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ABSTRACT

College undergraduates participated in a cost/benefit analysis and a speed/accuracy analysis of semantic priming in a lexical decision task. In both studies, half the cues were neutral and half were words from 30 semantic categories. Word targets were the category names, and nonword targets were derived from those names. The cue-word was valid 80% of the time and invalid 20% of the time. In the first experiment, cue time, a between groups factor, was either 200, 300, 400, 500, or 700 milliseconds (msec). It was found that valid cues produced facilitation at cue times as short as 400 msec, and invalid cues produced inhibition at cue times as short as 200 msec. The second experiment used a response-signal technique to collect information about the speed/accuracy trade-off in a lexical decision task. Cues were always presented for 800 msec, and targets were presented for varying time periods. Results indicated that subjects are capable of trading accuracy for speed, invalid cues can lower discriminability, and response bias in an active component in priming. The two experiments indicate that discriminability, criterion bias, and response bias seem to be integrated in providing facilitation, but that simple applications of criterion bias or response bias alone do not adequately explain the facilitation effect. (Author/GT)

CENTER FOR THE STUDY OF READING

Technical Report No. 113

PROCESSING FACILITATION IN A LEXICAL DECISION TASK

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Preliminary Note

Any adequate model of reading requires the incorporation of a process that allows prior information to affect ongoing word processing. This type of process is a subset of processes that are sometimes referred to as "top-down" processes. The justification for hypothesizing such mechanisms in reading is found in papers like Rumelhart's ("Toward an interactive model of reading", 1977).

One frequently mentioned finding that is used to point out the need for top-down considerations in word recognition is the semantic-priming effect found in lexical decision tasks. Briefly, priming studies show that the efficiency of processing a word can be affected by the semantic relationship of that word to the word(s) previously processed. These tasks are probably not perfect reflections of what occurs in the normal reading of text. However, they permit the fine degree of experimental control that might be necessary to discover what potentially could be occurring in reading. A good model of such word recognition effects could be a solid first step toward understanding how text is processed with efficiency by competent readers.

The criterion bias explanation claims that content allows the determination of what word is present without having to completely process the word. For example, if the word "BIRD" preceded the presentation of "PARAKEET," the latter might be recognized without complete processing. This "sophisticated guessing" model would suggest that when we read, we process only enough features of words to guess what the word must be. The discriminability explanation claims that content actually aids in the complete processing of the word in some manner. The fact that people can make accurate guesses based on less than complete information is probably not worth disputing, but having the ability does not mean that is how facilitation is always realized. Consequently, it is important to see if there are any increments in discriminability as a function of content.

Abstract

A cost/benefit and a speed/accuracy analysis of semantic priming in a lexical decision task provided information relevant to the automatic/conscious facilitation distinction made by Neely (1977) and Posner and Snyder (1975b). Information is also provided about the operation of discriminability, criterion bias, and response bias in the facilitation. In both studies, half the cues were neutral and half were words. Word-cues were instances from 30 semantic categories. Word targets were the category names, nonword targets were derived from those names. The cue-word was valid 80% of the time and invalid 20% of the time. In Experiment 1, cue time, a between groups factor, was either 200, 300, 400, 500, or 700 msec. Valid cues produced facilitation in RT at cue times as short as 400 msec. Invalid cues produced inhibition at cue times as short as 200 msec. These results, while similar in many respects to Neely's (1977), raise doubts about an "inhibitionless" kind of automatic facilitation in primed lexical decisions. Response bias and simple applications of criterion bias models are also ruled-out as the sole explanation of the facilitation. Experiment 2 used a response-signal technique to collect information about the speed/accuracy trade-off in a lexical decision task. Six college students participated in 10 sessions each. Cues were always presented for 800 msec, targets were variably presented within subjects for either 100, 200, 300, 450, or 600 msec. Results indicate that: (a) subjects are capable of trading accuracy for speed; (b) invalid cues can lower discriminability; (c) response bias is an active component in priming; (d) previous studies

that ignore the percent correct data, may be misleading. Taken together, the experiments indicate that discriminability, criterion bias, and response bias seem to be integrated in providing facilitation, but that simple applications of criterion bias or response bias alone do not adequately explain the facilitation effect.

Processing Facilitation in a Lexical Decision Task

A fundamental finding of lexical decision experiments is that the amount of time to decide that a letter string (e.g., NURSE) is a word is shorter if the preceding item was a semantically related word (e.g., DOCTOR) than if it was a semantically unrelated word (e.g., BUTTER) (Meyer & Schvaneveldt, 1971). This "semantic-priming effect" requires that a theory of word recognition must account for why prior context affects recognition. Some recent studies have focused on the possible mechanisms underlying these semantic-priming effects (e.g., Neely, 1977; Tweedy, Lapinski, & Schvaneveldt, 1977). A general model of processing facilitation has been developed by Posner and Snyder (1975a, 1975b), who postulate two independent processing modes under which facilitation can occur. One mode is "automatic activation," which is the result of past learning. It operates without intention or conscious awareness, and occurs in parallel with other mental activity. The second mode, "conscious control," is the result of the application of a specific capacity-limited mechanism. It always operates with intention and conscious awareness, and it can generate inhibition of other activities. Posner and Snyder suggest that a word is recognized when the "memory location" corresponding to that word is activated above some threshold. For any given word, this activation is thought to occur automatically when the word itself is presented. They further suggest this automatic activation spreads out to nearby memory locations. This means that the activation will spread to memory locations that correspond to words that are semantically related to the word presented. In this fashion, the recognition of a certain target word could be automatically facilitated by preceding the target presentation with a semantically related cue word. The activation that spreads as a result of cue presentation raises the activation level of the target-memory location. The target-memory location would then need to have less activation from actual target presentation to reach its threshold than if the target word were not semantically related to the cue. However, if the cue and target were unrelated, the activation in non-target memory locations would not inhibit target recognition.

A limited capacity attentional mechanism can also affect cued-word recognition according to Posner and Snyder. This process allows the readout from only one memory location at a time. Time is needed to shift from one location to another, and this time increases with the distance between locations. Thus, the semantic priming effect might exist because shifting time is less to nearby than to more distant memory locations (Neely, 1977; Posner & Snyder, 1975a).

A lexical decision study by Fischler (1977) claimed support for automatic activation. Subjects were presented with two letter strings on each trial and had to decide if both strings were words. Displays contained either two words, two nonwords or one of each. Out of the 16 trials that all subjects received, seven contained two words, none of which were semantically related pair. This presentation of only non-associated pairs was done to discourage subjects from consciously expecting related pairs.

Finally, on trial 17, half of the subjects received two related words and half the subjects received two unrelated words. Decision latency for the related pair was shorter than for the unrelated pairs. This apparently demonstrates automatic activation, since there was no reason for subjects to have developed a conscious expectancy for semantically related words.

On the other hand, Tweedy et al. (1977) found evidence for conscious strategies in a lexical decision study. The response latency for validly and invalidly cued targets was measured at three levels of cue validity: 1/8, 1/2, and 7/8. Valid cues were cues semantically related to the target word and invalid cues were cues semantically unrelated to the target word. If "ANIMAL" was a target, "BEAR" would be a valid cue, whereas "APPLE" would be an invalid cue. Cue validity is the ratio of the frequencies of occurrence of valid to invalid cue types in the experiment. Tweedy et al. found that the magnitude of the priming effect was positively correlated to the degree of cue validity. They attributed this to strategies, ruling out automatic activation as the only source of facilitation.

One of the above studies found evidence for automatic activation and one found evidence for conscious strategies. However, these experiments were not adequately designed to determine if <u>only</u> one or the other mode of processing was responsible for the effect. Also, whether Fischler's (1977) finding is evidence for automatic activation, relies heavily on the questionable assumption that subjects will have given up any conscious attention shifting strategies after seeing relatively few unrelated word pairs. These strategies might be more than lab-learned strategies. If this is the case, it would not be surprising to find that they are very resistant to any extinction type process. The Tweedy et al. (1977) study appears to demonstrate the operation of some kind of conscious strategies. If RTs were known for a non-cued or baseline condition there would be a way to determine whether the increasing priming effect is due to increasing facilitation of validly cued targets or increasing inhibition due to invalidly cued targets. The addition of a neutral cueing condition in these lexical decision studies would provide a baseline for the separation of benefit due to related (valid) cues and cost due to unrelated (invalid) cues.

