data

Analyses of reaction times and error rates were carried out on nonword data with variables: cue validity, prime mask SOA and prime type. Reaction time data analysed were means averaged over the errorless trials.

Mean nonword reaction time for the experiment was 984. No main effect or interaction was significant in nonword reaction time data. See Table 8.

Mean error rate for nonword trials was 40.6%. As shown in Table 8, more nonword errors occurred when the prime was a word than when it was a neutral prime, $\underline{F}(1,38) = 5.28$, $\underline{p}<.05$, EMS = 2.135. No other main effect or interaction was significant in error rates for nonword trials.

F. Discussion

Both reaction time data and error data provide support for the hypothesis that interference increases with prime mask SOA in the high cue validity condition In reaction time data, significant interference occurred only with the long prime mask SOA, with some indication that it increased with prime mask SOA. In error data, significant interference occurred at the two longest prime mask SOAs. In the low cue validity condition, no significant interference occurred in either reaction time or errors and there was no indication of an interaction of priming effects with prime mask SOA.

In previous research (McLeod & Walley, 1989) when a prime of 200 ms duration was not masked, strong interference effects were found in both high and low cue validity conditions in both reaction time and error data. The evidence may imply that, because activation of the prime node decays with prime target SOA, the prime node must be highly activated initially in order to be still generating inhibition at the time when the target node becomes activated. It may be that if the prime is unmasked and the target is brief and masked, sufficient activation of the prime node occurs to produce inhibition with or without attention to the prime. However, when the prime is masked, and therefore less highly activated, attention to the prime is required to provide enough activation to produce significant interference.

Alternatively, when the prime was not masked, subjects may have been attending to the prime in both cue validity conditions. As suggested earlier, even the 25% cue validity provided some cues to unclear targets, an improvement over no cues. When the prime was masked, however, subjects may have been discouraged from paying attention to the prime not only by the low cue validity but by the difficulty of identifying the masked primes at short prime mask SOAs.

It should be noted, as well, that in this experiment, the attention manipulation may have been less effective than is than is normally the case if subjects were not aware of the relationship between the prime and the target on some trials. On at least one third of word trials when the prime mask SOA was only 50 ms, the prime was difficult to identify and the relationship between prime and target less clear. Even so, a strong interaction of priming effects with cue validity was found.

In order to obtain the full benefit of the cue validity manipulation, and, as well, in order to evaluate more clearly the relative contributions of attention and prime mask SOA to interference effects, the same experiment was run again, but with prime mask SOA blocked. Prime mask SOA either increased or decreased across blocks and cue validity was either high or low.

V. EXPERIMENT 4

A. Subjects

Subjects were 80 undergraduate psychology students at the University of Alberta, 25 males and 55 females, volunteering as an option for course credit. All participants were native English speakers.

B. Experimental Design

The design was the same as in Experiment 3 with the addition of another between subjects factor which was order of prime mask SOA. This variable indicated whether prime mask SOA increased or decreased across the 3 blocks of trials.

C. Apparatus and Procedure

Apparatus was the same as that used in the previous three experiments. The procedure was the same as for Experiment 3 except that prime mask SOA was not varied randomly but was blocked. For half of the subjects, prime mask SOA was 200 ms in the first block, 100 ms in the second block, and 50 ms in the third block (decreasing prime mask SOA condition). For the other half of the subjects, prime mask SOA was 50 ms in the first block, 100 ms in the second block and 200 ms in the third block (increasing prime mask SOA condition). Cue validity (high or low) was varied orthogonally with this factor.

D. Stimulus Materials

Stimulus materials were the same as those used in previous experiments.

E. Results

Reaction Time Data

An analysis of variance was carried out on reaction time data with variables: cue validity, order of prime mask SOA, blocks, prime type and prime relatedness. Five subjects who made over 15 errors in the last 24 practice trials were excluded from the experiment. Data from 10 subjects who made errors on two thirds or more nonword trials were deleted. Data analyzed were means averaged over the errorless trials.

Mean reaction time for the experiment was 834 ms, a full 147 ms longer than for Experiment 3. As shown in Table 9 and Figure 6, in both the increasing and decreasing prime mask SOA conditions, interference occurred only in the high cue validity condition. In the decreasing prime mask SOA condition, results replicated Experiment 3 with interference only with the 200 ms prime mask SOA. However, as shown in Figure 7, the increasing prime mask SOA condition showed an unusual pattern of results, with interference occurring only with the 50 ms prime mask SOA.

Across the experiment, related prime trials and their controls were, on average, 34 ms faster than unrelated prime trials and their controls (817 vs 851 ms), $F(1,76) = 54.26$, $p<.001$, EMS = 5092.9. This difference was greater for the high cue validity condition than the low cue validity condition (55ms vs 13 ms), $F(1,76) = 20.91$, $p<.001$, EMS = 5092.9. Word trials were on average 13 ms faster than neutral prime trials (828 vs 841 ms), $F(1,76) =$ [illegible], $p<.05$, EMS = 7335.1. Across the experiment, there was 35 ms facilitation associated with a related prime and -9 ms interference associated with an unrelated prime, $F(2,152) = 23.13$, $p<.001$, EMS = 4871.7.. Again, priming effects were greater in the high cue validity condition, $F(1,76) = 9.97$, $p<01$, EMS = 4871.7. Mean facilitation associated with a related prime was 46 ms and mean interference associated with an unrelated prime was -26 ms in the high cue validity condition compared to 25 ms mean facilitation with a related prime and 10 ms mean facilitation with an unrelated prime in the low cue validity condition.

Reaction times became shorter in successive blocks, $F(2,152) = 33.77$, $p<.001$, EMS = 14616. Blocks also interacted significantly with prime type $F(2,152) = 3.33$, $p<.05$, EMS = 3126.8, with word prime trials 1 ms, 16 ms, and 23 ms faster than neutral prime trials in the first, second and third blocks respectively, reflecting the decreased interference across blocks. No other main effects or interactions were significant.

As shown in Figure 6 and Table 9, in the decreasing prime mask SOA condition, with high cue validity, a large interference effect occurred in the first block of trials (200 ms prime mask SOA), but not in successive blocks of trials with shorter prime mask SOAs. This interference was significant by t-test, $t(152) = 3.60$, $p<.001$. No significant interference occurred in the low cue validity condition.

As shown in Figure 7 and Table 9, however, an unexpected pattern of interference occurred in the increasing prime mask SOA condition. Again, no significant interference occurred in the low cue validity condition. However, in the high cue validity condition, significant interference again occurred in the first block of trials (50 ms prime mask SOA) $t(152) = 3.16$, $p<.01$, and not in successive blocks of trials with longer prime mask SOAs. As can be seen in Figure 6, no significant interference occurred in the 200 ms prime mask SOA condition.

Error Data

An analysis of variance of error data was carried out using the same variables as for reaction time data. Mean error rate across the experiment was 9.6%. As shown in Table 10 and Figures 8 and 9, a pattern of effects similar to that found in reaction time data was found. In the decreasing prime mask SOA condition, data appeared similar to Experiment 3: interference was found with both the 100 and 200 prime mask SOAs. However, in the increasing prime mask SOA condition, again interference occurred only with the 50 ms prime mask SOA. Again, it appeared that interference was greatest in the first block of trials and less apparent in later blocks. In fact, in error data, interference occurred even in the low cue validity condition in the first block of trials in both the increasing and decreasing prime mask SOA conditions.

Across the experiment 3.6% fewer errors occurred in related prime trials and their controls as compared to unrelated prime trials and their controls, $F(1,76) = 18.43$, $p<.001$, EMS = 2.353. There were, on average, 3.0% fewer errors with a related prime and 4.9% more errors with an unrelated prime, $F(1,76) = 41.02$, $p<.001$, EMS = 1.297. As in reaction time data, priming effects were greater in the high cue validity condition, $F(1,76) = 8.03$, $p<.01$, EMS = 1.297. with 5.3% fewer errors associated with a related prime and 6.0% more errors associated with an unrelated prime. In the low cue validity condition 0.5% fewer errors were associated with a related prime and 3.8% more errors were associated with an unrelated prime.

More errors occurred in the first block (11.6%) as compared to the second and third blocks (8.8% and 8.4% errors respectively) $F(2,152) = 8.64$, $p<.001$, EMS = 1.635. There was a difference in error rates between related prime trials and their controls and unrelated prime trials and their controls of 4.2%, 4.8% and 1.6% respectively in the three blocks $F(2,152) = 3.12$, $p<.05$, EMS = 1.060. In the first and second blocks, 3.4% and 1.2% more errors were associated with word prime trials than neutral prime trials but 1.5% fewer errors with word prime trials in the third block, $F(2,152) = 8.25$, $p<.001$, EMS = .839. Data indicated increased facilitation with a related prime and decreased interference from an unrelated prime across blocks, F(2,152) = 4.33, p<.05, EMS = .945. No other main effect or interaction was significant.

