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The Effects of Attention on the Time Course of Interference in a Priming Task

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Effects of Attention on the Time Course of Interference in a Priming Task submitted by Barbara E. McLeod in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date...Sept. 2, 1986.........

Dedication

This thesis is dedicated to my children, Sam and Cathy King.

Abstract

The purpose of this experiment was to determine whether, in a priming task, a prime word can inhibit processing of a target word that is unrelated to it under conditions when conscious attention is not directed to that prime, or at early stages of processing before conscious processing of the prime has had time to develop. According to the two process theory of Posner and Snyder (1975a, 1975b), inhibition should not occur unless conscious attention is being directed to the unrelated prime, and then only at long SOA's when such conscious processing has had time to develop. The Walley and Weiden theory (1973), however, proposes that conscious attention is not necessary for such inhibition to occur and predicts that inhibition should occur even at short SOA's and in the absence of direct attention to the prime.

The experiment used the cost benefit paradigm developed by Posner and Snyder (1975a, 1975b). On each trial, a prime which was either a strong associate of the prime, an unrelated word or a neutral prime of a string of X's was presented for 200 msec. After an SOA of 200, 400 or 800 msec, a target was presented for 33.3, 50 or 66.7 msec. The subject was required to read the target aloud as quickly as possible.

The amount of attention paid to the prime was manipulated by informing subjects of the probability of the prime being a strong associate of the target. In the high

cue validity condition, this probability was 75%, in the medium, 50% and in the low cue validity condition, 25%.

Results were not supportive of the Posner and Snyder two process theory. In all cue validity conditions, inhibition was greatest as measured by both reaction time and error data at the 200 msec SOA, and decreased at longer SOA's. Facilitation occurred only at the 400 and 800 msec SOA's. Inhibition and facilitati[illegible]th greatest at the shortest target durations.

Results are interpreted within the context of the Walley and Weiden theory which attributes inhibition effects to a process of lateral inhibition between logogens at the highest level of a hierarchy of feature analyzers.

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I would like to thank the members of my committee: Dr. R. E. Walley, Dr. A. R. Dobbs and Dr. R. B. Wilberg for their helpful assistance in the completion of this thesis.

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I. INTRODUCTION

A. The Priming Phenomenon

A prime is a word or other stimulus presented to a subject at the same time or at some interval before he is required to perform a task on other stimuli. It has been found that the nature of that prime can significantly influence the speed and accuracy with which he performs further mental operations. Meyer & Schvaneveldt (1971), for example, found that a lexical decision, i.e. a decision as to whether or not a string of letters is a word, can be performed more quickly if the word is presented with a prime word that is related to it. If, for example, the word 'NURSE' was presented as a prime, the word 'DOCTOR' would be more quickly recognized as a word than if an unrelated prime such as the word 'BREAD' were presented.

Priming effects have provided important clues to the structure and functioning of the human brain. Two current theories which provide different explanations of these effects are the Posner and Snyder two process theory (1975a, 1975b) and the Walley and Weiden theory (1973). These theories differ both in the mechanisms proposed to account for these effects and in the precise effects that they predict.

B. The Posner and Snyder Two Process Theory

In the theory of attention proposed by Posner and Snyder (1975a, 1975b) two processes are involved: one involving automatic spreading activation and the other deliberate, consciously directed attention.

Automatic spreading activation was first proposed by Collins and Loftus (1975). In their model, semantic memory is thought of as a network of linked nodes. These nodes correspond to concepts in memory, and the length of the various links connecting them corresponds to their strength of association. When a node in memory is activated, that activation is thought of as quickly and automatically spreading outward to other related memory nodes through these associative links. Activation is released from the node at a fixed rate as long as the concept is activated; through some mechanism, it gradually decreases thereafter over time and through intervening activity.

In a priming task, according to Posner and Snyder, the prime, even if not consciously attended to, activates the node in memory where its physical form, name and semantic content are represented, and thus releases activation to other related nodes. If the subsequently presented target word is related to the prime, it can then be processed more quickly because common pathways in memory have already been activated. This process of automatic spreading activation occurs without intention, without conscious awareness, and without interference with other mental activity (Posner &

Snyder, 1975a). Although it quickly facilitates the processing of related stimuli, it has no inhibiting effect on the processing of unrelated stimuli: it will not cause an unrelated target to be processed more slowly.

The mechanisms of conscious attention, on the other hand, are seen as slow, deliberate and serial. Conscious attention has a limited capacity; it can process only one thing at a time. Commitment to one mental operation, therefore, interferes with the operation of another. It is assumed in this theory that memory is structured in such a way that memory locations of related items are closer together and those of unrelated items are farther apart (Posner, 1978; Neely, 1976, 1977). The conscious mechanism of attention can "read out" of only one memory location at a time. In order to read out from another memory location, the attention must be shifted, and the farther away the new memory location is, the longer it takes to accomplish this shift. The processing of a new stimulus which is unrelated to the original stimulus will therefore take longer than the processing of a related stimulus which does not require such a long shift.

It follows, then, according to Posner and Snyder's theory, that in a priming task, if the subject is not paying conscious attention to the priming word, his performance on a related target word should be facilitated by automatic spreading activation, but if the target is not related to the prime, performance on it should not be affected at all.

If he is paying attention to the prime, however, both processes will tend to favor the processing of a related target, but due to the nature of the mechanism of conscious attention, the processing of an unrelated target will be inhibited.

C. **The Cost Benefit Paradigm**

To test this theory, Posner and Snyder have developed an experimental paradigm which allows the measurement of facilitation and interference in a priming task. Facilitation or benefit is calculated by subtracting reaction times and error rates when the prime matches or is related to the target from reaction times and error rates following a prime which is a neutral warning signal. Inhibition or cost is measured by subtracting reaction times and error rates obtained following the neutral warning signal from those obtained when the target was related to the prime.

In the experiment some method ~~is~~ used to manipulate the amount of conscious attention that the subject directs to the prime; for example, the probability that the prime is matched or related to the target may be varied for different groups of subjects. In the high validity condition, where the probability is high that prime and target are matched or related, it is expected that the subject will tend to pay conscious attention to the prime, thus improving his performance. In the low validity condition, where most primes and targets are not related or matched, it is expected that the subject will pay little conscious attention to the prime.

In order to chart the time course of these facilitation and inhibition effects, the time between the onset of the prime and the onset of the target is varied. It is predicted that when this interval, the stimulus onset asynchrony (SOA), is short there will be facilitation but no inhibition, since only the fast-acting automatic activation processes have had time to come into play. At longer SOA's, however, there will be time for the conscious processing of the prime, and, therefore, there will be both greater facilitation and considerable inhibition.

To summarize: in this paradigm, in the low cue validity condition and at short SOA's in both conditions, Posner and Snyder expect that only facilitation for a related prime will be found with no inhibition for an unrelated prime. In the high cue validity condition at long SOA's where the mechanisms of conscious attention are expected to be operating, inhibition is expected in the processing of targets unrelated to the prime as well as greater amounts of facilitation for a related or matching prime.

D. Problems with the Posner and Snyder Theory

One difficulty inherent in Posner and Snyder's theory may be its assumption that representations of words or concepts in memory are located in such a way that semantically related representations are located closer together and unrelated representations are located farther apart. Conscious attention, then, is thought of as moving around the network from one place to another. There would be some difficulty in extending this model, in which degree of relationship is represented by distance between nodes, to a situation involving learning. What happens, then, when learning takes place, and what was previously considered unrelated is understood to be related? In Posner and Snyder's theory this would involve a reorganization of the brain.

An alternative possibility is that representations in memory, sometimes called logogens, are actually networks of interconnected neurons which may be dispersed over some area in the brain. McClelland and Rumelhart (1985) describe one such distributed model of memory. For very familiar objects and concepts, the synaptic connections between these neurons are very strong. For less familiar, less easily discriminated objects or concepts, the connections would be weaker or fewer.

Grossberg and Stone (1986) point out another difficulty. Activation may build up in unattended memory locations, as when an unexpected target is presented in a priming task. No mechanism is posited, however, to explain how the attention is redirected to these activated logogens, i.e. in what way they draw attention to themselves.

E. The Walley and Weiden Theory

Another theory of attention which offers a different explanation of inhibitory effects and makes different predictions in the cost benefit paradigm is that of Walley and Weiden (1973). Like the more recent theory of McClelland and Rumelhart, it assumes that memory representations or logogens are composed of units which may be spread across some area of cortex but are connected by strong synaptic links. These logogens, which interact through excitatory and inhibitory interconnections, represent the highest level of a single hierarchical network of feature analyzers. Feature analyzers are neurons which respond selectively to certain attributes of the stimulus.