Posner and Snyder (1975a, 1975b) have developed a cost/benefit methodology for detecting when facilitation is being produced by automatic activation, conscious expectancies, or both. In an application of this methodology to the lexical decision task, subjects are presented with three cue-to-target relationships: valid, invalid, and neutral. In general, valid cues are cues that provide legitimate information about items that follow them. Invalid cues provide misleading information. Validly cued items might be called expected, and invalidly cued items would be called unexpected. A neutral cue might be merely a series of X's or any cue which is known by the subject not to provide any stimulus or response information about the target. With respect to the neutral cue, valid cues can produce a facilitation or benefit and invalid cues produce an inhibition or cost in target processing. Given these basic cueing conditions, the methodology attempts to control the likelihood that subjects will commit their conscious attention to the pathways activated by the cues. This control is gained by manipulating overall cue validity and/or amount of time between cue onset and target onset (i.e., stimulus onset asynchrony or SOA). If cues are relatively unreliable or SOA is very short, it is assumed that subjects would be less likely to commit any conscious attention. Benefit is measured by the difference in processing times between targets in the valid and neutral conditions; cost is measured by the difference between the neutral and invalid conditions. If within this generic design a particular experiment finds significant benefit in the absence of cost, the role of automatic activation is established. This is because automatic activation is hypothesized to be inhibitionless, whereas attentional processes are hypothesized to be inhibitory. If cost is always present, the cue's effect is hypothesized to be at least partially a function of conscious attentional processes (Posner & Snyder, 1975a, 1975b).

Two recent studies have applied the cost/benefit methodology to a lexical decision task. Neely (1976) displayed a cue which the subject read but did not respond to. The cue was either a series of Xs or a word, and SOAs were 360, 600, or 2000 msec. The data showed that for word targets there was a significant cost factor, but that cost did not increase with longer cue times as would be expected from the Posner-Snyder theory. On the other hand, the amount of facilitation was greater in the 600- or 2000-msec conditions than in the 360-msec condition.

A second study by Neely (1977) was interpreted as being much more supportive of the Posner-Snyder model. Any one of four unrelated category names could appear as a cue. Two of the category names were used in a "natural" priming condition. In this condition, subjects were told to expect instances in the category named by the cue. The other two categories were used in an experimenter-defined priming condition. In this condition, subjects were told to expect instances from the category not named by the cue. For example, if the cue was "BUILDING", instances from the category "BODY PARTS" could be expected (e.g., "ARM"). If "BODY" was the cue, instances from "BUILDING" were to be expected (e.g.,window). It was reasoned that the cues from this second condition could only produce benefit for their unrelated-expected targets via conscious attention. This condition was also assumed to allow automatic facilitation for target words taken from the category named by the cue. These category instances would be semantically related but not consciously expected. The range of SOA was 250 msec to 2 sec. Findings in both the natural and experimenter-defined priming conditions demonstrate the operation of a limited-capacity conscious mode of facilitation at SOAs of 700 and 2000 msec. The benefit connected with expected targets was found coincidentally with cost for all unexpected targets. This cost or inhibition suggests the operation of a limited capacity processing. A benefit was found for unrelated targets as long as they were expected. Also, there was cost for related targets if they were unexpected. The fact that experimenter-defined rules of expectancy that are counter to natural pre-existing expectancies can direct facilitation and inhibition effects is sound evidence of the operation of some kind of a conscious, attentional facilitation. Neely's argument for a second, less conscious, and more automatic processing facilitation, relies on what occurred in the natural and experimenter-defined groups when SOA was decreased to 250 msec. First, in the natural priming condition, benefit still existed for expected targets, but there was no apparent cost for unexpected targets. Second, in the experimenter-defined condition there is no more apparent benefit for expected items, but processing of unexpected-related targets is now facilitated rather than inhibited as it was at SOAs of 700 and 2000 msec. In accordance with the cost/benefit methodology, Neely argued that the disappearance of cost means that cue-time was insufficient to allow conscious attention-shifting strategies. Thus the existence of benefit without cost was interpreted as evidence of automatic facilitation in lexical decision. On this account, Neely suggests that his results require that a theory of word recognition have two independent mechanisms of facilitation.

There are some other important aspects of Neely's study which need to be taken into account if his results are to be properly interpreted. At the 250 msec SOA several key cueing conditions show evidence of possible speed/accuracy trade-off problems (Pachella, 1974). That is, some conditions which show no cost in RT, do show some cost in terms of errors. In the natural cueing condition, it is clear that a benefit in RT for targets preceded by semantically related cues exists without a cost in errors. However, the disappearance of cost in RT for targets preceded by unrelated cues occurs in conjunction with a cost in errors of 4.3%. There are also similar problems in the experimenter-defined cueing condition. When the target is unrelated to the cue, but expected on the basis of instructions, there is a cost in terms of errors of 5.5%. Also, in the unexpected related condition where a benefit in RT shows up at 250 msec SOA, there is a cost in errors of 2.7%. The only condition among the experimenter-defined cueing conditions which does not show a cost in terms of errors is the unexpected unrelated condition. Neely (1977) using Posner and Snyder's model, claims that the existence of automatic processing is established by finding inhibitionless facilitation (i.e., cost without benefit). Neely's data cannot be said to satisfy this claim unless one is willing to ignore the apparent trade-off in his data.

There is no direct empirical evidence that subjects can trade-off accuracy for speed in lexical decision tasks. Furthermore, even if it is assumed that the trade-off is possible there is no data that estimates the trade-off function. This makes it difficult both to judge what magnitude of trade-off is significant and to estimate the "true" RT. However, since the accuracy in the experiment was close to asymptotic, it would not be unlikely that small differences in accuracy are associated with large differences in reaction time (Wickelgren, 1977).

One additional aspect of Neely's study is an important characteristic of most lexical decision tasks in the literature. All the nonwords in Neely's study were generated by "...changing one letter in a word matched to each of the word targets on the basis of frequency of occurrence in the language, number of letters and number of syllables" (Neely, 1977, p. 235). To distinguish such nonwords from words in one's vocabulary might require looking at each letter carefully. However, the method does generate a heterogenous set of nonwords in the sense that the basic orthographic structures are derived from all different sorts of words. The case for "words" in Neely's study is different. They all belong to a relatively homogeneous set. All instances are from the categories of birds, body parts, and building parts. This might allow correct responding with less than complete stimulus information. For example, if the target word was "SPARROW" a subject would probably only need to process a few of the letters to be able to respond correctly because he already knows that birds are to be expected. As long as the nonwords in the study do not carry many of the orthographic features of words that are known members of the three expected categories, subjects need only obtain the structural aspects of the letter string which would allow it to be distinguished as a member of one of the expected categories. It is true that similar redundancy exists in everyday reading situations. However, it is theoretically important to know to what extent it is responsible for priming effects. Consequently, in the present study nonwords were either derived from an expected target word or derived from an unexpected word. Aside from controlling this possible effect of redundancy, this technique produces information about how cues are used for nonword targets.

Conceptualizations of the cued-lexical decision task can be separated into three different classes of models: (a) semantic comparison; (b) memory search; (c) discrimination. Semantic comparison suggests that the facilitation found in these semantic priming studies is produced by subjects responding on the basis of the similarity between the semantic features activated by the target letter string and the semantic features included in the subject's cue derived expectations (Neely, 1977). This assumes that cue and target are processed to some level of meaning. "Meaning" in the sense used here is representable as a set of semantic features (e.g., Smith, Shoben, & Rips, 1974). A high degree of feature overlap creates a tendency to respond "YES," the string is a word, thus facilitating word decisions. If the semantic features were dissimilar, the tendency would be to say "NO," the string is not a word, thus facilitating nonword decisions. Such a nonword facilitation effect has been found (Neely, 1976, 1977; Schubert & Eimas, 1977). This model must assume that semantic features are present prior to knowing the item is a word. There are some studies that argue that such semantic knowledge is present at what might be called an unconscious level (Wickens, 1972; Marcel, in press). Marcel (in press) has found a semantic priming effect even when subjects are at chance level on detecting the presence of the cue. It has also been found that the probability of a facilitation effect is inversely related to the probability of cue recall (Fischler & Goodman, 1978).