As shown in Figure 8 and Table 10, in the decreasing prime mask SOA condition, interference occurred in the high cue validity condition in the first block (200 ms prime mask SOA), t(152) = 5.21, p<.001, and in the second block (100 ms prime mask SOA), t(152) = 2.44, p<.05. Interference was also significant in the first block of trials in the low cue validity condition, t(152) = 2.77, p<.01.

In the increasing prime mask SOA condition, as shown in Table 10 and Figure 9, interference was significant in the high cue validity condition in the first block (50 ms prime mask SOA), t(152) = 3.42, p<.001, and in the low cue validity first block as well, t(152) = 3.42, p<.001. Significant interference did not occur at any other prime mask SOA in this condition.

Nonword Data

Analyses of variance were carried out on reaction times and error rates for nonword trials with variables: cue validity, order of prime mask SOA, blocks and prime type. Reaction time data analysed were means averaged over the errorless trials.

Mean reaction time for nonword trials was 1.141 ms. As shown in Table 11, nonword reaction times were longer in the high cue validity condition, F(1,76) = 4.35, p<.05, EMS = 251600, and tended to become shorter across blocks, F(2,152)

= 24.66, p<.001, EMS = 19442.

Mean nonword error rate across the experiment was 36.7%. As shown in Table 11, Error rates were higher when the prime was a word compared to when it was a neutral prime, F(1,76) = 18.92, p<.001, EMS = 3.489. Fewer errors occurred across blocks, F(2,152) = 16.85, p.001, EMS = 2.481. Although this decrease in errors across blocks tended to occur in both the increasing and decreasing prime mask SOA conditions, in the increasing prime mask SOA condition there was a sharp decrease in errors between the first and second blocks which did not occur in the decreasing prime mask SOA condition, F(2,152) = 6.62, p<.01, EMS = 1.002.

F. Discussion

As stated earlier, in the decreasing prime mask SOA condition, the results of Experiment 4 replicate the results found in Experiment 3. Again significant interference in reaction time was found only in the high cue validity condition, and only when the prime mask SOA was 200 ms. In error rates, significant interference occurred with both the 100 and 200 ms prime mask SOAs in the high cue validity condition.

These results suggest that the cue validity manipulation was equally effective in Experiment 3 and Experiment 4 even though in Experiment 3 identification of the prime was difficult in the 50 ms prime mask SOA condition. One unexpected result in the decreasing prime mask condition was the significant interference shown in error rates in the low cue validity condition when the prime mask SOA was 200 ms. This effect will be discussed later.

The increasing prime mask SOA condition, however, showed a quite unexpected pattern of results. Again, in reaction time data, significant interference occurred only in the high cue validity condition, but this time it occurred only with the 50 ms prime mask SOA. Error rates in the high cue validity condition also showed significant interference only with the 50 ms prime mask SOA. Furthermore, in the low cue validity condition error rates also showed significant interference with the 50 ms prime mask SOA.

What is common to the two patterns of interference is that in all cases interference tended to occur in the first block of trials. In the decreasing prime mask SOA condition, in the first block of trials the prime mask SOA was 200 ms; in the increasing prime mask SOA condition, in the first block of trials the prime mask SOA was 50 ms. How can this apparent effect of blocks be explained?

Again, as in Experiment 1, it seems reasonable to propose that this decrease in interference across blocks is an effect of target repetition. As in Experiment 1, unrelated targets in blocks of trials after the first block, had previously appeared in filler trials. In block 2, unrelated targets had previously appeared in block 1; in block 3, they had previously appeared in both blocks 1 and

2. Therefore, since, in experimental trials, the target sometimes appeared first with the neutral prime and sometimes first with the unrelated prime, in block 1 unrelated targets had previously been presented once or not at all. In block 2, they had been presented once or twice. In block 3, they had been presented twice or three times. Apparently the effect of even one extra repetition of the target was enough to compensate for most of the effect of masking on target node activation, although significant interference did occur in the second block in error data with the high cue validity condition and decreasing prime mask SOA. With 2 extra repetitions, by the third block, no evidence of interference was found even with the 200 ms prime mask SOA. As mentioned earlier, Schacter and his colleagues (Tulving & Schacter, 1990; Schacter, in press) have proposed that repetition priming effects are taking place in a perceptual representation system. Masking a brief word stimulus may greatly reduce activation or cause incomplete activation of the set of neurons corresponding to the perceptual representation of the target, and this degraded encoding would then be passed on to the semantic level so that the node in semantic memory corresponding to the meaning of the target node would also be activated at a reduced level. Repetition priming would increase activation of the perceptual representation, lowering its threshold such that less perceptual input would be required for full activation. With enough repetition priming even the reduced

input from a brief masked prime would be sufficient for full activation of the perceptual representation, and this full activation would be passed on to the semantic level. Even when prime node activation increased across blocks in the increasing prime mask SOA condition, target node activation was apparently increased enough by repetition priming at the perceptual level to compensate.

This still leaves the question of why significant interference occurred with the 50 ms prime mask SOA in the first block of this experiment when it did not occur in Experiment 3 in the same condition. Significant interference did not occur in Experiment 4 with the 50 ms prime mask SOA in the last block because of the repetition of unrelated targets. A post hoc analysis of reaction time data from Experiment 3 using blocks as a variable gave no evidence for interference in the first block of trials in the 50 ms prime mask SOA condition. Blocks was not used in the original analysis as a variable since that left only four possible data points per cell. The answer that suggests itself is that with the prime mask SOA blocked, subjects were able to develop strategies for making use of the prime as a cue to the target even when the prime was perceptually available for only 50 ms. When prime mask SOAs occurred randomly, subjects were apparently unable to make use of primes at shorter prime mask SOAs.

Comstock (1973) also provides evidence that subjects can develop strategies for attending to very briefly presented stimuli if they are required to do so. In her experiment, she assessed the amount of attention allocated at different times in a letter matching task by measuring the degree of interference in reaction times to an auditory probe. When the first letter presented was of only 15 ms duration and followed at an SOA of 100 ms by a mask, interference was found to auditory probes presented simultaneously with the first letter. This interference rose sharply during the first 50 ms after the onset of the letter. In a condition where the first letter was not masked, no increase in reaction times to probes was found until 100 ms after the onset of the first letter. In similar studies, Posner and Klein (1973) found with an unmasked exposure duration of 50 ms that interference to probes did not occur until 150 ms after the onset of the first letter. With longer durations of the first letter (150, 500 or 1000 ms), no interference to the probe was found even 150 ms after the onset of the first letter. In all of these studies, the duration or the masking of the first letter was blocked.

Comstock suggests that in the masked condition, subjects were forced to begin encoding the visual stimulus as soon as it appeared, whereas in the unmasked condition, they could attend to the auditory probe first and then return attention to the letter. Posner (Posner & Snyder, 1975a; Posner, 1978) interprets these findings as indicating that the central processor can be flexible in allocating attention at a particular time, if there is a good time cue, depending on the requirements of the experiment. It is not time locked to an external event.

The above argument does not contradict the original hypothesis that with shorter prime mask SOAs the node in memory corresponding to the prime would be less highly activated and would, therefore, generate less inhibition of the target node. In fact, without compensatory strategies, this is what appears to have happened in Experiment 3, where significant interference in response times occurred only with the 200 ms prime mask SOA, while significant interference in errors occurred with both the 200 and 100 ms prime mask SOAs. With consistent prime mask SOAs, however, subjects could apparently use attentional strategies which increased activation of the prime. This increased activation was apparently sufficient to produce inhibition.

A further unexpected result in Experiment 4 was the significant interference in errors that occurred in both the increasing and decreasing prime mask SOA conditions in the first block of trials in the low cue validity condition Subjects were told what proportion of primes and targets were related in these experiments, but they were never instructed to pay attention or not to pay attention to the prime. It seems likely that at the beginning of the experiment, subjects tended to pay attention to the prime even in the low cue validity condition until they learned that such attention was detrimental to their performance.

It is of note that the above effect as well as the significant interference found with the 100 ms prime mask SOA in error data but not in response times suggests that error rates may be a more sensitive measure of priming interference than response times. It is not entirely clear why this should be so. Error rate interference indicates a higher proportion of nonword reponses to word targets or nonresponses to word targets on unrelated prime trials as compared to neutral prime trials. Any response time over 2 s was counted as a nonresponse. Although all targets were of relatively high word frequency (mean word frequency of 81 across the 4 lists), they did vary considerably in frequency. Possibly lower frequency targets were more susceptible to interference especially from high frequency primes. This may have resulted in errors or very long response times which would count as errors, whereas higher frequency targets in the same conditions were not affected strongly enough to result in significant reaction time interference. This, again, is an hypothesis that will be tested in future research.