Logogens may become activated through a top-down process involving various cortical connections or through input from various sensory modalities. If there is top-down activation with no corresponding sensory input, this would result in mental imagery, or, in some cases, a sense of expectation or intention. If sensory input exists as well as input through cortical connections, the result would be consciously directed attention, corresponding to Posner and Snyder's limited capacity attentional mechanism. Sensory input without cortical input would correspond to perception without attention, which would correspond to Posner and Snyder's automatic spreading activation.

The activation of a logogen by either or both processes to the point where neural firing occurs would result in the activation of inhibitory collaterals. This process of lateral inhibition results in a generalized inhibition of unrelated logogens. The amount of inhibition will depend on how strongly activated the logogen is; if activation is subliminal, and firing does not occur, there will be no inhibition. McClelland & Rumelhart (1981a, 1981b) also propose such mutually inhibiting interactions between word nodes as part of their interactive activation model of context effects.

At the same time, neural firing in a logogen will lower the firing thresholds of neurons in logogens that have strong excitatory connections through learning to the first logogen. The strength of that facilitation will depend on how strongly activated the logogen is and the number and strength of the synaptic connections. Posner and Snyder (1975a) state that the Walley and Weiden theory cannot account for the presence of facilitation in a priming study. The theory in its published form did not discuss the facilitation effects of priming; an unpublished prepublication manuscript, however, does accommodate the evidence for facilitation by proposing that synaptic connections formed through learning could produce excitatory effects which would overcome the effects of lateral inhibition.

In the Posner and Snyder cost benefit paradigm, the Walley and Weiden theory predicts both facilitation of a target that is related to the prime and inhibition of an unrelated target regardless of whether the source of the activation is pre-attentive and automatic or conscious and voluntary. Unlike the Posner and Snyder theory, therefore, it predicts that if the activation is strong enough to fire the logogen for the related target, significant inhibition will occur in the low validity condition when subjects are not paying direct attention to the prime and also at short SOA's when there has not been sufficient time for conscious processing of the prime. Facilitation will also occur in these conditions. If activation is below firing threshold of the logogen for the related target, however, inhibition will not occur.

When conscious attention is directed to the prime, in the high validity condition at long SOA's, there will be even greater inhibition and facilitation since the prime logogen will be more strongly activated.

F. Experimental Evidence

In a review of their data using the cost benefit paradigm, Posner and Snyder (1975b) show some support for their theory. Results, however, were not unequivocal.

In one series of experiments, subjects were presented on each trial with a pair of letters and were required to respond as to whether or not they matched. This array was preceded by a prime which appeared directly above the array. The probability that the prime would match a matching pair of letters in the array was varied in order to manipulate the amount of attention paid it. When this probability was high, and subjects were presumed to be paying attention to the prime as a valid cue, both significant benefit and significant cost were found. In the low probability condition, significant benefit was found, but no cost. Significant facilitation occurred with SOA's from 50 to 500 msec, while cost was significant only at longer SOA's from 300 to 500 msec.

In another experiment, an array of two words was presented, one above the other. The subject's task was to press one key if either of the words was an animal name, and the other if neither of the words was an animal name. The prime was either a plus sign or an animal name. In conditions where the probability was 80% or 50% that an animal name prime was a valid cue to an array which also contained an animal name, both significant cost and benefit were found. In the condition where that probability was only 20%, only benefit was found.

Evidence, however, from a digit search task seemed less clear. A clear benefit was shown when prime and target matched 100% of the time, but when that probability was reduced to .5, there was neither benefit nor cost. In a subsequent experiment, when subjects were explicitly instructed to use the prime, a small significant cost was found but benefit was not significant by t-test.

A defect in these experiments, however, pointed out by the researchers themselves was that subjects may have been employing the strategy of matching the prime to the target array. If this were so, inhibition may have occurred not because of limitations inherent in a limited capacity attentional mechanism, but because a mismatch inclined a subject toward a "no" response.

Neely (1976) used a lexical decision task with word primes that were either semantically related to the target, unrelated to the target or a semantically neutral string of X's. He thus avoided the matching problem. SOA's were 360, 600 or 2000 msec. With these relatively long SOA's Neely found a large semantic facilitation effect and a smaller but significant inhibition effect. Facilitation increased as a function of SOA, but inhibition remained relatively constant. Since he did not attempt to use short SOA's or to manipulate attention as a variable, this experiment did not, however, provide clear support for either theory.

Posner and Snyder's theory gets its strongest support from Neely's 1977 experiment. In it, Neely again used a lexical decision task while manipulating conscious attention by explicitly directing the expectations of the subject. Primes were category names. SOA's again were relatively long: 250, 400 and 2000 msec. Results showed facilitation at all SOA's but significant inhibition only at 400 and 2000 msec in conditions where the subject's attention was misdirected.

Antos (1979), however, has pointed out that none of the cuing conditions in Neely's study showed facilitation without some cost in errors. His data do not provide support for the existence of inhibitionless facilitation unless one ignores these speed/accuracy trade-off problems (See Pachella, 1974). Antos found in a lexical decision task that invalid cues produced inhibition at SOA's of 200 msec.

Myers and Lorch (1980) point out that Posner and Snyder's letter matching task and Neely's lexical decision task require little in the way of semantic processing. In a semantic verification task, they found significant inhibition at their shortest SOA which was 250 msec.

Posner & Boies (1971) measured interference by examining reaction times to a secondary task, the detection of an auditory probe, interpolated at different stages in processing in the primary task, which involved detecting matches in sequentially presented letters. They found evidence that the processing of the first letter did not interfere with probe detection.

Ogden, Martin & Paap (1980), however, using a similar paradigm, compared conditions that required letter encoding and those that did not. They found that letter encoding did produce interference with a secondary task. In a primed letter classification task, Paap & Ogden (1981) found more interference when subjects deliberately attended to a letter prime, but still significant interference when they tried to ignore it. Thus early perceptual components may be considered automatic in the sense that they are obligatory but they still produce interference. Comstock (1973), McLean

& Shulman (1978), and McLean (1977), cited by Posner, 1978) also found interference effects in early perceptual processing as measured by a secondary probe task.

Posner (1978) interprets this evidence of early interference as indicative of an early commitment of conscious attention, thus giving up the distinction between fast automatic processes and slow deliberate conscious processes. Since he has, however, defined conscious voluntary processes as those in which interference occurs, his reasoning runs the risk of becoming circular.

Furthermore, Fischler & Bloom (1979) in a lexical decision task using incomplete sentence contexts found that subjects were unable to eliminate inhibition when instructed to ignore context implications. The evidence seems to indicate that interference does occur with fast early processing and also that it occurs where voluntary processing is not involved. The strict division between fast inhibitionless-obligatory processes and slow, deliberate, conscious processes involving inhibition does not seem to hold up.

Given the above evidence, the Walley and Weiden theory may be the more parsimonious explanation of the data. Rather than positing two distinct mechanisms of attention, it suggests that logogens form the top level of one hierarchical system of neurons which may be activated from two different directions. Interference increases as a function of level of activation, and does not relate to its direction of origin. Subjective consciousness and, indeed, sense of intention may be a function of level of activation and its relative speed of movement more than anything else.

G. The Purpose of this Experiment

Despite the speed/accuracy trade-off problems mentioned by Antos (1979) in Neely's (1977) experiment, the fact that he did not find interference at the 250 msec SOA and in conditions where explicitly directed expectations were not involved must be dealt with. One strong possibility is that the category primes used in his study did not provide sufficient activation of related logogens to produce an inhibitory effect when targets were not related. The strength of association between category and example could, in fact, vary a great deal, introducing an unwanted source of variation.

The present study used strongly associated words as related primes and targets, such that the target had at least a .40 probability of being the first associate to the prime according to free association norms. This was to ensure that activation of the prime had a high probability of strongly activating a logogen which might or might not be the target in that trial. If the target was the word strongly associated to the prime, there would be a strong facilitation effect. If the target was not the strongly associated word, there would be a strong inhibition effect since activation of the related logogen would cause a general inhibition of other logogens.

To further ensure sufficient activation of the prime logogen, the prime on all trials was displayed for a full 200 msec. SOA's were varied from 200 to 800 msec, and the duration of target words was varied from 33.3 to 66.7 msec. A similar method was used by Tulving & Gold (1963) in an experiment examining the effects of sentence context on visual duration threshold. In that experiment, each target word was first exposed at 10 msec and exposure durations increased in successive steps of 10 msec until the subject identified the word correctly.