The second conceptualization of lexical decision processes is memory search. This approach is closely associated with network theories of memory (e.g., Collins & Loftus, 1975; Collins & Quillian, 1969). These models assume that memory is structured such that semantically related items are in some analogical sense spatially closer to each other. Proximity then predicts speed of shifting location or the amount of activation which in turn determines the degree of semantic priming from the cue. This model seems to be a useful way to think about the kind of effects that exist in an associative memory. However, the model lacks any strong assumptions about processing.

The discrimination approach conceives of lexical decision as a discrimination task where the words in the study must be discriminated from the nonwords. A second important assumption is that word identification, independent of lexical decision tasks, can be considered a discrimination task. Words can be considered either as forms or as groups of forms (e.g., letters or syllables). Whatever the functional level of representation, identifying a word is viewed as discriminating a form or set of forms from other sets of forms (i.e., other words). A cognitive representation based on features of the letter string must be distinguishable from those representations with which it could be confused. This processing routine can also be understood using common spatial analogies. Addressing that memory location which corresponds to a word in memory requires an address sufficient to arrive at that location. An adequate address points to the correct location out of a set of possible locations. This set of possible locations is less for valid than for neutral cues. Thus, the discrimination task with the valid cue is in some sense easier. The items in the cued population are the only items that the target string would be confused with if the cue was valid. Once again a spatial analogy might be used to describe how the cue operates. The cue points to a vicinity (or neighborhood). Addressing the exact location within the neighborhood can be accomplished with an address sufficient to distinguish places in that vicinity. The above model does not <u>necessarily</u> assume that the facilitation effect is due to fewer features being extracted from validly primed targets. It does assume, however, that the cue word directs how those features that are extracted should be used to calculate the memory location.

Whatever exact form a discrimination model assumes, it must somehow include a mechanism by which cueing allows a more efficient use of the stimulus information in the target. There are three specific ways in which this efficiency could be gained. The first is like a sophisticated guess model and has been given a mathematical description in Morton (1969). It is referred to as the Logogen Model. Without going into the mathematical detail, this model is a criterion bias model and suggests that the context provided by the cue allows us to determine what the target is with fewer sensory features than we would need without a cue.

The second way in which target processing efficiency might be increased is by assuming that some of the basic feature extraction processes can be by-passed when a semantic cue is provided. According to this Verification model, feature extraction provides only enough information to suggest possible words that the target might be (Becker & Killion, 1977). It does not provide sufficient information to determine what the target is exactly. The featural information suggests a number of possibilities in lexical memory. These possible words are like prototypical representations for words and each possibility is compared to the stimulus representation in a visual information store until a match is found. When a valid semantic cue is provided, possibilities for the target are derived from the cue rather than from the target stimulus, thus feature analysis may be by-passed. According to this model, feature analysis operates in parallel with testing cue-derived possibilities. If there is no quick match between the cue derived possibilities and the low level representations, the possibilities suggested by the extracted features are tested.

Directed feature analysis is a third way by which the target stimulus could be processed more efficiently. It assumes that the cue allows a more efficient use of the information extracted from the target stimulus itself. The cue could be useful as soon as feature extraction begins if expectations were strong or after some primary features have been extracted for weaker expectations. For example, if the cue was "FRUIT" and the first letter of the target was "A" we might look for "PPLE." This approach is similar to Verification because those things that are looked for in the target stimulus must be derived from some sort of lexical memory. The main difference between these models is that while both models assume cue and target information to be independent, Verification considers them to contribute independently towards the selection of possibilities. The directed analysis approach suggests they work interactively. According to the Verification model, a cue will facilitate target processing only if the cue allows this by-passing of feature extraction. Consequently, target recognition is either based on cue information or target information but not both at the same time. According to the directed feature approach, the cue information can make target information more useful in the selection of possibilities.

The above three discrimination models can be divided into two types with respect to how they suggest valid cues increase processing efficiency of the target: (a) those models which assume a better use of the available cues (i.e., Verification and directed feature analysis); and (b) those which assume we use less stimulus information altogether (i.e., Morton's Logogen model). The present study will provide evidence to distinguish which of these two assumptions is most useful. This will be accomplished by making the discrimination between words and nonwords in a lexical decision task such that a subject is logically required to look at the entire string to make a correct decision. If valid cues produce facilitation under these conditions, then Morton's model is not completely adequate, since it suggests that a valid cue allows recognition with less stimulus information than is required with no cue. Morton's model and criterion bias models in general argue that cues decrease the amount of target information that is processed before correct responding. The lexical decision task allows this model to be tested. The target can have many of the characteristics of the expected word and still not be a word. By replacing a letter in the expected word so that the replacement letter has features similar to the letter it replaces, the subject is forced into a fairly complete processing of the target, regardless of the cue. If under these circumstances priming is produced, criterion bias models are questionable. If criterion bias models are correct, there should be at least a severe reduction in priming.

The study will also test the adequacy of the Verification as compared to the direct feature analysis models. The Verification model has trouble in providing a good account of cost. It predicts that the effects of an invalid cue are very similar to the effects of the neutral cue, since both of them merely wait for the more discriminating features of the target string to become available. The model appears to have no easy way to explain the increase in cost as a function of cue time. The model might hold that if a wrong cue based verification was in progress that the featural based verification would have to wait. However, that puts invalid-cue targets no more than one verification behind the neutrally-cued targets, while validly primed targets must be one or more verifications ahead. This predicts that cost should never surpass benefit. That is, valid cues can put target recognition way ahead of non-cued targets, but invalid cues are not hypothesized to slow down normal non-cued feature extraction. Neely (1977) reports that cost can be of larger magnitude than benefit at the longer cue times. The directed analysis hypothesis merely assumes that the separation of the three cueing conditions will be a function of the strength with which the subject uses a cue-directed encoding strategy.

In summary, Experiment 1 was designed basically to determine whether: (a) a model for lexical decision requires the inclusion of two independent processes, and (b) a logogen, criterion bias model or a discriminability model provides a more adequate account of the results.

Experiment 1

Method for Cost/Benefit Task

General

Each subject was placed in one of five cue time conditions and participated in two or three 50 min sessions. Session one consisted of instructions and one stimulus set of 252 items, 52 practice, and 200 experimental. Session two consisted of instructional review and two 252 cue-target stimulus sets with a 5 min rest period between sets, except in the 700 msec cue time condition where subjects were run for three sessions, one stimulus set per session.

Subjects initiated each trial by pressing a button which brought some cue to the center of a CRT screen. The cue remained visible for a time period specified by the group the subject was in. Cue termination was coincidental with target string presentation. That is, cue duration and SOA were confounded and the terms will be used interchangeably. The target remained on the screen until the subject responded. Word-nonword responses were made with the right and left index fingers that rested over response keys. Hand to response assignment was counterbalanced across subjects. The word "CORRECT" or "INCORRECT" appeared on the screen following each response, informing subjects of their response accuracy. Also, during the practice trials only, the decision latency in milliseconds was displayed following correct responses.

The cue word was either an instance from the category suggested by the target, a valid cue (V); an instance from some other nonrelated category, an invalid cue (I); or a neutral cue (Neut), the word "NEUTRAL." Since these cueing conditions could occur in conjunction with Word (W) and nonword (NW), six cue-target conditions can be specified: V-W, I-W, Neut-W, V-NW, I-NW, Neut-NW. Half the targets were words and half were nonwords. Half the cues were category instances (i.e., V or I) and half were neutral (i.e., "NEUTRAL").

Materials

Letter strings for the experimental condition were derived from 30 different categories, chosen from the Battig and Montague (1969) norms. All category labels were single words. The 30 categories were divided into three sets of 10 categories each, creating stimulus sets I, II, and III. Ten instances were chosen from each category. All instances were chosen to be instances relatively typical of their category. Although typicality is not known exactly it probably does not vary much across instances. Half of the instances were used as cues in the W condition and half were used as cues in the NW condition. Five nonwords were generated from each category label by changing one letter in the word such that the letter string produced was a pronounceable nonword and such that the features of the substituted letter were usually close to the features of the original letter. For example, the word "FRUIT" could be made to be the nonword "FROIT." This was done to compel the subject to fully process each letter string in order to make a correct response. The cue in the neutral condition was always the word "NEUTRAL."