VI. General Discussion

The four experiments described here were conducted as tests of a theory of priming proposed by McLeod and Walley (1989) in which interference effects associated with unrelated primes are attributed to processes of competitive lateral inhibition between nodes corresponding to concepts in semantic memory. According to this theory, the more strongly activated a node is, the more strongly it will tend to inhibit other nodes, and, thus, a more strongly activated node will win out over other activated nodes in the competition for response mechanisms. At short SOAs in a priming task there will be competitive lateral inhibition between the nodes corresponding to the prime and the target; at longer SOAs in a condition where there is a high proportion of related primes and targets, competition will be between the node corresponding to the expected target and the node corresponding to the target actually presented when it is unrelated to the prime.

It was further suggested that at short SOAs interference has not normally been found, because by the time the target is presented, activation of the prime node has already considerably decayed. However, when the target is brief and masked, activation of the target node is considerably reduced making it more susceptible to inhibition generated by the prime.

In Experiment 1, it was hypothesized that if brief targets were masked in a priming experiment with a long prime target SOA, the interference normally found in a high cue validity condition on unrelated trials would be considerably increased. This hypothesis was confirmed in Block 1, where interference increased from -24 ms to -86 ms when the 50 ms target was masked. In Block 2, there was no difference in interference in the masked and unmasked target conditions and it was suggested that repetition of target words in the second block may have compensated for the effect of the mask, priming the target node or perhaps the node corresponding to the perceptual representation of the target such a way that target nodes were equally competitive with expected target nodes in both masked and unmasked conditions.

In Experiment 2, an attempt was made with a short prime target SOA to vary the activation level of both the prime and target nodes by masking both prime and target at different stimulus mask SOAs. It was hypothesized that interference should occur only when the prime mask SOA was longer than the target mask SOA. Low cue validity was used because in previous research equal interference had occurred in both high and low cue validity conditions. In this experiment, with prime and target mask SOAs of 50, 83.3 and 116.7 ms, interference did not occur as predicted. In Experiment 3, target mask SOA was maintained at 50 ms and prime mask SOA was 50, 100 or 200 ms, with a cue validity manipulation. In this experiment, interference occurred in reaction time data with the 200 ms prime mask SOA and in error data with both the 100 and 200 ms prime mask SOAs, in both cases only in the high cue validity condition when attention was presumably being paid to the prime.

The results of Experiment 3 confirm the predictions of the model of priming we have proposed: that interference would occur when prime mask SOA was longer than target mask SOA. However, it is of note that in previous research we have found that when a prime of 200 ms duration was not masked but the target was brief and masked, equally great interference occurred in both high and low cue validity conditions. Here, with a masked prime, even at a prime mask SOA of 200 ms, attention to the prime was apparently necessary for interference to occur. Evidently without attention to the prime, prime node activation was not great enough to generate significant inhibition.

In previous research (McLeod & Walley, 1989), we have suggested that at short prime target SOAs there would not be enough time for subjects to generate an expectancy for the target based on the prime as a cue. Evidence from our research (McLeod & Walley, 1989, Experiment 1) and from Neely (1977) suggested it might take as long as 400 ms for subjects to generate an expectancy. We suggested, therefore, that perhaps at short prime target SOAs the cue validity manipulation did not work as subjects quickly learned that there was not enough time to use the prime as a cue to the target and therefore they did not pay attention to the prime in either cue validity condition. However, Experiment 3 gives clear evidence that the cue validity manipulation does work at short prime target SOAs. Exactly why it works is not so clear. It seems unlikely that subjects can generate an expectation at such a short SOA, but perhaps with attention to the prime, related target nodes are facilitated more and/or earlier than with unattended primes. On average, however, across conditions, there was only 7 ms more facilitation from a related prime in the high cue validity condition.

In Experiment 4, when prime mask SOA was blocked in either an increasing or decreasing order, evidence was again found that repetition of the targets may compensate for target masking. Interference in both orders was greatest in the first block of trials and no significant interference occurred in subsequent blocks except in errors in one condition. Again, no significant response time interference was found in the low cue validity condition.

In the decreasing prime mask SOA condition, as in Experiment 3, significant interference was found with the 200 prime mask SOA in reaction time, and with both the 100 and 200 ms prime mask SOA in error data. In addition, however, in the increasing prime mask SOA condition, significant interference was found with high cue validity in the 50 ms prime mask SOA condition indicating that when prime mask SOA is blocked, subjects can develop strategies for using the prime as a cue to the target even when the prime is perceptually available for only 50 ms.

From these experiments and earlier research the following conclusions can be drawn:

(1) Significant interference occurs at short prime target SOAs when the target is brief and masked.

(2) At long SOAs, the interference normally found in the high cue validity condition is considerably increased when a brief target is masked.

(3) At short SOAs, when the target is brief and masked and the prime is of 200 ms duration and not masked, equally large interference effects are found in both high and low cue validity conditions (McLeod & Walley, 1989), indicating that apparently attention to the prime is not necessary to produce these large interference effects. However, when a prime of 50 ms duration is masked with prime mask SOAs varied randomly, significant interference does not occur in the low cue validity condition, and, in the high cue validity condition occurs only when the prime mask SOA is considerably longer than the target mask SOA.

(4) When prime mask SOAs are blocked, however, in the high cue validity condition interference occurs when prime mask SOA and target mask SOA are equal.

All of this evidence is consistent with a model of priming involving competitive lateral inhibition between nodes in semantic memory representing concepts. Masking the prime or the target appears to considerably reduce the activation level of the corresponding node in memory, making it more susceptible to interference from other activated nodes. Thus, when a brief target is masked at a short SOA the target node becomes more susceptible to inhibition by the prime node. In a high cue validity condition at long SOAs when the brief target is masked it becomes more susceptible to interference generated by the node corresponding to the expected target. If the prime is also masked at short prime target SOAs, activation of the prime node is also considerably reduced and it is no longer competitive with the target node except when attention is paid to the prime and there is a long prime mask SOA. However, when prime mask SOAs are blocked, attentional strategies may increase activation of the prime node such that the prime node can be competitive with a target node even when prime and target mask SOAs are equal. Exactly how these different factors may affect the activation level of a node will be discussed later.

<u>Other Theories of Priming</u>

The Posner and Snyder Two Process Theory of Attention: The data from these experiments are consistent with the proposed competitive lateral inhibition theory, but can the Posner and Snyder two process theory of attention also account for them? Originally it was predicted from the Posner and Snyder theory that interference in a priming study should occur only at long prime target SOAs when the subject was directing attention to the prime. Facilitation, on the other hand, should occur at all SOAs and whether or not attention is paid to the prime. Evidence of this difference between facilitation and interference effects has been taken as support for the two processes proposed (e.g. Neely, 1977). The conscious attentional mechanism was said to move slowly and therefore to take time in moving from the node corresponding to the prime to the node corresponding to the unrelated target, an additional assumption being the Collins and Loftus (1975) model of semantic memory in which unrelated nodes are farther apart than related nodes (Neely, 1977; Posner, 1978). It was this additional time to move to the unrelated target node that accounted for the interference effect at long SOAs when attention was paid to the prime.

An additional assumption was that commitment of attention to the prime took time. This accounted for the lack of interference at short SOAs in the attention condition. It was not exactly clear, however, why it took time to commit attention to the prime. In fact, as shown in this and earlier research, it does not take subjects long to commit attention to a briefly presented target. Possibly it was thought that the attentional mechanism had to move to the node representing the prime from wherever it was before, and that this was a slow process.

As mentioned above, however, Posner (Posner & Snyder, 1975a; Posner, 1978) has proposed that, depending on the experimental conditions, subjects may be able to commit attention earlier, even at the onset of the stimulus. With this additional assumption the Posner and Snyder theory can account for the presence of interference at short SOAs which occurred in our previous research and in Experiments 3 and 4 in the high cue validity condition. However, it is not clear from their theory why sometimes it takes time to commit attention while at other times attention can be committed very quickly. Surely, even when the target is clearly discernable it would improve performance if subjects committed their attention to the prime early, but typically in these conditions interference is not found at SOAs shorter than 400 ms. Furthermore, in Neely's (1977) study, subjects in all conditions were instructed and trained to use the prime as a cue to the target, and yet, apparently, these instructions did not induce them to commit attention early when SOAs were short. If it is a question of the time it takes to move the attentional mechanism from where it previously was to the node representing the prime, why should the attentional mechanism move slowly on some occasions and more quickly on others?