Rather than a lexical decision task, a pronunciation task was used. Several studies have indicated that as a measure of lexical access, the lexical decision task has disadvantages. West & Stanovich (1982) point out that in such a task, a binary decision must take place after the word has been identified and understood. Thus some of the effects detected by the task may be occurring post-lexically. Various studies comparing the two tasks have found different priming effects involved in each (Becker & Killion, 1977; Forster, 1981; West & Stanovich, 1982; Balota & Chumbley, 1984; Lupker, 1984; Seidenberg, Waters, Sanders & Langer, 1984; Balota & Lorch, 1986; Lorch, Balota & Stamm, 1986). The general consensus seems to be that many of the priming effects found in the lexical decision task involve post lexical decision processes. The pronunciation task has been argued to be better suited for determining the circumstances in which memory locations receive activation (West & Stanovich, 1982; Balota & Chumbley, 1984; Lupker, 1984).

The calculation of inhibition and facilitation effects was similar to the Posner and Snyder method. A neutral condition was provided on half the trials where the prime was not a word but a string of X's. Facilitation and inhibition were calculated by subtracting errors and reaction times obtained following a word prime from those obtained when the prime was a string of X's. If the resulting number was positive, facilitation was indicated; if negative, inhibition.

There were 3 cue validity conditions with the probability that primes and targets were strongly associated being 75%, 50% or 25%.

According to the Posner and Snyder theory, facilitation should occur in this experiment when target and prime are strongly associated at all SOA's and in all cue validity conditions. Inhibition, however, should be expected only in the high validity condition when prime and target are unrelated, since the subject is expected to direct more conscious attention to the prime as a cue.

According to the Walley and Weiden theory, facilitation and inhibition should occur at all SOA's in all conditions, but in the high validity condition, both should become greater as SOA increases due to top-down activation of the target logogen corresponding to attention and expectancy. In the medium validity condition, where the prime is a valid cue 50% of the time, facilitation and inhibition should occur in amounts midway between the other two conditions.

Inhibition should be greatest at short target durations where an unrelated prime inhibits perception of the target which is not activated very strongly. At longer target durations, the target logogen would be more strongly activated which would counteract the inhibitory effect of the prime. Facilitatory effects of primes on related targets would also be greatest at the shortest durations, since, compared to the neutral condition, there would be greater activation of the target logogen when the prime is related to it. At longer target durations, activation of the target logogen would be more like the neutral condition.

The basic difference in what is predicted by the two models is in whether inhibition will occur when consciously activated attention is not involved. Walley and Weiden predict that it will: inhibition will occur at short as well as long SOA's and in the low cue validity condition as well as the high cue validity condition. Posner and Snyder predict that inhibition will occur only at long SOA's and only in the high cue validity condition since inhibition requires that the slow limited capacity processes of conscious attention be involved.

II. METHOD

A. Subjects

Subjects were 108 undergraduate psychology students at the University of Alberta, 46 males and 62 females, participating in the experiment 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 included cue validity and SOA. There were 3 cue validity conditions: high, in which 75% of the primes were strong associates of the target, medium, in which 50% were strong associates, and low, in which 25% were strong associates. The interval between onset of the prime and onset of the target was either 200, 400 or 800 msec. Within subject variables were target duration, whether the prime was a word or a string of X's, and, if the prime was a word, whether it was a strong associate of the target or not associated. Target durations were 33.3, 50 or 66.7 msec.

One dependent variable was the time required to pronounce the target word as measured from the onset of the target to the onset of the subject's vocal response. The other was the number of errors including reading the wrong word and being unable to read the target at all.

C. **Procedure**

General instructions were presented to each subject prior to the experiment. Subjects were informed what probability they could expect of the prime word being related to the target.

Stimuli were presented to each subject individually on a monitor within a small sound attenuating chamber. The monitor was an Electrohome model ESM-914 with a P4 phosphor. Brightness of the monitor screen measured approximately 6.5 candles per square meter in the centre, where stimuli were presented. Distance between the subject's eyes and the screen measured approximately 80 cm.

Before each trial, the word 'READY' appeared on the monitor. The subject then pressed a button, beginning 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 a full 200 msec. After an SOA of 200, 400, or 800 msec, the target word appeared directly below the fixation point for 33.3, 50 or 66.7 msec. Both prime and target were in lower case letters. The target was followed in the next refresh cycle by a mask of 33.3 msec duration consisting of a string of 8 number signs (#).

The subject was instructed to read the target word out loud as quickly as he could without making errors. If he could not read the word, he was instructed to say nothing. A two second response time was allowed. Subjects were allowed to correct themselves if they wished. Reaction times were measured by a voice activated relay. The experimenter typed into the computer whether the response was correct or incorrect.

Subjects were first given a block of 72 practice trials, using a different word list from those in the experimental trials (See Appendix 1). During these practice trials, the 3 target durations were gradually shortened until they were the same as those in the experimental trials. In trials 1 to 18, target durations were 83.3, 100 and 116.7 msec; in trials 19 to 36, target durations were 66.7, 83.3 and 100 msec; in trials 37 to 54 target durations were 50, 66.7 and 83.3 msec and in trials 55 to 72, target durations were 33.3, 50 and 66.7 msec. Approximately 15 subjects who were unable to read the prime correctly on 12 of the last 18 practice trials did not complete the experiment.

The 216 experimental trials were given in 3 blocks of 72 trials with one minute breaks between.

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 target was at least .40. Mean probability was .58. (See stimulus materials in Appendix 1.)

Since it was felt that the word frequency of the primes might be directly related to the amount of logogen activation caused by the prime, the lists were matched as well as possible for mean word frequency using the Kucera & Francis norms (1967). Frequencies varied from 1 to 21,341 per million. Median word frequencies for the 4 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 were .58, .58, .58, and .57 in the 4 lists.

Subjects were divided into 4 groups of 27. 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 4 groups was to ensure that all items appeared equally often in all conditions. Since groups was not a variable of any experimental interest, however, it was not considered in the analysis of variance.

In each cue validity condition, there were 216 trials consisting of: 36 trials in which prime and target were related pairs from the list of interest, 36 trials of neutral primes consisting of 5 X's paired with the same targets, 36 trials of primes from the list of interest paired with unrelated targets from other lists, and 36 trials of a neutral prime of 5 X's paired with each of these unrelated targets. All primes and targets from the list of interest thus appeared equally often.

In addition, in each cue validity condition, there were 72 filler trials composed of primes and targets from the other 3 lists. The purpose of these filler trials was to provide enough extra trials to make up each of the cue validity conditions. In the high validity condition, for example, all of the 72 filler trials consisted of related primes and targets; in the medium validity condition, 36 were related pairs and 36 were trials where primes were paired with targets from other lists. In the low validity condition, all 72 filler trials consisted of primes paired with unrelated targets from other lists.

Subjects were given 3 blocks of 72 trials. Within each block, order of trials was randomized. In the trials that were of experimental interest, the following rules applied. For the related primes and their controls, each prime target pair appeared once in each block of trials, each time with a different target duration. For the unrelated trials, each prime appeared once in each block of trials with a different target and target duration in each block. Each prime and target thus appeared equally often at each target duration. In the filler trials, target durations occurred randomly and were not systematically varied.

Filler trials in each block used primes and targets from two of the other lists. For example, if List 1 were being used in the experimental trials, filler trials in block 1 would make use of lists 3 and 4, paired appropriately or paired with targets from the other list depending on the cue validity condition. Block 2 would use lists 2 and 4, and block 3, lists 2 and 3.

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 72 practice trials. (See Appendix 1.)

In the high validity condition, of the 72 randomly ordered practice trials, 36 consisted of related pairs, 12 consisted of primes paired with unrelated targets from the same list, and 24 consisted of targets preceded by a neutral prime of 5 X's. In the medium cue validity condition, 24 practice trials were of related pairs, 24 trials of unrelated pairs, and 24 trials of targets preceded by a neutral prime. In the low cue validity condition, 12 practice trials consisted of related pairs, 36, of unrelated pairs and 24 of targets paired with the neutral prime.