Design

Half of the cues were instances in some category and half were the word "NEUTRAL." The word "NEUTRAL" was used here instead of the commonly used plus signs or X's to control the tendency subjects displayed in a pilot study to respond to the second linguistic event. Subjects reported, and the data confirmed, that when X's were used as the neutral cue they showed a tendency to regard the target as a cue and wait for a letter string to follow the target. This tendency was most prevalent when the cue time was short, and tended to artifactually increase the RTs for the neutral condition. The cue was displayed in the center of the screen and remained visible for 700, 500, 400, 300, or 200 msecs, depending on which group the subject was in.

The ratio of words to nonwords was one to one for all cueing conditions. Cue and target were presented in the same central screen location in order that subjects would fixate on that position for the duration of the cue. It was also felt that there would be little integration or masking of the cue and target and that if there was any it would not be substantially different between critical cueing conditions.

When the cue word was a category instance, it was followed by its category label (V-W) or nonword generated from its category label (V-NW) 80% of the time and by a nonrelated category label (I-W) or a nonword generated from a nonrelated category label (I-NW) 20% of the time. Subjects saw a given category label 10 times, 4 times with a valid instance cue, 5 times with the neutral cue, and once with an invalid cue. They saw the 5 different nonwords generated from the same category label on 10 different trials, 4 with instance cues, 5 with neutral cues, and one with an invalid cue. Within cue time groups, stimulus sets I and II were counterbalanced with respect to sessions. Except for subjects in the 700 msec condition, stimulus set III was presented as the second stimulus set in the second session. Stimulus set III was presented last because according to pilot work it was the most difficult, and a fully counterbalanced design including this set would have required more subjects than were needed for each cue-time condition. For subjects in the 700 msec condition, stimulus set was fully counterbalanced.

The 52 practice items that preceded each experimental stimulus set exposed subjects to the four conditions V-W, V-NW, N-W, N-NW, for each of the 10 categories used in experimental trials. Stimuli only for conditions I-W and I-NW were developed from categories not used in the experimental trials. This practice was designed to familiarize subjects with all the potential categories from which targets were derived. Also, subjects were lead to expect 80% valid cues, while not thinking any particular experimental category was more likely to be preceded by an invalid cue. All cues in the practice trials were presented for the same period of time as the experimental cues. Each subject received a different random ordering of cue-target pairs.

Subjects

Subjects were 79 right-handed, University of Illinois undergraduates, participating for course credit. Approximately equal numbers of males and females took part. There were 24 subjects in the 700 msec condition and 14 subjects in every other cue time condition except the 200 msec condition where there were 13 subjects.

Procedure

Instructions included a thorough description of the stimulus events, required subject responses, and a characterization of the stimulus. They were told to focus their attention on the cue word because it might help them in their lexical decision on the target string, but that they were never to make any button press to the cue word.

Subjects were run on a computer system capable of handling multiple subjects simultaneously. Each was seated in front of his own CRT ADDS terminal with two thumbs resting lightly on the space bar and their right and left index fingers over the "O" and "R" keys respectively. The space bar was used to initiate a new trial, so subjects could begin a new trial at their own discretion after reading their feedback from the previous trial. There was a 500 msec blank screen time prior to the cue display and about a 750 msec delay after the subject's response to the target before feedback was presented. Targets were presented for 100, 200, 300, 400, 500, or 700 msec, depending on group. Thus, the shortest possible intertrial time from termination of target display to presentation of a new cue, would be about one and a quarter seconds. Letter strings presented on the screen subtended approximately 1.5 degrees of visual angle horizontally and a third of a degree vertically.

Results of Cost/Benefit Study

General

Table 1 displays the RTs and errors for the valid, neutral, and invalid

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Insert Table 1 about here

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cue conditions at each of the five cue durations. A global analysis of variance on latencies showed no main effect for the between subjects factor of cue duration, $minF' = 1$. This factor in an error analysis was also not significant, $minF' = 1.76$. The decision latencies for word targets were significantly shorter than for nonword targets, $minF'(1,88) = 8.9$, $p < .01$, a common finding in lexical decision tasks. There were also fewer errors on words than nonwords $minF'(1,35) = 4.16$, $p < .05$.

Cue type, one of the main factors of interest, did show a significant effect on latencies, $minF'(2,77) = 12.6$, $p < .01$, indicating an overall effect in the expected direction. That is, in general, the latency analysis showed that relative to the neutral cue, a valid cued decreased lexical decision latency, whereas an invalid cue increased that latency. As can be seen in Table 1, percent errors as a function of cue type showed the same relative orderings as the latencies in the words, but the differences were nonsignificant. The ordering for nonwords was less systematic and also nonsignificant. The exact nature and degree of effect that a given type of cue had on target decision latencies depended upon lexicality of the target and duration of the cue. The interaction of cue type with lexicality was significant, minF′(2,73) = 3.93, $p < .05$. In general, type of cue had less of an effect on nonwords. The analysis for interaction of cue type by cue time showed significance, minF′(8,32) = 4.3, $p < .01$. Although this function was complex, it was generally characterized by a decrease in effect of cue type with decreasing cue duration. Table 2 shows the effects of the

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Insert Table 2 about here

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valid and invalid cue in terms of benefit and cost. Benefit is the difference in latency or percent error between the neutral and valid cue conditions. Cost is the difference between the invalid and the neutral cue conditions. As can be seen in Table 2, cost started relatively high and dropped rapidly, particularly for word targets as the cue duration decreased to 400 msec. Cost then remains constant, increasing slightly at 200 msec. for words.

For each of the five groups defined by cue duration, an analysis of variance was performed to test for the significance of cost and benefit. This was done for both latency and percent error as the dependent measure. Any main effects or interactions that are not specifically mentioned were not significant. The exact F-ratios for the cost and benefit effects are presented in Table 2.

700 msec Cue Duration

As can be seen in Table 1, average latencies ordered by cue type was as expected: VALID < NEUTRAL < INVALID, $\underline{\text{minF}}'(2,86) = 14.8$, $\underline{p} < .01$. For nonwords the ordering was VALID = NEUTRAL < INVALID, but the difference in errors was nonsignificant. Although the ordering of latencies was the same for words and nonwords the magnitude of the difference was less in nonwords. This interaction was significant in both the RT and error data, $\underline{\text{minF}}'(2,88) = 4.46$, $\underline{p} < .05$, $\underline{\text{minF}}'(2,44) = 7.65$, $\underline{p} < .01$, respectively. The relative differences in amount of variance accounted for by type of cue can be estimated by comparing $\underline{F}$-ratios from separate analyses of words and nonwords, since these two analyses are identical in form. For words $\underline{\text{minF}}'(2,71) = 30.6$, $\underline{p} < .01$, for nonwords $\underline{\text{minF}}'(2,43) = 3.3$, $\underline{p} < .05$. In the error analysis of words there were no significant differences, type of cue just failed, $\underline{\text{minF}}'(2,13) = 1.0$. For the nonword error analysis, type of cue was significant $\underline{\text{minF}}'(2,37) = 11.0$, $\underline{p} < .01$. In nonwords there were actually fewer errors in the invalid condition compared to the valid and neutral condition which were equal.

As can be seen in Table 2, the analyses for benefit and cost were significant in both words and nonwords. In general, for all groups, the variance of the benefit distribution is lower than that of the cost distribution and the variance of these difference distributions in words is less than in nonwords. The greater variance in the cost distribution could be due to the smaller sample size for invalid cueing.

500 msec Cue Duration

At a cue duration of 500 msec the ordering of cueing conditions by latencies was the same as it was for the 700 msec cue duration. Word targets were responded to faster than nonword targets, minF′(1,58) = 8.8, $p < .05$. Table 2 shows that cost and benefit were both found significant. Nothing reached significance in the error analysis for words although the invalid cue condition as shown in Table 1 has an apparently higher error rate than the other types of cues. For nonwords, Table 1 shows a greater percentage errors for the valid cue type; however, the difference is not significant minF′(1,40) = 3.7.

Non-significant cue effects for the nonword targets may be an indication that a greater amount of cue processing time is required for the cue to be useful in nonwords. The fact that the magnitude of the cost effect was more than cut in half for words is noteworthy. A simple t-test found this cost reduction significant $t(35) = 2.5$, $p < .05$. This sharp decrease in cost occurs with little or no decrease in benefit. Decreasing cue time to 400 msec reduces cost again.