In previous research, we also found that interference occurred at short SOAs in a condition of low cue validity. In order for the Posner and Snyder theory to fit these data it must be assumed that subjects did, in fact, try to use the prime as a cue to the target even in the low cue validity condition, even though it interfered with performance on 75% of word trials.

With these additional assumptions, the Posner and Snyder theory will fit the data of previous experiments and of Experiments 3 and 4. It can be assumed in Experiment 3 that subjects required 200 ms to commit attention to the prime, and therefore interference did not occur when the prime mask SOA was shorter than that. In Experiment 4, it can be assumed that when the prime mask SOA was blocked, subjects were able to commit attention to the prime even faster and therefore interference could occur in the 50 ms prime mask SOA condition. If the time taken for the commitment of attention is completely flexible and variable, interference at any SOA can be explained by the Posner and Snyder theory, but then it is not entirely clear why it has been consistently found that when the target is clearly discernable, interference does not occur before an SOA of 400 ms.

An additional problem with the Posner and Snyder theory is understanding where the attentional mechanism is when the subject is attending to the neutral prime, and why it would take less time for the attentional mechanism to move from that location to the target node, as compared to the time it takes to move from the prime to an unrelated node. However, if attention to the neutral prime is thought of as corresponding to the activation of a perceptual representation at the letter level (X's), there is no reason to think that this should affect subsequent performance at the semantic level.

Even with additional assumptions, it is difficult to see how the Posner and Snyder theory could account for the results of Experiment 1, where increased interference occurred in the high cue validity condition at long SOAs when the brief target was masked. If interference is attributed to the time it takes for the attentional mechanism to move from the prime node to the target node, or at long SOAs, from the expected target node to the node corresponding to the target actually presented, why would masking the target or otherwise degrading it as in Meyer, Schvaneveldt and Ruddy (1975) or Becker and Killion (1977) cause the attentional mechanism to move more slowly? Unless one makes additional assumptions such as perhaps the assumption that movements of the attentional mechanism are guided by activation levels of the nodes, it is hard to see how these data fit the Posner and Snyder theory. However, Posner and Snyder (1975a) have stated explicitly that in their theory the limited capacity attention mechanism operates independently of levels of activation.

Becker's Verification Model: Becker's model of word recognition involves a verification process in which a set of candidate words is verified one at a time against an image of the word held in visual memory. When a word is preceded by a prime word, the set of words activated by the priming process is first sampled in the verification process. If none of those words match the image in visual memory, another set of words is sampled which is derived from a feature extraction process. Becker assumes that the process of feature analysis is slowed down but the image in visual memory is unaffected when a word target is degraded. Thus he explains the interaction found when targets were degraded (Becker & Killion, 1977) by proposing that responses to related targets are not affected because their verification process does not involve the feature analysis process. Unrelated targets, however, must be verified by using the set of word derived from the feature extraction process and therefore degrading the target slows down responses to unrelated targets.

In Experiment 1, however, reaction times to unrelated targets were increased in a condition where the target was not degraded but masked. The effect of the mask would not be to slow down the process of feature extraction but to overwrite or erase the image in visual memory. This would seem to make the verification process impossible. The above effect of the masked target was also true in Experiments 3 and 4, but in these experiments as well the short prime target SOA should have made a lengthy verification process impossible. Becker's experiments have all used very long prime target SOAs. Paap, Newsome, McDonald, & Schvaneveldt (1982) have extended Becker's model. They suggest that when SOAs are short or when targets are masked, verification would be impossible, and in these cases the word in the lexicon that was most highly activated would be chosen. This is what our theory suggests, assuming also the presence of competitive inhibitory interactions between nodes.

Neely's Theory of Retrospective Checking: Neely (1989; Neely, Keefe & Ross, 1989) proposes that subjects will check for a relationship between the prime and target when a lack of relationship could serve as a cue to the nonword status of the target, and that some interference effects may be due to this process of backchecking. However, he suggests that lack of relationship between prime and target can be a cue to the nonword status of the target only if there is a high probability that the target is. a nonword, given that the target is unrelated to the prime. This would occur, for example, if a large proportion of the targets were nonwords. In the experiments reported here, only 25% of targets were nonwords, and the probability was not high that the that the target would be a nonword, given that the target was unrelated to the prime. Furthermore, in Experiments 3 and 4, masking the prime should have made a backchecking strategy difficult if not impossible, and it is difficult to see how masking the prime would affect this backchecking strategy.

De Groot's Theory of Post-Lexical Coherence Checking: De Groot (1984) believes that because of well learned processes used in reading texts, subjects tend to look for a meaningful relation between prime and target. When prime and target are related, they quickly find this coherence, but when prime and target are unrelated, they do not find it, but the continued search for coherence in these cases results in longer reaction times. Again, it would seem that masking the primes in Experiment 3 and 4 should make this backward checking for coherence difficult if not impossible. It is also difficult to see why masking the target should make this coherence checking process take longer.

Attentional Mechanisms Involved in Priming

Instead of proposing an attentional mechanism that moves through memory, or a central processor that allocates attention, the competitive lateral inhibition theory suggests more of a systems approach to attention. An interaction of excitatory and inhibitory mechanisms produces attentional effects at the semantic level, resulting in the facilitatory and inhibitory effects found in priming studies.

Various factors appear to affect the level of activation of a semantic node, and, therefore how competitive it will be with other nodes. First, activation levels will be influenced by the current threshold level of the node. This threshold may be lower for more frequently used concepts or highly affective concepts (Treisman, 1969) or concepts recently activated themselves or related to recently activated concepts.

Second, spatial attention to the stimulus appears to increase activation level. At short prime target SOAs, the node corresponding to the prime may be activated without attention, but evidence from Experiments 3 and 4 showing response time interference only in the high cue validity condition suggests that prime nodes are activated more strongly when spatial attention is focussed on the area of the visual field where the prime is presented. Posner, Snyder and Davidson (1980) found evidence that covert visuospatial attention cannot be allocated to two different locations in the visual field, but that the size of the one attentional focus may vary according to the requirements of the experiment. Stimuli within the attentional focus are processed more quickly and accurately.

Readiness to perceive in a certain location may involve a kind of priming of those areas of visual cortex receiving input from the part of the retina corresponding to that particular part of the visual field. When these areas are primed, thresholds are lowered, and less input from that area of the visual field is required for activation. Posner's experiments show cost as well as benefit when location is cued, indicating that there may also be some inhibition of areas of cortex not receiving input from the area in question.

In the priming experiments described, the focus of spatial attention when subjects were paying attention to the prime may have been larger, including locations of both the prime and the target above and below the fixation point respectively. In the low cue validity condition, the focus may have been smaller including only the target location. Alternatively subjects could have first focussed on the prime location and then on the target location in the high cue validity condition.

Third, Experiment 3 shows that interference even in the high cue validity condition occurred only with the 200 ms prime mask SOA. This suggests that the duration of visible persistence will affect the level of activation of the prime node even with spatial attention. The duration of visible persistence may correspond to the duration of activation of a sensory representation of the stimulus corresponding subjectively to seeing the stimulus. This may lead to activation of a perceptual representation which is more abstract and less sensory but still perceptual, belonging to the perceptual representation system (Tulving & Schacter, 1990; Schacter, in press).

Duration of visible persistence, will, of course, also affect the level of activation of the target node (McLeod & Walley, 1989), as will spatial attention. It should be noted that, since the task demands attention to the target, while attention to the prime is optional even in the high cue validity condition, other things being equal, the target node should have the competitive edge.

Fourth, strategies for very precisely timing spatial attention to the location where the prime is presented can apparently affect activation levels of the prime node. In Experiment 4, there is evidence that when prime mask SOA is blocked, subjects can develop strategies for timing spatial attention to the prime very precisely thus maximizing activation of the prime node and minimizing the effect of the mask. It may be possible to create a very narrow temporal window during which input from one area of the visual field is primed. The timing mechanism involved may well involve the cerebellum, which has been linked to other precisely timed processes (e.g. Thach, 1980).

Fifth, at long SOAs, another factor influences the activation level of nodes, and that is the development of an expectancy. When most prime target pairs are related, the subject develops an expectancy for a target that is related to the prime. This may involve a lowered threshold for the node corresponding to the expected target. The fact that significant interference usually occurs at long SOAs in a high cue validity condition argues that this 'top down' activation corresponding to expectancy has a very strong effect on activation levels, making the expected target node competitive with the node corresponding to the target actually presented despite the competitive edge the target node has due to spatial attention and temporal cues.

The attentional mechanisms involved in priming effects are, therefore, many. Mechanisms of spatial attention and temporo-spatial attention can work in parallel with mechanisms of word recognition to influence the activation levels of semantic nodes, which are also influenced by a history of previous activations, both more and less recent, and by the expectations and intentions of the subject. Activation levels are also influenced by facilitatory and competitive inhibitory interactions within semantic memory.