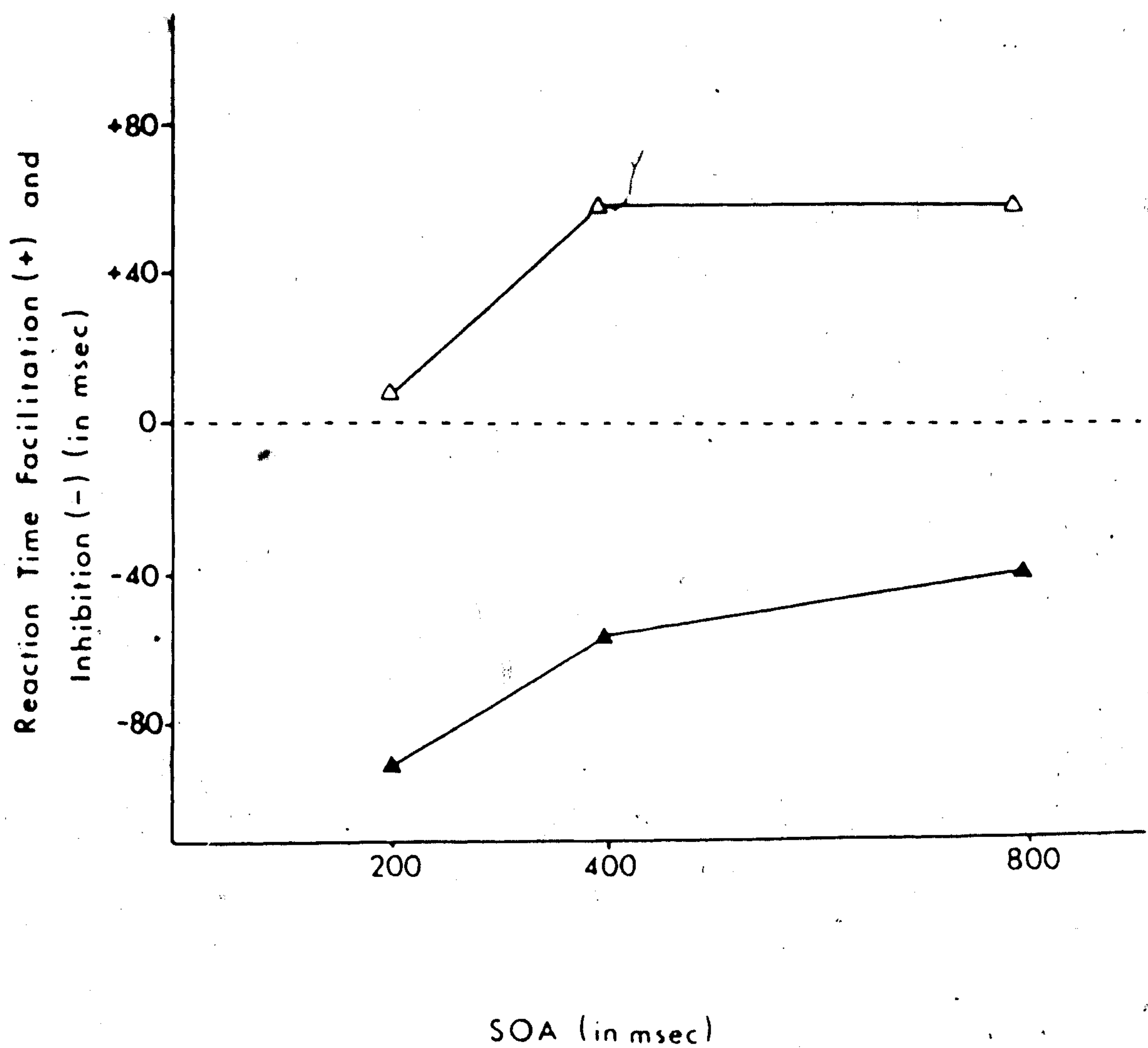
III. RESULTS

A. Reaction Time Data

An analysis of variance was carried out on reaction time data with variables cue validity, SOA, target duration, whether the prime was a word or a string of X's (prime type), and, if a word, whether related or unrelated (prime relatedness). The variable blocks was not included in the reaction time data analysis. Although error rates were low, less than 2% overall, a few subjects had many errors especially with short target duration trials. Since the data were retained only from correct trials, there would have been too much missing data involving too many empty cells especially at short target durations for a valid analysis. With blocks retained as a variable, each cell potentially included data from only 4 trials; with blocks removed, each cell could include up to 12 data points. An analysis was also done with blocks as a variable, but with only the two longer target durations. Reference will be made to this analysis for significant interactions with blocks.

Figure 1 shows reaction time facilitation with related primes and inhibition with unrelated primes as a function of SOA. Facilitation and inhibition were calculated by subtracting mean reaction times when primes were related or unrelated words from those when primes were a string of X's. Inhibition effects were greatest at the shortest SOA, [illegible] msec, measuring on average 91 msec, and decreased as a

Figure 1: Reaction Time Facilitation with Related Primes and Inhibition with Unrelated Primes as a Function of SOA.



Reaction Time Facilitation (+) and Inhibition (–) (in msec)
+80
+40
0
-40
-80
200
400
800
SOA (in msec)

function of SOA. Facilitation, on the other hand, appeared only at longer SOA's of 400 and 800 msec. Inhibition at the 200 msec SOA was significant by two-tailed t-test using the appropriate error term from the analysis of variance, $t(132) = 4.58$, $p<.001$. Inhibition at the 400 msec SOA was also significant, $t(132) = 2.77$, $p<.01$.

The interaction of SOA with prime type and prime relatedness shown in Figure 1 was not significant. Averaged over both related and unrelated word prime trials, however, the effect of net inhibition at 200 msec SOA trials and net facilitation at longer SOA's for word primes as compared to neutral primes was highly significant, $F(2,99) = 13.47$, $p<.001$. This significant interaction of prime type and SOA is reflected in Figure 1 in the increase in facilitation and decrease in inhibition with increasing SOA.

The analysis shows a significant main effect for prime relatedness, $F(1,99) = 119.71$, $p <.001$. Trials with related primes (mean reaction time 731 msec) were on average 61 msec faster than trials with unrelated primes (mean reaction time 792 msec). On average, related primes showed 37 msec of facilitation and unrelated primes showed 61 msec of inhibition as compared to neutral primes, an interaction which was also significant, $F(1,99) = 108.92$, $p<.001$. Trials with word primes were significantly slower (mean reaction time 767 msec) than trials with neutral primes (mean reaction time 755 msec) overall, $F(1,99) = 6.06$, $p <.05$.

There was no significant main effect for cue validity or interaction of cue validity with SOA. Figure 2 shows that for all cue validity conditions the trend was for inhibition to be greatest at the 200 msec SOA and to decrease at longer SOA's. Facilitation did not occur at the 200 msec SOA, and tended to remain constant at SOA's of 400 and 800 msec. A separate analysis of variance using only trials with unrelated primes and their controls showed this interaction as significant, $F(2,99) = 3.93$, $p<.05$. By t-test, inhibition in the low cue validity condition at the 200 msec SOA was significant, $t(108) = 2.36$, $p<.05$.

Figure 3 shows absolute facilitation and inhibition effects in the 3 cue validity conditions. As the histogram shows, both inhibition and facilitation increase with greater cue validity, but whereas with inhibition, there is a greater increase between the low and medium cue validities, with facilitation, the increment is greatest between the high and medium cue validities, $F(2,99) = 3.42$, $p < .05$.

There was a significant main effect for target duration, $F(2,198) = 83.42$, $p < .001$, with shorter reaction times as target duration became longer. Target duration, did not, however, interact significantly with other variables.

The analysis with blocks indicated a significant main effect, $F(2,198) = 17.26$, $p < .001$, with reaction times tending to become shorter as a function of blocks. Blocks also interacted significantly with cue validity and the two

Figure 2: Reaction Time Facilitation with Related Primes and Inhibition with Unrelated Primes for 3 Cue Validity Conditions as a Function of SOA.