400 msec Cue Duration

There was an overall significant effect for lexicality, latencies to words were shorter than to nonwords, minF′(1,47) = 7.93, $p < .05$. However, the interaction of type of cue and lexicality showed that cues were having their effect in words, minF′(22, 80) = 3.7, $p < .05$. As can be seen in Table 2, the direct test of benefit was significant; cost was not significant.

The interesting aspect of this cue duration is that not only have all significant cue effects except benefit in words dropped out, but the level of effect for benefit has not diminished with the drop in cue time from 500 msec to 400 msec. The magnitude of the *F*-ratios for word benefit in the 400 msec and 500 msec conditions can be directly compared to see the constant percent of variance accounted for by valid cueing. This comparison is possible since the two analyses are identical with the same number of subjects and items. It ought to be noted, however, that eleven out of fourteen subjects showed some cost effects.

<u>300 msec and 200 msec Cue Durations</u>

At 300 msec of cue time, there were no significant effects in latencies. The only significant effect in the error analysis was type of cue for nonwords, $\underline{minF}'(2,36) = 10.59$, $p < .05$. The *t*-score for the difference between invalid and neutral cue conditions is $t(13) = 1.86$, for subjects and $t(29) = 1.38$ for items. This effect does not reach significance at conventional alpha levels. However, even though cost does not reach significance at 300 msec, its magnitude observed in conjunction with what occurs at 200 msec may suggest that some cost is present at these shorter cue times. In fact, if the cost condition in words for 400, 300, and 200 msec conditions are combined for statistical analysis, the result is significant cost, $\underline{minF}'(1,64) = 6.06$, $p < .05$.

At a cue duration of 200 msec, type of cue was significant, $\underline{minF}'(2,64) = 4.67$, $p < .05$. Table 2 shows that for words the level of cost was significant at this SOA, but that benefit was not. Neither cost nor benefit was significant in nonwords, but there appears to be a general inhibition which occurs for both valid as well as invalid cues. Nothing was significant in the error analysis for words. In the nonword latency analysis, type of cue was significant, minF′(2,48) = 3.40, $p < .05$. Type of cue was also significant in the nonword error analysis, minF′(1,39) = 6.34, $p < .05$. If cost and benefit are considered together as an estimate of some cost factor, conventional levels of significance can be reached, minF′(1,67) = 6.77, $p < .01$.

A cost for invalidly cued words is hinted at in the 300 msec condition and statistically significant in the 200 msec condition. Unlike the cost at longer cue durations this cost has little cost in errors associated with it. Also, both invalid and valid cues appear to produce some cost in nonwords in the 200 msec condition. It is apparent that the overall response latencies in the 200 msec and 300 msec conditions are somewhat longer than those at longer cue durations. A look at Table 1 shows the overall increase in response latencies present at 200 and 300 msec. However, the global analysis of the effect of a duration on decision latency is nonsignificant so no legitimate post-hoc analyses were applied. This sudden increase when considered together with subject reports of the relative difficulty of the non-neutral cues may indicate that processing of the cue is incomplete when the target string arrives. This might suggest that some of the cost at the shorter cue durations is due to the neutral cueing condition suffering less from its close temporal contiguity with the target string.

Discussion

The fact that priming exists at all in this study appears to indicate the inadequacy of a simple application of a criterion bias model in accounting for these context affects. In order for subjects to make a correct response, they had to process each letter in the target string, regardless of the cueing condition. Also, the position within the nonword where the incorrect letter occurred was varied so subjects would not learn to check one location for the error. Thus, even if the cue was valid, it does not allow an accurate response without complete processing. Consequently, any significant benefit produced by a valid cue when the target was a word is evidence against models that claim that the only effect of context is to allow correct target decisions with less information. The case might be brought against this analysis by suggesting that subjects process fewer features of each letter in the word when that word is validly primed. However, in many cases the letter that was substituted in the word to generate the nonword target had similar features. For example, from the word "ANIMAL" the nonword "AMIMAL" was derived. Thus, a strict criterion bias model without additional assumptions, seems unable to explain the effects present in this study even at the featural level.

Even a wholistic pattern recognition model would have trouble using such criterion bias models to explain the results. The way in which nonwords were generated would make the validly cued nonword look like the expected word. Such a similarity in pattern would force longer target stimulus processing. This would at least reduce the degree of the facilitation effect. However, if the results found in this study are compared to those of a similar experiment where the nonwords were not generated to force such detailed processing, there is little difference. In both Neely's study and the present one, the difference in response latency between the valid and invalid cueing condition was about 90 msec at 700 msec SOA.

The results from the 700 msec condition demonstrate that facilitation occurs even when the target string is a nonword, so long as the nonword has a high degree of likeness to the word suggested by the cue word. Thus, both "YES" and "NO" lexical responses can be facilitated. Furthermore, this occurs with the accuracy in the valid cue condition approximately equal to the accuracy in the neutral condition, suggesting that the benefit in decision time cannot simply be attributed to a lower criterion for validly primed targets. This result indicates that some benefit gained with a valid cue must be due to an increased processing efficiency at some level before the response system. However, this does not mean that a valid prime has no effect on the response system. It may well be the case that when a target is validly primed, a subject determines early in processing that the orthographic structure of the target is congruent to a great extent with the expectations generated by the cue. This may lead to an initial priming of a positive response which after further processing is executed when the target is a word and inhibited when the target is a nonword. This would suggest greater benefit for words than nonwords. The difference in amount of benefit for words and nonwords is in the expected direction, the t-tests for subjects and items produced t-values of about 1.76, but this fails to reach conventional levels of statistical significance. However, it is the case in general, across the other cue duration conditions that benefit is more predominant in words than nonwords. As a summary, the results do indicate some increase in processing efficiency not attributable to simple response bias. Whether or not response bias also operates in facilitation is not clear.

Cost in the 700 msec condition gives a stronger appearance of being tied to the response system. There is a latency cost for invalidly cued words, but the increased latency for nonwords, while significant, is much less so than for words. The fact that the degree of cost is linked to the type of response being made seems to implicate the response system. The cost in terms of errors is not significant in words. In nonwords, there is a significant benefit in the invalid condition with respect to errors. This decrease in errors for invalidly primed nonwords might indicate that there is a general response bias of "NO" when the graphical structure of the target is other than what was expected by the cue. Consequently, when the invalidly cued target turns out to be a word, not only might there be a decrease in efficiency to process the structure that exists, but the negative response must be inhibited and the positive or "YES" response made. If the target is a nonword, such response type switching is unnecessary.

The results of the present study, particularly for word targets, are in many ways similar to Neely's (1977) results. In fact, Neely's study, in general, and the present study from the 700 to the 400 msec SOA condition are consistent with the Posner-Snyder (1975a, 1975b) explanation of cost and benefit. In the present study, benefit in word targets is fairly constant and significant at 700, 500, and 400 msec of cue time. Cost, however, shows a rapid decrease as cue time is shortened and is significant in the 700 and 500 msec conditions, but is not significant at 400 msec of cue time. Neely's pattern of results was quite similar. The SOA at which benefit without cost was found, however, was shorter (i.e., 250 msec). The results of the two studies up to this point are similar. However, two findings in the present study are counter to Neely's findings: (a) In word processing, cost occurs without benefit at the cue times below 400 msec, particularly at 200 msec. (b) In nonword processing, cost is evident for some cueing conditions.

The appearance of cost without benefit at short cue durations, and to some extent, the cost found in nonword target processing, appear to be a function of the present experiment's design. Both of the counter results indicate a tendency towards a greater cost in processing. In terms of the Posner-Snyder framework, this would suggest that target processing is to a great degree, controlled by a limited-capacity attentional component. This might be the result of at least four characteristics of the present study: (a) A relatively small number of possible targets are repeated frequently. Such repetition and learning of the targets might increase the subjects' use of an attentional mechanism (Neely, 1976). (b) Category instances were used to prime category labels. This allows the targets to be almost completely predicted from the valid cue. Increasing the target predictability in such a manner might be like increasing the cue's validity. (c) The more standard type of cue validity, that is, the percentage of valid to invalid cues was 80%. Neely's (1977) study had a cue validity of 67%. (d) Nonwords were constructed so that cue validity could be manipulated in nonword processing. This increased the response complexity of the task. Even if the cue was a valid cue and thus provided some information about the target, the response requirement was not necessarily to respond "YES" as in Neely's (1977) study. If it is the case that a cue's validity can be successfully tested prior to complete target processing, the present study does not allow correct responding based on that early test.