It seems, therefore, more accurate to speak of a system of attentional mechanisms, rather than one attentional mechanism or a central executive that allocates attention. The fact that we experience a limited attentional capacity, and a unity of consciousness does not necessarily imply that this unity cannot be the product of a complex attentional system.

VII. TABLES

Table 1

Mean Reaction Times (ms) for Experiment 1

Cue Validity	Target Condition	Prime Relatedness	Block 1			Block 2		
			WP	NP	Diff	WP	NP	Diff
High	Masked	R	651	742	+91	527	588	+61
		U	802	716	-86	638	615	-23
	Unmasked	R	570	613	+43	534	578	+44
		U	652	628	-24	612	588	-24
Low	Masked	R	635	701	+66	537	589	+57
		U	731	741	+10	635	617	-18
	Unmasked	R	591	627	+36	533	562	+29
		U	630	627	-3	571	565	-6

Table 2

Mean Error Rates (%) for Experiment 1

Cue Validity	Target Condition	Prime Relatedness	Block 1			Block 2		
			WP	NP	Diff	WP	NP	Diff
High	Masked	R	2.1	2.1	0	.8	1.7	.9
		U	10.4	6.7	-3.7	2.9	3.8	.9
	Unmasked	R	1.7	2.1	.4	.8	1.3	.5
		U	1.3	1.3	0	1.7	.8	-.9
Low	Masked	R	4.6	6.3	1.7	.8	1.7	.9
		U	12.9	12.1	-.8	5.4	1.7	-3.7
	Unmasked	R	2.5	.8	-1.7	.4	2.1	1.7
		U	1.7	1.3	-.4	2.5	.8	-1.7

Table 3

Mean Nonword Reaction Times (ms) and Error Rates (%) for Experiment 1

Cue Validity	Target Condition	Block 1 WP	Block 1 NP	Block 1 Diff	Block 2 WP	Block 2 NP	Block 2 Diff
				Reaction Times			
High	Masked	946	972	+26	929	901	-28
	Unmasked	810	810	0	727	743	+16
Low	Masked	1003	1024	+21	803	806	+3
	Unmasked	752	763	+11	761	774	+13
				Error Rates			
High	Masked	26.7	21.7	-5.0	31.3	35.0	+3.7
	Unmasked	10.0	8.3	-1.7	6.7	4.6	-2.1
Low	Masked	28.8	30.4	1.6	20.8	25.0	+4.2
	Unmasked	11.3	10.0	-1.3	8.8	6.3	-2.5

Table 4

Mean Reaction Times (ms) for Experiment 2

Target Mask SOA (ms)	Prime Relatedness	Prime Mask SOA (ms)								
		50			83.3			116.7		
		WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
50	R	689	665	-24	617	626	+9	588	611	+23
	U	676	670	-6	660	637	-23	621	598	-23
83.3	R	657	665	+8	633	627	-6	599	604	+5
	U	694	673	-21	656	630	-26	600	591	-9
116.7	R	642	646	+4	619	620	+1	586	601	+15
	U	685	666	-19	656	612	-44	603	589	-14

Table 5

Mean Error Rates (%) for Experiment 2

Target Mask SCA (ms)	Prime Relatedness	Prime Mask SOA (ms)								
		50			83.3			116.7		
		WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
50	R	7.1	10.0	+2.9	3.3	3.3	0	1.7	4.2	+2.5
	U	17.9	12.9	-5.0	5.8	1.7	-4.1	2.1	2.5	+.4
83.3	R	15.0	12.5	-2.5	2.5	3.3	+.8	3.8	2.9	-.9
	U	18.8	16.7	-2.1	8.8	5.4	-3.4	4.2	2.5	-1.7
116.7	R	11.7	8.3	-3.4	5.8	4.6	-1.2	3.3	2.5	-.8
	U	17.9	15.0	-2.9	7.9	2.1	-5.8	4.6	2.5	-2.1

Table 6

Mean Nonword Reactions Times (ms) and Error Rates (%) for Experiment 2

	Prime Mask SOA								
		50			83.3			116.7	
Target Mask SOA (ms)	WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
				Reaction Times					
50	946	866	-80	933	871	-62	909	887	-22
83.3	876	846	-30	885	855	-30	928	846	-82
116.7	834	826	-8	851	818	-33	869	841	-28
				Error Rates					
50	37.9	29.2	-8.7	41.3	36.3	-5.0	41.3	37.1	-4.2
83.3	23.8	17.9	-5.9	32.1	22.5	-9.6	26.7	22.1	-4.6
116.7	20.0	20.4	+.4	20.0	15.0	-5.0	23.3	16.3	-7.0

Table 7

<u>Mean Reaction Times (ms) and Mean Error Rates (%) for Experiment 3</u>

Cue Validity	Prime Relatedness	Prime Mask SOA (ms) 50 WP	NP	Diff	100 WP	NP	Diff	200 WP	NP	Diff
		Reaction Times (ms)								
High	R	637	660	+23	619	647	+28	614	646	+32
	U	684	669	-15	681	660	-21	710	654	-56
Low	R	706	725	+19	687	730	+43	682	685	+3
	U	746	749	+3	747	728	-19	690	727	+37
		Error Rates (%)								
High	R	5.8	9.2	+3.4	3.8	3.8	0	2.5	4.6	+2.1
	U	10.8	9.2	-1.6	13.8	5.8	-8.0	14.6	7.1	-7.5
Low	R	7.1	7.1	0	4.2	6.7	+2.5	7.9	5.4	-2.5
	U	7.1	10.0	+2.9	14.2	10.8	-3.4	10.0	7.5	-2.5

Table 8

Mean Nonword Reaction Times (ms) and Error Rates (%) for Experiment 3

	Prime Mask SOA								
Cue		50			100			200	
Validity	WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
				Reaction Times					
High	935	938	+3	928	917	-11	944	948	+4
Low	1047	1024	-23	1032	997	-35	1057	1041	-16
				Error Rates					
High	37.5	37.1	-.4	40.4	37.9	-2.5	45.4	40.0	-5.4
Low	35.8	37.9	+2.1	49.2	40.0	-9.2	45.8	39.6	-6.2

Table 9

Mean Reaction Times (ms) for Experiment 4

			Prime Mask SOA								
			50			100			200		
Cue Validity	Order of Prime Mask SOA	Prime Relatedness	WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
High	Increasing	R	907	933	+26	831	876	+45	787	844	+56
		U	1001	944	-57	911	886	-25	853	870	+17
	Decreasing	R	787	842	+55	790	832	+42	815	863	+48
		U	867	851	-16	874	861	-13	957	892	-65
Low	Increasing	R	804	827	+23	761	776	+15	722	755	+33
		U	832	823	-9	766	780	+14	751	769	+18
	Decreasing	R	786	785	-1	771	810	+39	839	878	+39
		U	781	801	+20	805	818	+13	870	872	+2

Table 10

Mean Error Rates (%) for Experiment 4

			Prime Mask SOA								
			50			100			200		
Cue Validity	Order of Prime Mask SOA	Prime Relatedness	WP	NP	Diff	WP	NP	Diff	WP	NP	Diff
High	Increasing	R	11.3	14.6	+3.3	4.6	7.1	+2.5	3.8	13.3	+9.5
		U	21.7	12.9	-8.8	14.2	12.5	-1.7	12.5	8.3	-4.2
	Decreasing	R	5.8	13.8	+8.0	5.4	8.8	+3.4	8.3	13.3	+5.0
		U	12.5	10.4	-2.1	18.3	12.1	-6.2	22.5	9.2	-13.3
Low	Increasing	R	6.7	7.5	+.8	3.8	4.6	+.8	2.9	2.9	0
		U	14.6	5.8	-8.8	7.9	4.2	-3.7	6.3	6.3	0
	Decreasing	R	8.8	9.2	-.4	8.8	8.3	-.5	6.3	7.9	+1.6
		U	8.3	8.8	+.5	12.1	8.3	-3.8	15.0	7.9	-7.1

Table 11

<u>Mean Nonword Reaction Times (ms) and Error Rates (%) for Experiment 4</u>

Cue Validity	Order of Prime Mask SOA	Prime Mask SOA 50 WP	50 NP	50 Diff	100 WP	100 NP	100 Diff	200 WP	200 NP	200 Diff
				Reaction Times						
High	Increasing	1269	1251	-18	1194	1183	-11	1118	1096	-22
	Decreasing	1162	1131	-31	1207	1179	-28	1249	1228	-21
Low	Increasing	1169	1145	-24	1140	1113	-27	1052	1036	-16
	Decreasing	1046	1054	+8	1057	1049	-8	1129	1130	+1
				Error Rates						
High	Increasing	51.3	45.8	-5.5	41.7	30.0	-11.7	38.3	26.7	-11.6
	Decreasing	38.8	29.6	-9.2	44.6	40.4	-4.2	44.6	38.3	-6.3
Low	Increasing	47.5	46.3	-1.2	41.3	31.3	-10.0	35.8	32.1	-3.7
	Decreasing	28.8	26.3	-2.5	34.6	25.0	-9.6	30.0	31.3	+1.3