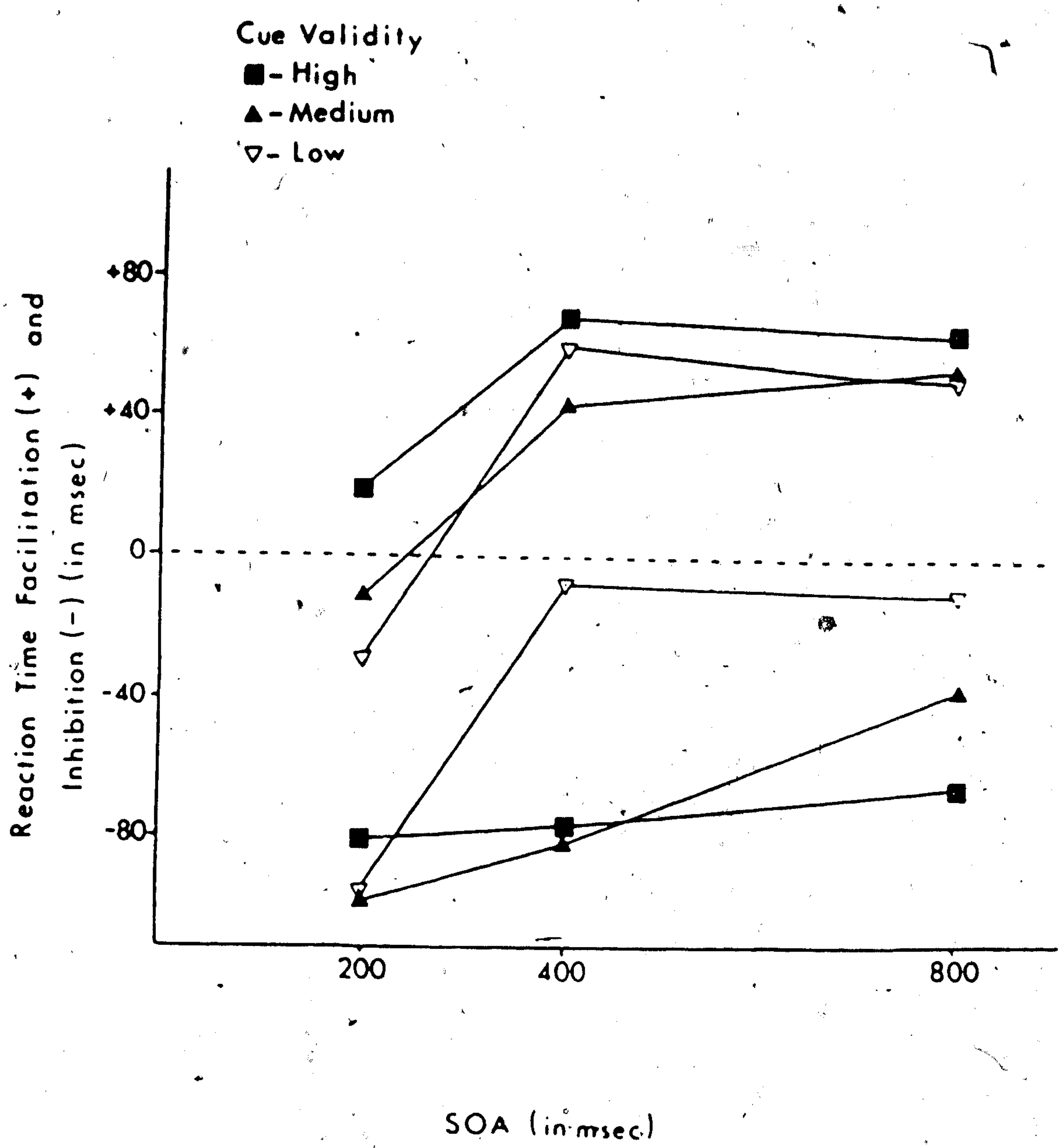
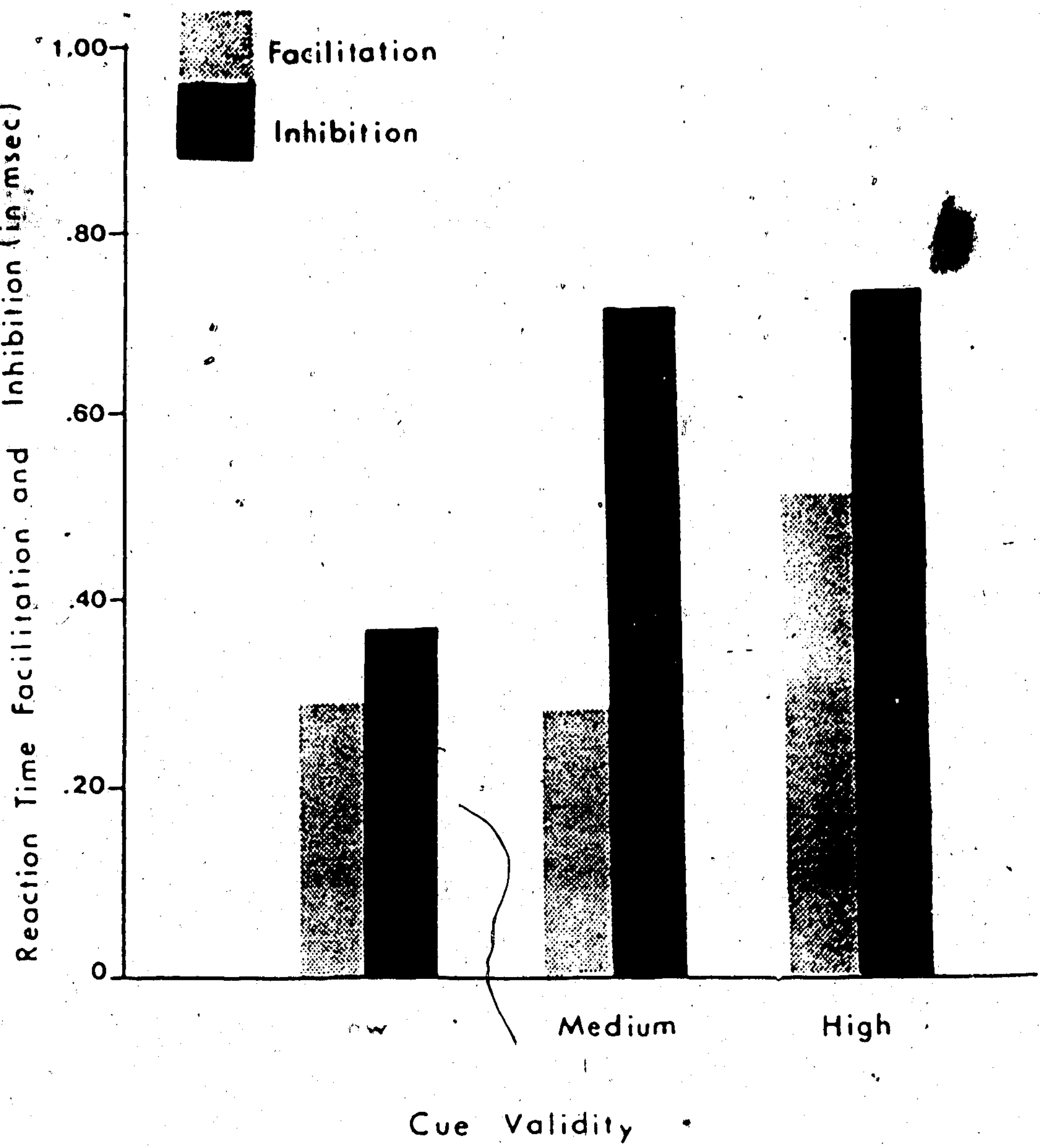

Cue Validity
■ - High
▲ - Medium
▽ - Low
+80
+40
0
-40
-80
Reaction Time Facilitation (+) and Inhibition (-) (in msec)
200
400
800
SOA (in msec)

Figure 3: Reaction Time Facilitation and Inhibition Effects for 3 Cue Validity Conditions.



Facilitation
Inhibition
Reaction Time Facilitation and Inhibition (in msec)
1.00
.80
.60
.40
.20
0
Medium
High
Cue Validity

target durations used in this analysis, $F(4,198) = 2.52$, $p < .05$. This interaction, however, based on a small number of observations per cell, was difficult to interpret and may be a Type 1 error.