The importance of the above fourth characteristic of the present study increases when it is examined in the light of the concept of attention proposed by Posner and Snyder (1975a). Their concept of attention suggests that attention might have an important inhibitory function. One function of attention might be to inhibit irrelevant responding. In the present study, where the orthographic difference between words and nonwords is slight and where responding can not simply be linked to initial tests of cue validity, attention could be necessary to inhibit premature responses. When the response is tied to an expected stimulus and a nonexpected stimulus occurs a "shifting" of attention is necessary.

The failure to find benefit in the absence of cost is not necessarily evidence against automatic facilitation. Automatic facilitation effects might have been overshadowed by the strong attentional task requirements noted above. Given the possibility of this overshadowing, it is likely that the way in which the cost/benefit methodology was applied in the present study did not allow a sensitive measure of automatic facilitation. The basic thrust of the cost/benefit approach as designed by Posner and Snyder was that whatever exact experimental technique is used the technical goal is to manipulate the probability of the application of conscious attention. Manipulating cue duration might not be an adequate way to achieve that goal in the present study. It is also possible that some tasks (i.e., lexical decision) because of a complex relationship between stimulus and response, or for whatever reason, require a significant amount of attention. And on that account the attention level cannot be adequately manipulated.

Some aspects of word processing do appear to be automatic and without inhibition. According to Posner and Snyder (1975a) the Stroop phenomenon is an example of automatic, inhibitionless word recognition. However, the question of whether or not semantic priming has an automatic component is an independent question. Automaticity, of some nature, appears to be a characteristic of the facilitation. Fischler and Goodman (1978) find significant priming with only a 40 msec cue duration. At least two studies have found priming effects when the cue word could not be reported (Fischler & Goodman, 1978; Wickens, 1972). Marcel (in press) finds priming occurring when subjects are at chance level on detecting the presence of the cue. While these two findings point to automaticity in one sense of the word, they do not provide support for <u>inhibitionless</u> facilitation. This is because neither study uses a cost/benefit approach, so the facilitation cannot be separated from the inhibition.

Neely's (1977) study is the only cost/benefit analysis of primed lexical decisions which attempts to support inhibitionless activation. On this account, it is important to know if that study really does find significant benefit without cost. The RT data from Neely's study supports costless (inhibitionless) facilitation. However, as pointed out earlier, none of the cueing conditions in his study show facilitation without some cost in errors. If subjects traded-off accuracy for speed in Neely's study, his data does not support inhibitionless facilitation.

The following study is an attempt to determine if subjects can trade-off speed for accuracy, and if so, what the empirical relationship is between the two measures. Trade-off functions for RT and speed/accuracy studies are not necessarily the same. There is the possibility of a fundamental difference between these two types of studies. However, the speed/accuracy experiment still represents a kind of estimate of the trade-off function in the RT study. The speed/accuracy study will also provide data concerning the utilization of the cue information. For example, it can possibly provide clues as to what point in time cue information is integrated or active in target processing.

Experiment 2 will also provide a direct look at the degree to which response-bias is active in the priming effect. Explanations based on RT data alone easily neglect the contribution of response-bias. Such response-biases become more obvious when performance variability is forced out of RT and into accuracy. In doing this the nature of the task changes to some extent such that speed/accuracy tasks cannot be taken as proof of what is occurring in an RT task. However, the information gained in speed/accuracy tasks can provide valuable insights into what might be occurring.

Experiment 2

Method for Speed/Accuracy Task

General

Each subject participated in ten sessions. Session one consisted of 40 response-timing practice trials and a block of decision practice trials. Sessions two through ten each consisted of two blocks of experimental decision trials with a 5 min rest between blocks. A block of trials included 52 warm-up trials followed by 200 experimental trials.

The basic trial procedure was as in Experiment 1 except the cue word was always displayed for 800 msec. The target string was displayed for 100, 200, 300, 450, or 600 msec. These target times were mixed randomly across trials. The termination of the target was coincidental with a tone presented through earphones. Lexical decision responses had to be made within 250 msec after target display termination and the initiation of a clearly audible 100Hz response signal tone. If their signalled response latency was longer than 250 msec, the message "TOO LONG!!!" blinked repeatedly on the screen and a tone was presented several times through the earphones. Likewise, if the subject made a response prior to the response signal he got the same series of tones with the flashing visual information "YOU JUMPED THE GUN!!!". After each response the subject made, except gun jumps, signalled response latency was displayed on the screen in milliseconds. At the end of each set of warm-up trials and after ever 25 experimental trials subjects were shown their number of gun jumps and their average signalled response latency. Also, in the experimental trials, subjects were presented information stating the percentage of trials they had completed.

The cue word, as in the first series of experiments was either: an instance from the category suggested by the target, a valid cue; an instance from some other nonrelated category, an invalid cue; or a neutral cue, the word "NEUTRAL." All these cueing conditions occurred in conjunction with word and nonword targets. Cue validity was 80% as in Experiment 1.

Materials

Letter-strings for the experimental sessions were generated from the same 30 categories used in Experiment 1. In addition to the three groupings of 10 categories each formed for the cost/benefit study, two other such 3-set groupings were formed randomly from the same pool of 30 categories. For each set in each 3-set grouping, a replication of that set was produced by rearranging which instances cued nonwords. For example, two or three of the instances used to cue a particular category word in replication one of a set were used to cue nonwords in replication two. Likewise, some nonword cues in the first replication were word cues in the second replication. Also, which cue word was used as an invalid cue was usually different for the two replications. In general, this re-ordering of cues in the second replication was done to keep subjects from being able to predict anything about the target string due to their experience with a particular cue word.

Consequently, even for between set groupings a cue was as likely to precede a word as a nonword.

All the nonwords used in the cost/benefit study were also used in this speed/accuracy study. Set replications utilized the same nonwords, (i.e., five different nonwords for each category in the set). However, each different grouping had a different set of nonwords. Thus, 300 new nonwords, 10 derived from each category target, were added to the 150 used in the previous study. The same 300 category instances, ten from each of the 30 categories used in the cost/benefit study were also used in the speed/accuracy study. A given instance over the experiment cued nonwords about as often as it cued words. Each instance was also about as equally likely to be used as the invalid cue.

For the first session, which was entirely practice, items were generated from a set of ten categories distinct from those used in the experimental sessions. The practice session was exactly like an experimental session in all respects except for this difference in word materials.

Design

The nature and relative frequency of each of the three cueing conditions, neutral, valid, and invalid, were the same as specified for the cost/benefit task. In the speed/accuracy experiment, however, the cue presentation time was not varied, it was always 800 msec. This time was chosen because it was considered to provide adequate time for cost and benefit to develop as well as give adequate time for the subject to prepare to meet the response requirements of the task.

The five target display times occurred equally often for each category target and for each cueing condition. For a particular category, within a set of materials, each of the five target display times was used for one of the five non-neutral word target displays and one of the five non-neutral nonword target displays. The same sort of distribution was true for the neutrally cued presentation of those same targets. Thus, each particular category word-target set and each particular category nonword-target set included two replications of each of the five display times, one under word cueing conditions and one under neutral cueing conditions.

In one set of materials each of the five target display times occurred 20 times; 10 times in the nonword target condition. They occurred 16 times in the valid cueing condition; 8 times for words, 8 times for nonwords. They occurred 4 times for invalid cues, twice in words and twice in nonwords. Also, each category target occurred twice in conjunction with an invalid cue, once in words and once in nonwords. This number of replications of the invalid cue condition, thus, represents an overall 20% invalid or 80% valid cue distribution, as it was in the previous study.

The three major stimulus groupings were defined by what ten categories were grouped together for each set in the grouping. If the letters A, B, and C stand for the three groupings and a prime indicates the replication of that grouping, the following group sequences were used for two subjects each: AA′BB′CC′; BB′CC′AA′; CC′AA′BB′. Since each primed and unprimed letter represents 3 sets and two sets of stimuli were present each experimental session, there were nine sessions. All other aspects of the design such as the warm-up sets that preceded each set of experimental trials was identical to the design specified in the previous experiment.