VIII. FIGURES

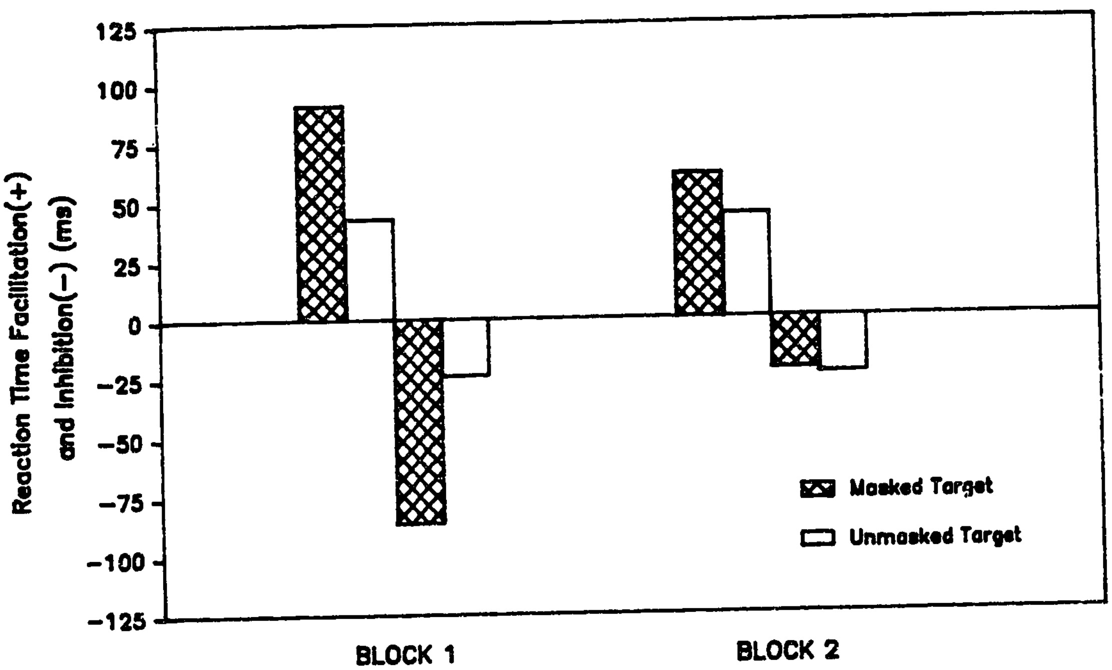

Figure 1. Reaction Time Facilitation with Related Primes and Interference with Unrelated Primes in a High Cue Validity Condition and at a Long Prime Target SOA When Brief Targets Were Masked in Either Block 1 or Block 2 Trials.

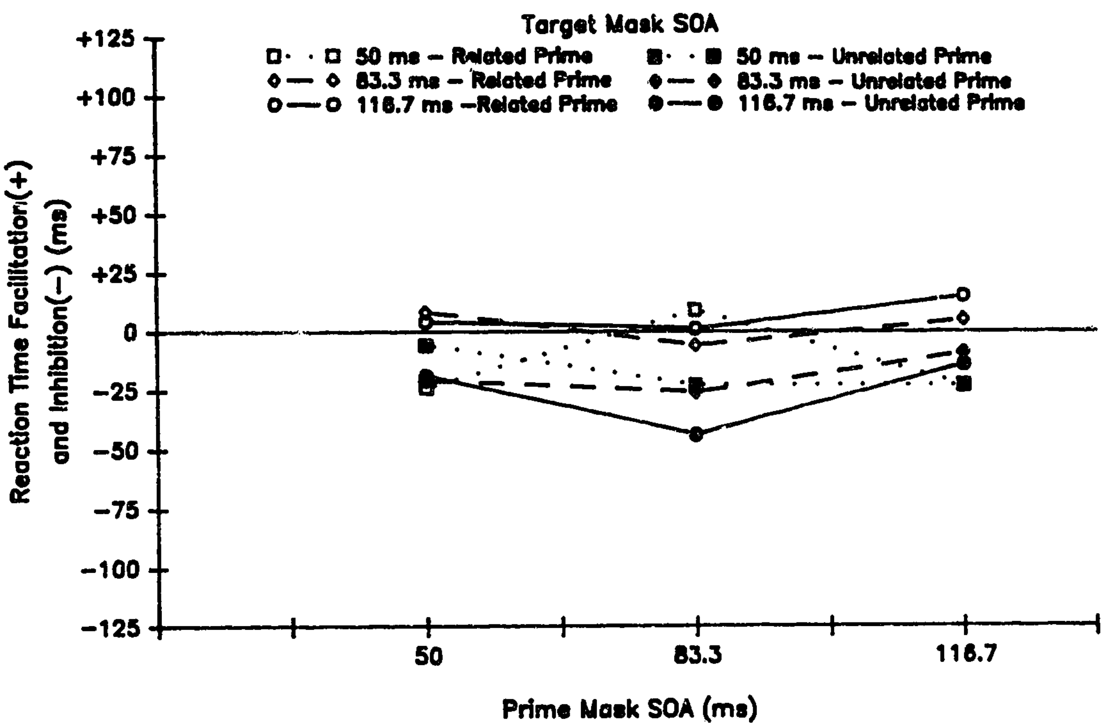

Figure 2. Reaction Time Facilitation and Interference in a Low Cue Validity Condition at a Short Prime Target SOA as a Function of Prime Mask SOA When Target Mask SOA is 50, 83.3 or 116.7 ms.

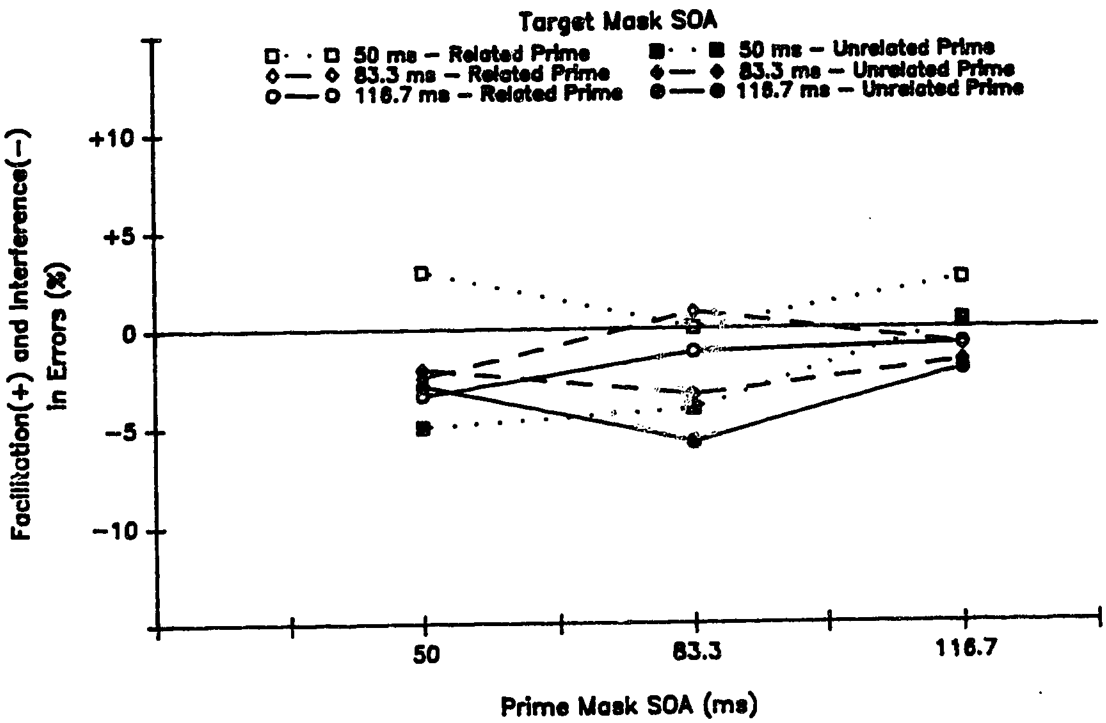

Figure 3. Facilitation and Interference Effects on Error Rates in a Low Cue Validity Condition at a Short Prime Target SOA as a Function of Prime Mask SOA When Target Mask SOA is 50, 83.3 or 116.7 ms.