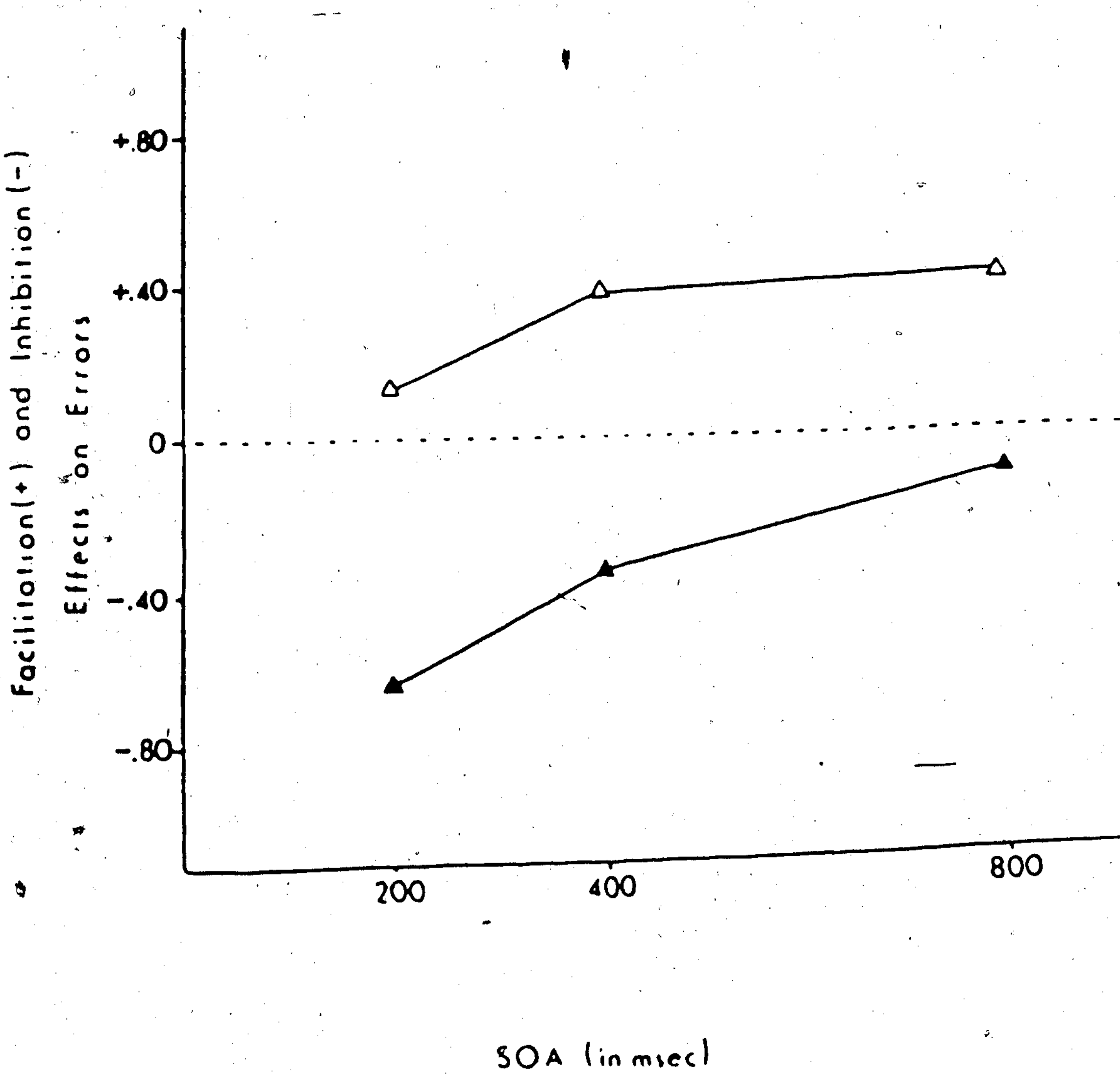
B. Error Data

The frequency of errors in the experiment was very low, with only 1.77% of experimental trials occasioning incorrect responses. The results of the analysis of error data must, therefore, be considered less meaningful than that of the reaction time data. Interpretation is also more difficult because of the existence of floor effects. With this note of caution, it may be stated that the analysis of error data yielded a pattern of effects similar to that obtained from the reaction time data.

Figure 4 shows overall facilitation and inhibition effects on errors as a function of SOA. Inhibition is greatest at the shortest SOA, 200 msec, with, on average, .65 more errors with an unrelated prime than with a neutral prime. This inhibition is significant by t-test, $t(132) = 3.39$, $p < .001$. This inhibition decreases and is not significant at longer SOA's.

Again, the interaction of SOA with prime type and prime relatedness shown in Figure 4 was not significant. Averaged over both related and unrelated word prime trials however, the effect of net inhibition in 200 msec SOA trials and net facilitation at longer SOA's for word primes as compared to

Figure 4: Facilitation and Inhibition Effects on Errors as a Function of SOA.


Facilitation(+) and Inhibition(-)
Effects on Errors
+.80
+.40
0
-.40
-.80
200
400
800
SOA (in msec)

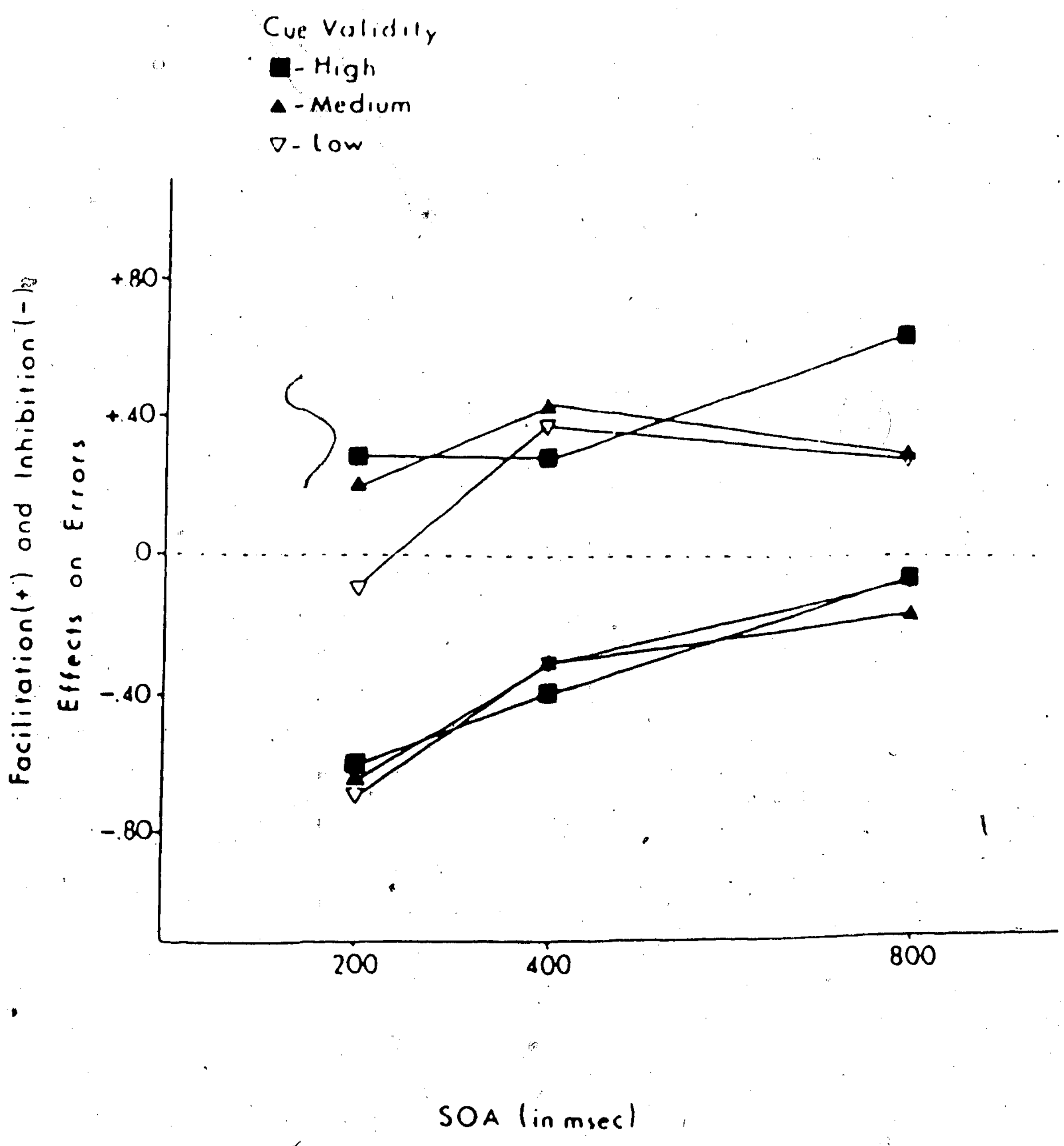
neutral primes was highly significant, $F(2,99) = 21.32$, $p<.001$. Mean errors in the word prime condition were 1.05 at the 200 msec SOA, as compared to .79 for the neutral prime; .89 at the 400 msec SOA as compared to .91 for the neutral prime, and .66 at the 800 msec SOA as compared to .81 for the neutral prime. This significant interaction of prime type and SOA is reflected in Figure 4 in the increase in facilitation and decrease in inhibition with increasing SOA.

The analysis again shows a significant effect for prime relatedness, $F(1,99) = 173.04$, $p <.001$, with, on average, .50 more errors with unrelated primes (mean errors 1.10) than with related primes (mean errors .60). On average, related primes showed .31 fewer errors and unrelated primes .36 more errors than neutral primes, a significant interaction, $F(1,99) = 167.29$, $p<.001$.

There was no significant main effect for cue validity or interaction of cue validity with SOA or target duration. Figure 5 shows that for all cue validity conditions, the general trend was for interference to be greatest at the 200 msec SOA and to decrease as a function of SOA. Facilitation, on the other hand, tended to increase with SOA.