Subjects

Subjects were five female and one male, University of Illinois undergraduates. They were paid $2.25 per session and all participated for 10 sessions.

Procedure

Instructions to the subjects were similar to those for the cost/benefit study. However, subjects were given speed/accuracy instructions in line with the response signal methodology being used. They were told to make the best response they could based on the information they had at the time they received the response signal. They were further told that if they did not have adequate information to make a judicious response, to guess, or at least to make some response within the 250 msec time allowed.

The same computer system described in the previous study was used in the present task. The 500 msec blank screen prior to cue display and the 750 msec delay between the subject's response and feedback was identical to the previous experiment. An experimental session lasted about 45 min.

Results of Speed/Accuracy

Figure 1 shows the latency of response following the response signal (i.e., signalled response latency) as a function of target display time separately for each type of cueing condition. Latencies to word and nonword

Insert Figure 1 about here

targets were combined since an analysis of variance found no significant effect on signalled response latency for lexicality. As can be seen in the figure the differences in signalled response latency for different types of cues is negligible. The main aspect of the figure is the inverse relationship between signalled response latency and display time. This finding is consistent with other speed/accuracy studies that use this same response-signal methodology (Dosher, 1976; Reed, 1973, 1976; Wickelgren, 1977). To take into account the slight variation in signalled response latency between type of cue conditions and target display time, accuracy measures are plotted against total latency. This includes target display time plus average signalled response latency for the condition being plotted (see Reed, 1973).

Figures 2 and 3 show percent correct as a function of total response

Insert Figures 2 and 3 about here

latency for each cue type for words and nonwords respectively. The data points in these figures are averages across all six subjects; individual subjects all produced similar results.

The mean percent correct in words for valid, neutral, and invalid cue conditions are: 79.0%, 76.3%, and 71.9%; for nonwords they are: 76.5%, 77.5%, and 79.1%. The main effect for target display time was highly significant, $\underline{\min F'}(4,50) = 96.14$, $\underline{p} < .01$. Type of cue was also significant $\underline{\min F'}(2,10) = 4.4$, $\underline{p} < .05$, as was the interaction of cue type with lexicality $\underline{\min F'}(2,39) = 4.99$, $\underline{p} < .05$. Using the pooled error term, a difference of 3.8% or greater is necessary for a significant difference in pairwise comparisons. Accordingly, no significant differences occur in the nonwords. In the words, there is a significant difference between valid and invalid cues and between neutral and invalid cueing conditions. Comparing this percent correct measure to the RT measure used in the first experiment there are some similarities as well as differences. In terms of performance on word targets, the effect of cue type on performance is the same for both experiments. Valid cues produced the best performance, neutral the next best and finally invalid cues. As shown in Figure 2, this relative ordering seems to fit across the entire range of response latencies. For nonwords the percent correct measure derived from the speed/accuracy experiment shows that the best performance is in the invalid priming condition, the worst performance is in the valid conditi n. While this ordering is not unlike the accuracy measures collected in the cost/benefit study, it is not consistent with the overall shorter latencies found in the valid nonword condition of Experiment 1. Figure 3 shows that the relationship between cue types is less clear for nonwords than it was for words. Finally, the overall performance in terms of latencies for the first study showed shorter latencies for words whereas this speed/accuracy study found the percent correct a bit higher in nonwords, although not significantly so.

Figures 2 and 3 also provide evidence about the time course of target information extraction. At about 300 msec of total target time, responding is still at chance level. Percent correct across words and nonwords is not significantly different from chance. There is a tendency toward a "NO" response. Some subjects claimed to have usually responded "NO" when a judicious response could not be made; some subjects responded more randomly. More than 300 msec of total target time is necessary before enough target information has accumulated for above chance responding.

Figure 4 shows $\underline{d}'$ as a function of total response latency. For the

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Insert Figure 4 about here

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purpose of calculating $\underline{d}'$ in this study nonwords were assumed to represent the noise distribution placed on a decision axis representing a continuum of wordness. Subjects were assumed to be making judgements of how much like a word the target string was. The mean $\underline{d}'$ scores across all latencies for all subjects were 1.92, 1.85, and 1.67, for valid, neutral, and invalid cue types. This pattern of results is generally true across subjects. A target display time by cue type analysis of variance yielded a nonsignificant main effect for cue type, $\underline{F} < 1$. The main effect for target display time was significant $\underline{F}(4,20) = 150.71$, $\underline{p} < 01$. Also, significant was the interaction of the two variables $\underline{F}(8,40) = 2.83$, $\underline{p} < .02$. In individual contrast ratios, cue type was found significant at target display times of 300 and 600 msec, $\underline{F}(2,10) = 4.3$, $\underline{p} < .05$, and $\underline{F}(2,10) = 7.34$, $\underline{p} < .02$, respectively.

It can be observed in Figure 4 that the only notable difference at the above target display times is between the invalid cue condition and the other two conditions. The reduction of the cue type effect that occurs when the entire decision axis is considered, strongly suggests that response bias is an active component in the lexical decision process. The analysis of beta seems to support this suggestion. The main effect for type of cue just failed significance $F(4,20) = 2.5$. The interaction, of cue type and target time, however, was significant, $F(8,40) = 2.73$, $p < .02$. In individual contrasts, only the 400 msec target display condition showed a significant cue effect $F(2,10) = 9.6$, $p < .01$. The difference again is due to a higher beta score for invalid cueing, whereas the valid and neutral condition are about the same. This beta analysis demonstrates that there is a greater tendency to say "NO" in the invalid as compared to the valid and neutral cueing conditions. The response bias involved here must be distinguished from criterion bias. Response bias is a propensity to execute one response rather than another. The execution may or may not be based on complete stimulus information. The term criterion bias as used here is a propensity to decide something is the case independent of the task-response requirements. The present speed/accuracy study suggests that at least part of the valid cue's facilitation effect is due to a bias to respond "YES" when the cue is valid, regardless of lexicality. Also, part of the inhibition in the invalid cueing condition is due to a tendency to say "NO" when the cue is not valid. The probability of being correct is greater in the valid cueing condition than the invalid cueing condition for words, the reverse is true for nonwords.

The response-bias present in the lexical decision task cannot be a simple kind of response-bias. If valid cues create a response tendency to say "YES" this bias can only have been generated after some processing of the target. That is, the subject must have some information about the cue's validity before he knows for sure whether or not the target is a word. Also, the response bias that appears to be present in the speed/accuracy study cannot account for all of the RT study's results, since valid cues did prime nonwords (i.e., "NO" responses).

Many of the lexical decision studies currently in the literature fail to take into account the whole decision axis when formulating models of the decision process. An accurate representation of how decisions are being made for word targets can only be hoped for if the nonword decisions are taken into account. The present speed/accuracy study demonstrates the advantage attached to using speed/accuracy studies in conjunction with RT-derived facilitation and inhibition scores to infer the nature of the lexical decision process. The speed/accuracy data suggest that facilitation and inhibition might be partially a function of response-bias based on partial information. The partial information is gained only in cases where there is a cue, since the information is based on the degree to which cue derived expectations match early target information. This would lead one to say that the cue might have no effect on lexical access, but allows one to make "preliminary decisions" about lexicality. Then the degree of cost or benefit produced may represent the degree to which this preliminary decision was allowed to influence the response system.

The degree to which response-bias contributes to priming effects is difficult to determine from RT studies. The speed/accuracy data in the present study suggests that what have been called attentional effects may be due to a response-bias. This is not to say that because response-bias is involved that the concept of attention has no place. Quite to the contrary, attention is needed to tie the response system into the preliminary decision and at the same time inhibit response execution until complete stimulus information is obtained.