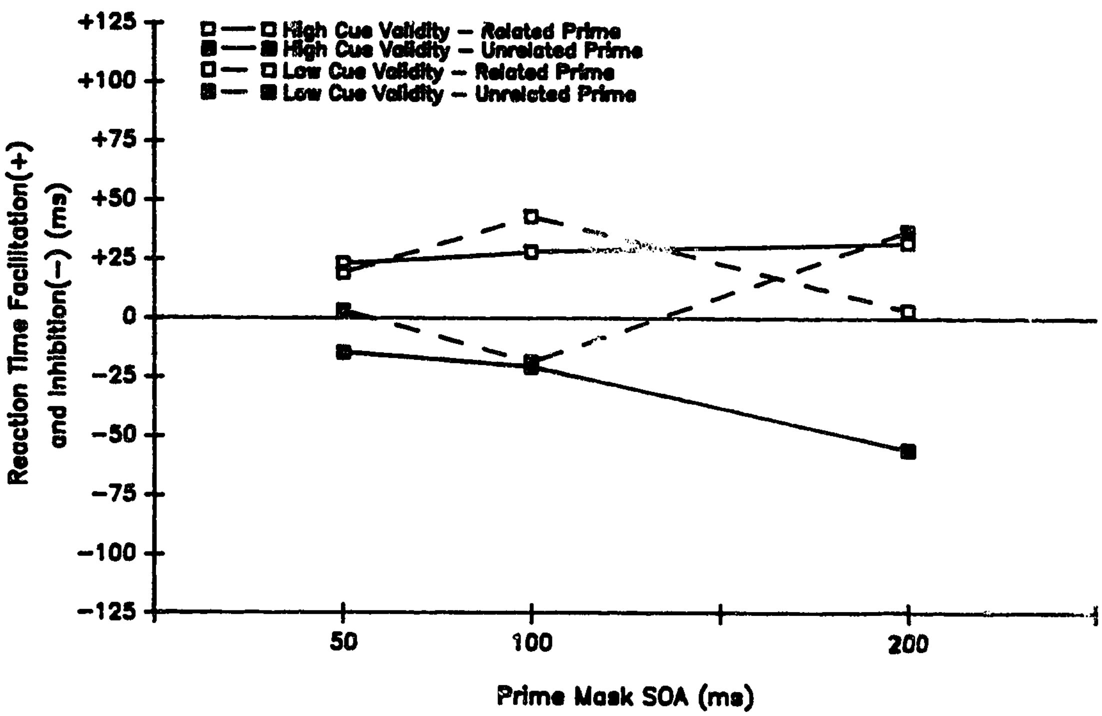

Figure 4. Reaction Time Facilitation and Interference Effects at a Short Prime Target SOA for Two Cue Validity Conditions as a Function of Prime Mask SOA When Target Mask SOA is 50 ms.

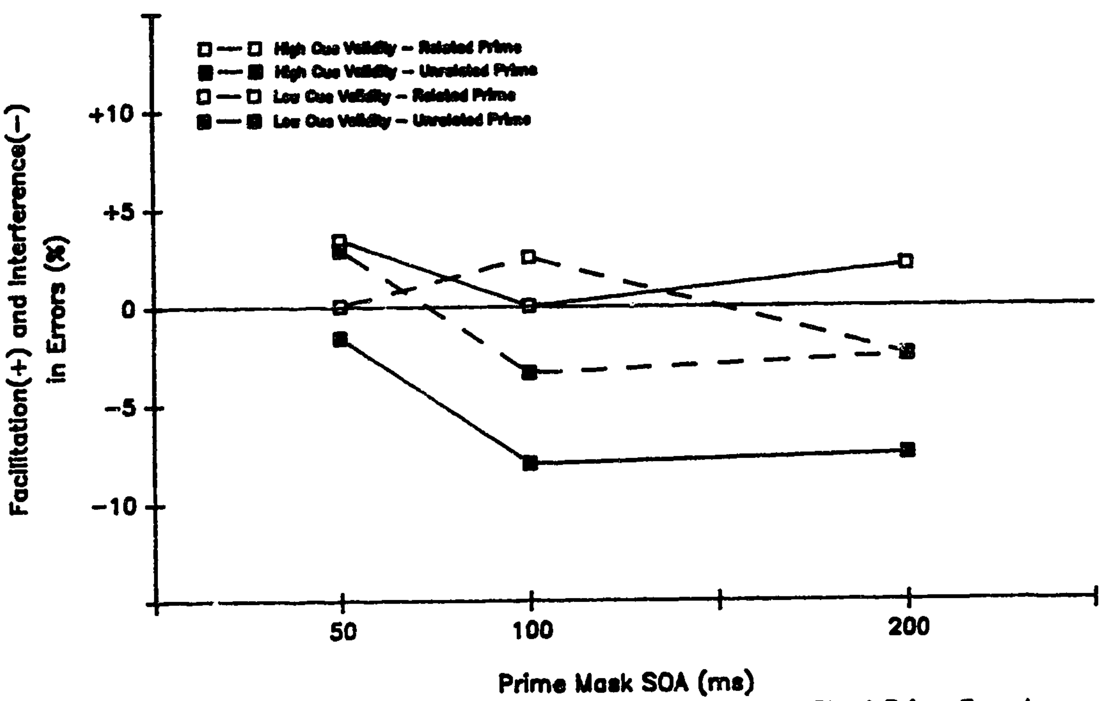

Figure 5. Facilitation and Interference Effects on Error Rates at a Short Prime Target SOA for Two Cue Validity Conditions as a Function of Prime Mask SOA When Target Mask SOA is 50 ms.

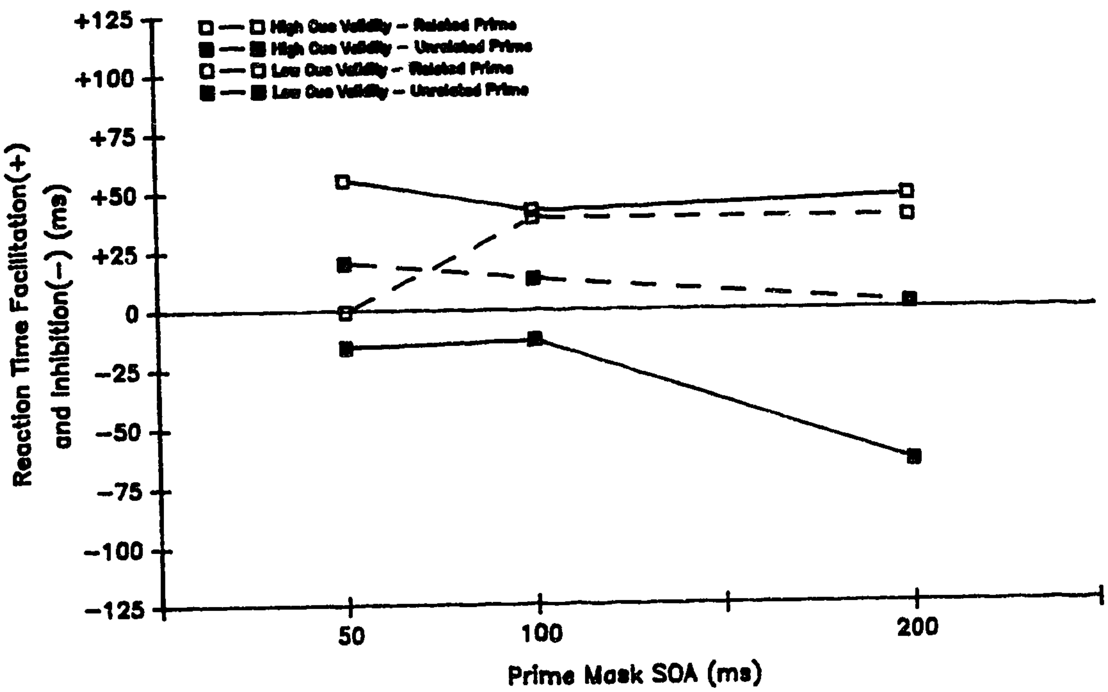

Figure 6. Reaction Time Facilitation and Interference Effects in Decreasing Prime Mask SOA Condition for Two Cue Validity Conditions as a Function of Prime Mask SOA When Target Mask SOA is 50 ms.