There was a significant effect of target duration on errors, with fewer errors as target duration increased, $F(2, 198) = 313.95$, $p <.001$. Target duration also interacted with prime relatedness, $F(2,198) = 34.10$, $p <.001$, such that there was a larger decline in errors with increases in cue duration for the unrelated trials than for the related

Figure 5: Facilitation and Inhibition Effects on Errors for 3 Cue Validity Conditions as a Function of SOA.


Cue Validity
■ - High
▲ - Medium
▽ - Low
Facilitation (+) and Inhibition (-)
Effects on Errors
+.80
+.40
0
-.40
-.80
200
400
800
SOA (in msec)

trials. Since error rates were much lower for the related trials it is possible that the smaller decline in errors for the related trials may represent a floor effect.

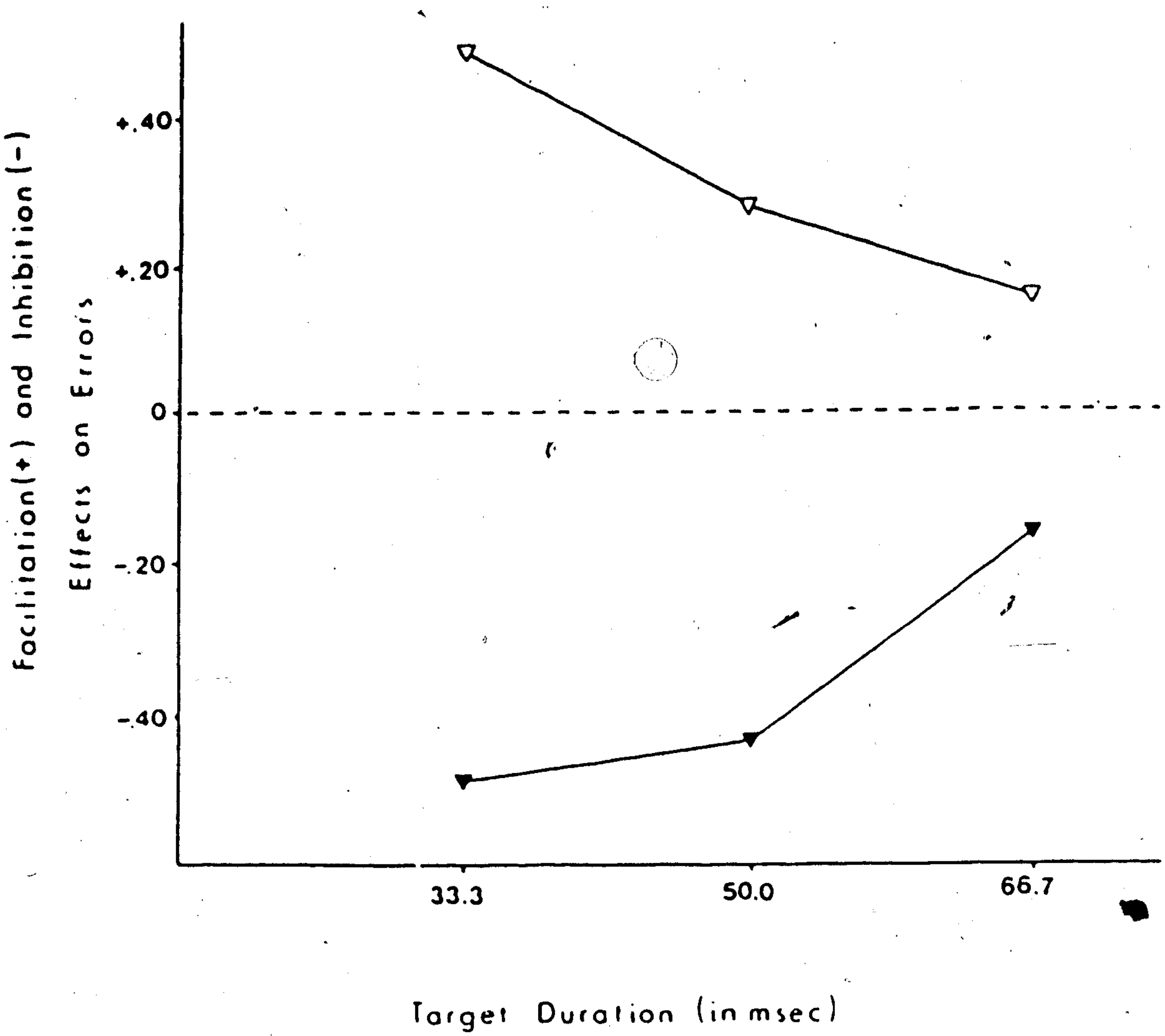
Target duration also interacted with prime type and prime relatedness, $F(2,198) = 24.03$, $p<.001$. Figure 6 shows that while facilitation and inhibition were both greatest and approximately equal with the 33.3 msec target duration and decreased at longer target durations, there was a much greater decrease in facilitation at the 50 msec target duration, with the amount of inhibition changing very little. At the 66.7 msec target duration, inhibition and facilitation were about equal.

Again, there was a significant main effect for blocks, $F(2,198) = 91.06$, $p<.001$, with errors becoming fewer over blocks.

An interaction of blocks with cue validity showed the high validity condition with the greatest number of errors in the first block, but having the fewest errors of the 3 cue validity conditions by the second and third blocks, $F(4,198) = 3.62$, $p<.01$.

Blocks interacted with target duration, $F(4,396) = 16.92$, $p<.001$, with the 33.3 msec target duration trials making the greatest improvement of the 3 target durations in terms of number of errors between the first and second blocks, again, a possible floor effect, as error rates for the 50 and 66.7 msec target durations approached the minimum possible.

Figure 6:Inhibition and Facilitation as Reflected in Number of Errors as a Function of Target Duration.


Facilitation(+) and Inhibition(-)
Effects on Errors
+.40
+.20
0
-.20
-.40
33.3
50.0
66.7
Target Duration (in msec)

A floor effect may also be indicated in an interaction of blocks with prime relatedness. Trials with unrelated primes showed a somewhat greater improvement in terms of fewer errors over blocks than trials with related primes did, $F(2,198) = 3.51$, $p<.05$.

Blocks also interacted with prime type, $F(2,198) = 3.07$, $p<.05$. More errors were made with word prime trials in the first block, but by the second and third blocks errors were somewhat fewer with word prime trials.

An interaction of blocks with prime relatedness and prime type, $F(2,198) = 7.71$, $p<.001$, showed a much greater incidence of inhibition than facilitation being exhibited in error data from the first block. This inhibition decreased over blocks, becoming slightly less than facilitation by the third block, while facilitation remained relatively constant.

Other higher order interactions included an interaction of blocks with cue validity, target duration and prime relatedness, $F(8,396) = 1.99$, $p<.05$; an interaction of blocks with cue validity, SOA, target duration, and prime relatedness, $F(16,396) = 2.09$, $p<.01$, and an interaction of blocks with SOA, target duration, prime relatedness, and prime type, $F(8,396) = 2.42$, $p<.05$. These interactions are difficult to interpret and may indicate a combination of practice effects and floor effects.

IV. DISCUSSION

Results of the experiment appear to confirm that significant inhibition can take place in a priming experiment at an SOA as short as 200 msec, and under conditions where the subject is not directing conscious attention to the prime. The existence of this inhibition supports the Walley and Weiden theory which suggests that activation of a logogen corresponding to a word causes generalized inhibition of other logogens regardless of whether that logogen is activated by perceptual input, top-down cortical connections or both.

The fact that both reaction time and error data show the same pattern of effects argues against any contamination by a speed accuracy trade off (Pachella, 1974).

The pattern of inhibition and facilitation obtained, however, while very different from that predicted by Posner and Snyder's two process theory is also somewhat different from that predicted by the theory of Walley and Weiden. It was expected that facilitation and inhibition would occur at all SOA's in all conditions but in the high validity condition both should become greater as SOA increased due to top-down activation of the target logogen caused by attention and expectancy.

In fact, there was no significant interaction of cue validity with SOA. In all conditions, and in both reaction time and error data, facilitation was nonexistent at the 200 msec SOA. In reaction time data, there was even a suggestion of inhibition with related primes at this SOA (See Figure 2). Facilitation appeared at the 400 msec SOA, and, remained relatively constant between 400 and 800 msec SOA.

Inhibition, on the other hand, was greatest at the 200 msec SOA in all conditions and with both reaction time and error data, and decreased at longer SOA's. This is a pattern of inhibition exactly opposite to that predicted by Posner and Snyder's two process theory. In reaction time data, inhibition seemed to decrease faster between the 200 and 400 msec SOA's for the low cue validity condition than for the other conditions.