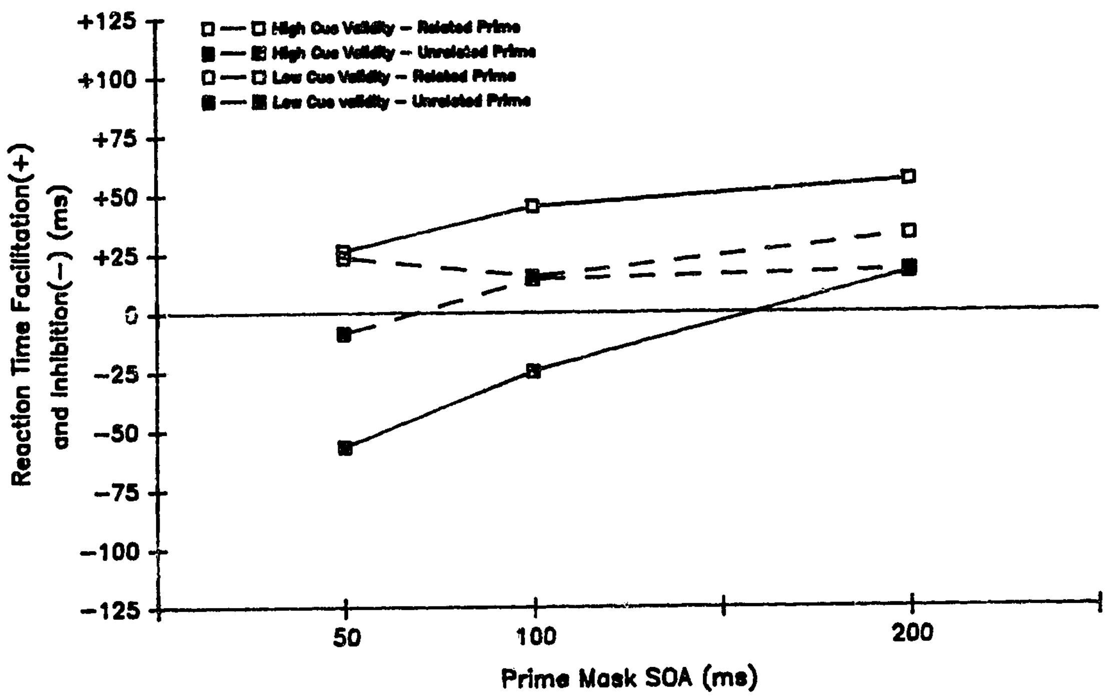

Figure 7. Reaction Time Facilitation and Interference Effects in the Increasing Prime Mask SOA Condition in Two Cue Validity Conditions as a Function of Prime Mask SOA When Target Mask SOA is 50 ms.

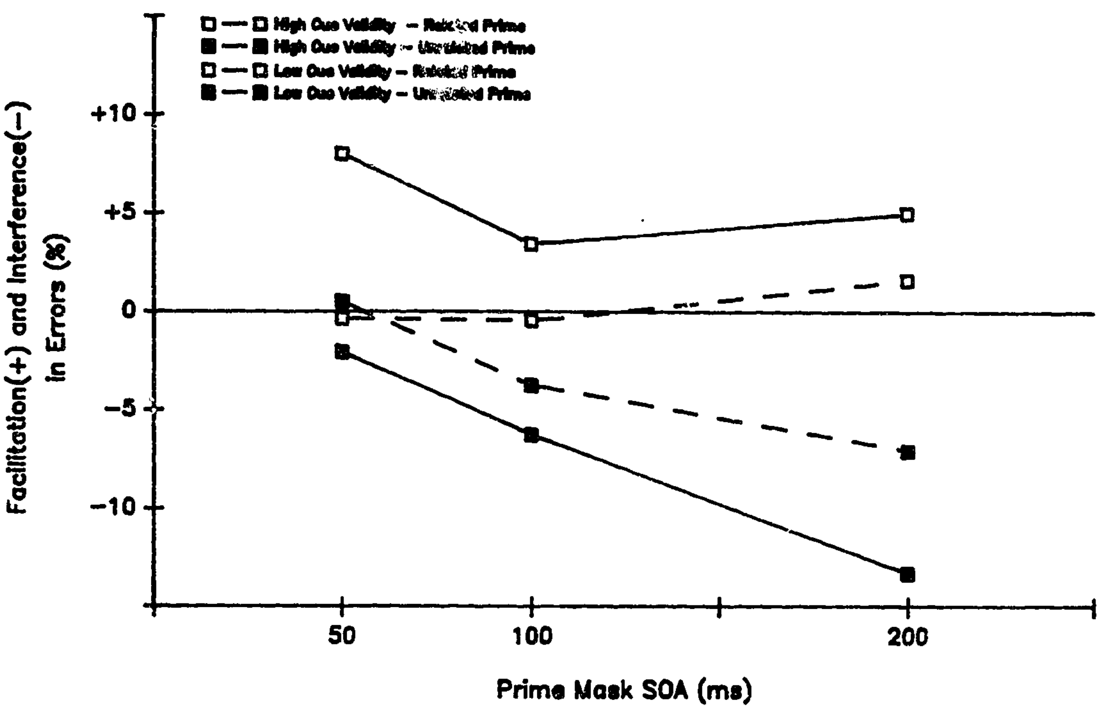

Figure 8. Facilitation and Interference Effects on Error Rates in the Decreasing Prime Mask SOA Condition for Two Cue Validity Conditions as a Function of Prime Mask SOA When Target Mask SOA is 50 ms.

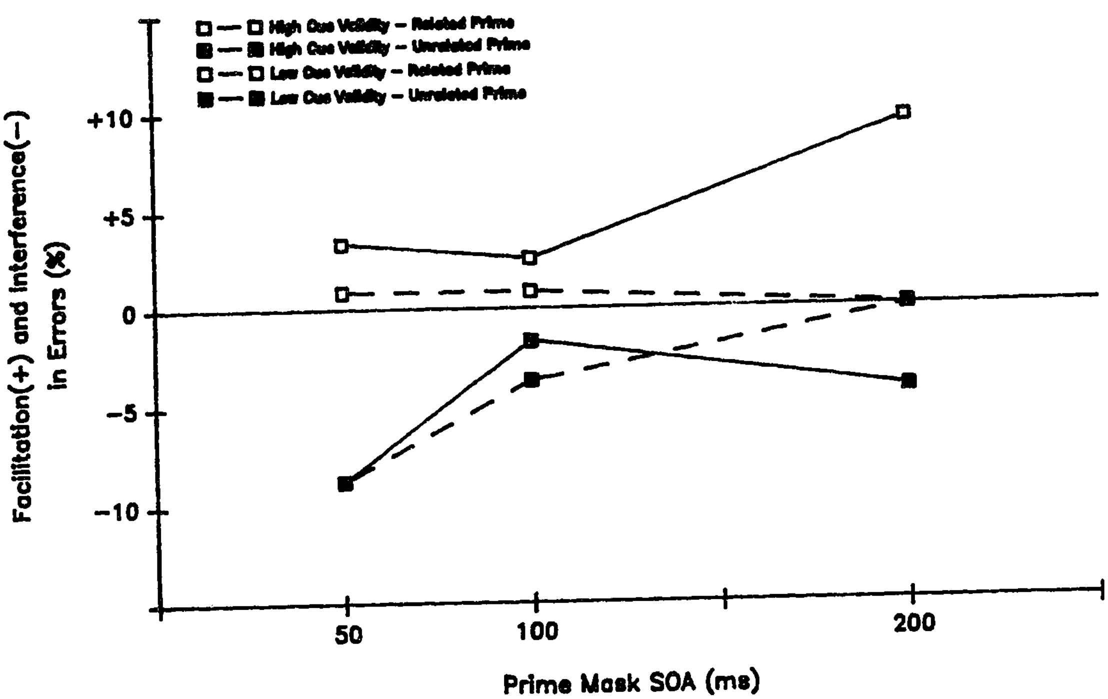

Figure 9. Facilitation and Interference Effects on Error Rates in the Increasing Prime Mask SOA Condition for Two Cue Validity Conditions as a Function of Prime Mask SOA When Prime Target SOA is 50 ms.

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X. APPENDIX 1: STIMULUS MATERIALS

PRACTICE TRIALS

anger	mad	quiet	loud
arm	leg	rough	smooth
bath	clean	shoes	feet
cottage	house	sickness	health
deep	shallow	small	large
priest	church	square	round
now	then	stand	sit
over	under	thinner	fatter
pain	hurt	we	they

LIST 1

in	out	grass	green
bed	sleep	hot	cold
fruit	apple	perhaps	maybe
doors	window	scissors	cut
bitter	sweet	man	woman
blossom	flowers	needle	thread

LIST 2

eagle	bird	male	female
eating	food	sky	blue
easier	harder	stop	go
me	you	bad	good
glove	hand	night	day
on	off	boy	girl

LIST 3

hammer	nails	slow	fast
spider	web	king	queen
sister	brother	black	white
salt	pepper	dark	light
his	hers	down	up
butter	bread	always	never

LIST 4

thirsty	water	father	mother
carpet	rug	long	short
one	two	table	chairs
dogs	cats	hard	soft
sell	buy	tobacco	smoke
younger	older	high	low