An explanation [illegible] the above effects may be as follows. At the 200 msec [illegible] logogen corresponding to the prime should still have been fully activated above firing threshold at the onset of the target thus causing generalized inhibition of other logogens. If the target was unrelated to the prime word, its activation was therefore strongly inhibited thus lengthening reaction times and increasing errors. Evidence presented here indicates that it is not necessary for consciously directed attention to be directed to the prime for it to achieve this level of activation. There was no significant difference between cue validity conditions in the amount of inhibition at the 200 msec SOA.

If, at this SOA, the target was related to the prime, facilitation was also tempered by this initial strong inhibition from the fully activated prime logogen. Thus, while reaction times at this SOA for related primes are shorter and there are fewer errors than for a target unrelated to the prime, compared to the neutral condition there is little facilitation and may in fact be some slight inhibition.

At the 400 msec SOA, inhibition resulting from previous activation of the prime logogen had 200 msec more in which to dissipate than at the 200 msec SOA. It is interesting to note, therefore, that reaction time data shows that in the low cue validity condition, where subjects were presumably not directing conscious attention to the prime, inhibition decreases abruptly from 95 msec to 7 msec between the 200 and 400 msec SOA's. It could be assumed, therefore, that it is top-down activation of the logogen of the primary associate, corresponding to expectancy, that maintains a relatively high level of inhibition in the medium and high cue validity conditions at the 400 msec SOA.

Considerable facilitation is also seen at the 400 msec SOA. It appears that, in priming, initial inhibition dissipates more quickly than facilitation unless maintained by attention and expectancy.

At the 800 Msec SOA, with a further 400 msec in which the inhibition caused by prime logogen activation would be able to dissipate, there is no further decrease in inhibition in the low validity condition. The slight decrease seen in Figure 1 seems to be primarily the result of a decrease in the medium cue validity condition. This implies that initial inhibition caused by activation of the prime dissipates within at least 200 msec unless protracted by top-down activation due to post lexical attention and expectancy as in the higher cue validity condition.

Facilitation does not increase between the 400 and 800 msec SOA's. There is also no difference in facilitation between the 3 cue validity conditions. This lack of symmetry between inhibition and facilitation effects is not predicted by the Walley and Weiden theory. In part, it may be due to a floor effect for reaction times, such that high and medium cue validity cannot achieve greater amounts of facilitation to match their greater inhibition. Still, the fact that low cue validity facilitation appears to exceed that of the medium cue validity, almost matching the high cue validity, while its inhibition is so much less than in the other two conditions, is difficult to explain.

Why did Neely in his two studies (1976, 1977) not obtain the same pattern of results? One major difference in Neely's studies is the nature of the task: Neely used a lexical decision task rather than a pronunciation task. Lorch, Balota & Stamm (1986) in 3 experiments compared the effects of unrelated primes for a lexical decision task and a naming task. They found, with a prime of 1400 msec duration, an ISI of 50 msec and a target duration that lasted until a response was made, that there were large inhibition effects for the lexical decision task and no inhibition effects for the naming (pronunciation) task. They interpreted their results as showing that inhibition effects in the lexical decision task did not affect recognition processes, but rather post-lexical decision processes. West and Stanovich (1982) using sentence contexts rather than primes, also found greater inhibition in the lexical decision task than the naming task. They, too, concluded that post-lexical decision processes were responsible for the larger inhibition effects in the lexical decision task. This would explain why Neely obtained larger inhibition effects at longer SOA's whereas inhibition in this study decreases with SOA. It does not, however, explain why Neely did not get the same early strong inhibition. Otherwise, in Neely's 1976 study, results do not seem to be all that dissimilar to the present study. Neely used SOA's of 360, 600 and 2000 msec. He found inhibition relatively constant as a function of SOA with slightly greater inhibition at 360 msec than at 600 msec. At the 360 msec SOA, his facilitation was significantly less than at later SOA's.

One obvious conclusion would be that in the pronunciation task, as opposed to the lexical decision, response competition is involved. The early inhibition in this study may be caused by the prime activating articulatory mechanisms which interfere strongly at the short SOA with the articulation of the target. Balota and Lorch (1986), however, in both a lexical decision task and a pronunciation task did not find this early strong inhibition.

Another possibility is raised by the fact that in Neely's studies as well as in the Balota and Lorch experiment, prime and target were presented at the same position on the screen, one after the other. In the present study, prime and target appeared above and below a fixation point. It is possible, therefore, that in Neely's study, the target may have acted as a mask for the prime, interfering with processing that would otherwise have caused strong inhibition. Terminating the processing of the prime in this way would terminate the inhibition caused by the prime, but it would not affect the facilitation of the logogen corresponding to the primary associate which had already occurred. Thus, it is not inconsistent with this masking hypothesis that Neely did obtain facilitation at his 250 msec SOA. Antos (1979), in the study mentioned earlier, also presented his primes and targets in the same position on the screen. His reported interference at the 200 msec SOA had a mean of 39 msec, much less than the 95 msec inhibition found in the present study. Possibly, in the Antos experiment, due to a difference in the intensity of the target, or to some other factor, less masking occurred so that some, though weakened inhibition was still manifested.

It could still be argued that, masked or not, the inhibition at the 200 msec SOA was caused by response competition. An unpublished study from this laboratory, however, using exactly the same method as the present experiment, except that the task was a lexical decision, did find significant inhibition, although not as much as in the pronunciation task, at the 200 msec SOA. Furthermore, the reason subjects were allowed to correct their responses was that it was felt that if response competition played a significant role in inhibition effects, subjects would, as in Stroop experiments from this laboratory, recognize immediately if they had made the wrong response and correct it. This sort of correction, however, occurred very seldom.

It is suggested, therefore, that although a small amount of the early inhibition in the pronunciation task may be accounted for by response competition, it can by no means all be accounted for in this way. The hypothesis that early strong inhibition was masked by the target in Neely's experiments could be tested by examining the effects of a masked prime as compared to an unmasked prime at short SOA's in an experiment similar to the present study.

One issue that has been raised with the cost benefit paradigm generally is whether the neutral prime is indeed neutral. DeGroot, Thomassen, and Hudson (1982), for example, found that relative to a neutral prime consisting of the word "blank", a row of crosses inhibited the processing of the following target. They suggest that in studies using a row of crosses as a neutral prime, facilitation effects have been overestimated and inhibition effects underestimated.

Jonides and Mack (1984) have criticized the cost benefit paradigm and enumerated its pitfalls. They suggest, for example, that reaction times to neutral primes may vary as a function of SOA for unknown reasons and, in this way, affect measures of inhibition and facilitation. Furthermore, they point out that it is really impossible to equate neutral and informative primes on every dimension excluding the information in the informative prime.

In the present study the same neutral prime of a string of X's has been used as that used in many other studies including those of Neely. Reaction times to neutral primes were found to vary very little as a function of SOA. It is acknowledged that it is impossible to know how processing of this neutral prime differed from that of the theoretical purely neutral prime. While keeping this caveat in mind, however, it should be possible to compare patterns of facilitation and inhibition found in this study to those found in other similar studies.

It was also predicted by the Walley and Weiden theory that in this study inhibition would be greatest at the shortest target duration, where an unrelated prime would inhibit perception of the target which was not very strongly activated. This was not supported by reaction time data but is supported by error data (See Figure 6). Figure 6 also shows that in terms of number of errors facilitation was also greatest at the shorter target durations, as predicted. Since error data consists of information from different trials than does reaction time, it is not surprising that this effect should show up in one set of data and not the other. In effect, in reaction time data, trials on which subjects had difficulty in perceiving the target were eliminated, leaving only the trials on which they were successful in detecting it. The fact that target duration does interact with the amount of facilitation and interference does, however, add weight to the idea that these inhibition and facilitation effects are occurring in early processes of recognition rather than in response mechanisms.

In brief, the present study has shown evidence in a naming task for strong early inhibition and no measurable facilitation at a short SOA, with inhibition decreasing and facilitation increasing as a function of SOA. These data are supportive of and have been interpreted within the context of the Walley and Weiden theory which explains inhibition in a priming task in terms of lateral inhibition between logogens at the highest level of a hierarchy of perceptual feature analyzers. Data seem to show a pattern of inhibition directly contrary to that predicted by the Posner and Snyder two process theory.

Further research using strongly associated primes and targets and a range of short SOA's might be instructive in clarifying the time course of this early inhibition. The Walley and Weiden theory also predicts that inhibition in selective attention will become stronger as a function of level of arousal. Manipulation of level of arousal within a priming task would also provide some useful data.

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VI. 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