Because speed can be traded for accuracy, caution must be exercised in the interpretation of RT studies when errors are inversely related to RT. For example, at 250 msec SOA, in the natural priming condition, Neely (1977) reported 33 msec of benefit for valid cues and no cost for invalid cues. However, as mentioned earlier, there was still a 4.3% cost in terms of errors on valid cues at 250 msec. It would be informative to know what that 4.3% cost is in terms of latency. How much would subjects in Neely's study have had to slow down in the invalid cue condition so that they would make the same number of errors in that condition as in the neutral condition? It must be noted that the present speed/accuracy study is a very different kind of study than Neely's (1977) RT study. On this account, any estimates of latency costs from accuracy costs occuring in an RT study are only suggestive of what might have been the case. The trade-off function for Neely's data could be different. Speed/accuracy data should not be a correction procedure for RT experiments (Pachella, 1974). The speed/accuracy study here, however, does seem to correspond to the RT study reported in Experiment 1. For example, for validly cued word targets in the 700 msec condition, the average RT was 687 msec and the average per cent error was 2%. In Figure 2 a line drawn from the ordinate at 98% correct comes close to intersecting a perpendicular drawn from the abscissa at 685 msec. If we assume the speed/accuracy function in Neely's experiment to be approximated by Figure 2, an estimate of what a 4.3% cost in errors means in RT can be calculated. Neely's overall error rate for the study was 2.4%. In Figure 4, two lines, perpendicular to the ordinate, one at 95% and one 4% lower are extended to the valid cue's trade-off curve. Reflecting the points of intersection onto the abscissa shows a difference in RTs of 65 msec. Even though it is not known how well this estimates the trade-off function in Neely's study, it is known that the asymptotic performance for the valid cue condition is about the same for both studies. Asymptotic performance in Neely's study was 94.8% and in the present study 94.4%. Also, the estimation here is kept conservative because the valid rather than the neutral or invalid curves are used. The neutral and and invalid curves asymptote more quickly and would thus give larger trade-offs. The point to be made here is not that the speed/accuracy experiment can accurately correct RT data. The point is that a small cost in terms of errors occurring when performance is close to asymptotic can very possibly represent a significant latency effect.

General Discussion

In summary, the two experiments reported here have found the following: (a) substantial priming effects in an experiment that forced complete stimulus processing; (b) a benefit and a cost in nonword processing for valid and invalid cues; (c) cost in invalidly cued word processing at 200 msec; (d) cost in nonword processing at 200 msec for both valid and invalid cueing conditions; (e) subjects were able to trade-off speed and accuracy in a lexical decision task; (f) acquisition of sufficient target information for above chance responding required more than 300 msec of target processing; (g) both d' and beta were found significant at certain target durations in the speed/accuracy experiment.

The general assumption of verification, originally set forth by Becker (1976) will be restated here and used to help integrate the above findings. The recognition of a word occurs over time. When a letter string is presented, preliminary feature analysis generates probes for searching lexical memory. Such probes select a lexical entry which on some probabilistic basis is the correct lexical memory. Determination of correctness occurs on verification by comparing lexical memory information with the lower level representations of the presented letter string.

The focus on the above assumption that recognition occurs over time is motivated by three factors: (a) Becker and Killion (1977) found a verification process helpful in understanding the results that show an increase in priming effects when encodability of the letter string is decreased by partial masking or contrast reduction (Meyer, Schvaneveldt &

Ruddy, 1974; Becker & Killion, 1977). (b) The present study finds substantial priming when accurate lexical discriminations can only be made after detailed analysis. Such fine discriminations such as spelling would seem to require a memory driven stimulus analysis. Here, "memory driven" means an analysis that is based on information from lexical memory. (c) Stable coding of a given word probably requires feedback from memory. According to the discrimination approach stated earlier, a word must have a coding that allows it to be discriminated from letter strings with which it might be confused. Even under this constraint, there are many ways to code a presented letter string. The preliminary coding that is not driven by lexical memory most likely has some stabilizing aspects connected with it such as are produced by characteristics of the visual system. Further reductions in variability are likely to come from some lexical memory that is suggested by preliminary coding. The verification assumption suggests that we have recognized an item only if a lexical memory for that item can make valid predictions about the to-be-recognized word.

Up to this point the question of what kind of information is stored in lexical memory has been neglected. It is assumed that among other information about our experience with words, lexical memory has habitually applied coding or processing routines. These routines might be considered instructions on how to code the orthography in the letter string. Such information would allow the generation and testing of hypotheses about type and location of features in the target stimulus. If such routines when applied to the target point unambiguously back to the same lexical memory from which the routines were derived, the word might be said to be formally recognized.

In accordance with the above assumptions and the findings in this study, a good picture of the possible processes involved in cued and noncued lexical decision can be obtained. How the cue operates to affect the lexical decision process is the crucial question. Two clear possibilities exist under the above assumptions. First, a valid cue may increase the speed of accessing the lexical coding routine. Second, as target information accumulates its relationship to the cue-derived expectations biases a response. The present study appears to show evidence of both types of processes.

In the present study, where a single definite word is suggested by a cue word, the lexical memory for the target may be accessed even before target presentation. In studies where cue words do not point to just a single word, accessing lexical memory requires some features from preliminary target analysis. Neither valid nor invalid cues are thought to change the rate at which target features are extracted. Instead, it is assumed that a valid cue allows faster accessing of the lexical memory. It is a type of criterion bias selection of the lexical memory. However, because the memory, once located, has all the necessary information for complete accuracy, the final response is not based on an incomplete analysis of the target.

The main supporting evidence for this facilitation in lexical access is the fact that nonword processing can be facilitated even when the nonwords look very similar to the word expected. Response-bias cannot explain this finding because "NO" responses were facilitated. Another way to state this cue effect is to say that the cue temporarily reduces the noise in selecting lexical routines. This type of facilitation might predict a greater _d′_ for the valid than for the neutral condition. Although the difference in _d′_ for the valid and neutral conditions found in this study is in the right direction, it is not large enough to directly support the model. The significant differences in _d′_ that do occur indicate that the invalid cue, possibly by its inappropriate restriction of the noise distribution, decreases target discriminability. The design of the speed/accuracy study presented here may not be adequate to fully test this _d′_ prediction. The reduction in the noise distribution due to a valid cue is probably not large in the present design. Each block of materials had only ten word-targets and the subject was familiarized with these before the experimental trials. Being familiar with these ten possibilities already reduces the potential noise population because the target must be derived from this set of ten known items. Along similar lines, if the lexical routine is obtained more quickly, information about the target should accumulate faster for validly cued than for neutral or invalidly cued items. A look at Figure 4 shows that the slope of the neutral and valid curve are approximately equal. The slope of the invalid cue line may be a little less than the other two. However, the differences in slope are not large. What is needed to clear up these points is a speed/accuracy study in which the cue causes a greater relative decrease in the noise distribution.

Response-bias definitely plays a role in the facilitation effect. The pattern of error rates in Experiment 1 showed a tendency to respond "YES" to validly cued targets and "NO" to invalidly cued targets, independent of lexicality. Further evidence of response bias was found in Experiment 2. Using proportion correct as a dependent measure yielded a significant *F*-value in an analysis of variance. When response-bias was controlled for with *d′* the differences between cueing conditions did not appear as large. In addition, the analysis of beta scores was significant when the target display time was 400 msec. This suggests that valid cues bias a "YES" response and invalid cues bias a "NO" response.

Figure 5 is a flow chart of the proposed sequence of processing events

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Insert Figure 5 about here

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in the lexical decision task. At longer SOAs (e.g., 700 msec) lexical memory of the expected target can be accessed, except in the neutral condition where processing must wait for target presentation. Because the cue words in the present experiment suggest only one target word, lexical access of the exact expected word in memory is possible. As the target information becomes available a response bias for "YES" develops if the cue is valid, and a response bias for "NO" develops if the cue is invalid. The exact placement of response bias in the processing sequence is not well specified. Figure 5 has the bias before the memory driven analysis of the target. It is possible, however, that response bias develops all along the processing route as a function of the congruence between the cue and target based information. For words, any response bias for "YES" is executed, for nonwords it must be inhibited. This predicts less facilitation for validly cued nonwords than for validly cued words, which is obtained. For invalidly cued words the cost is relatively large because the subject must inhibit the use of lexical memory accessed by the cue as well as inhibit a "NO" response. Less inhibition is predicted for the invalidly cued nonword because only the selected memory needs to be inhibited, the biased "NO" response may be executed.

In summary, the valid cue's effect on the speed of target processing is through both increased speed of lexical access and early preparation of the response system. Inhibition produced by the valid cue is not thought to be an inhibition of target-based lexical access, but is thought to be due to having to inhibit using the cue-accessed memory.

Any explanation of what occurs at 200 msec SOA in the present study is tenuous. In terms of the flow chart model, it could be assumed that cue-based and target-feature-based memory access occur independently. It then might be the case that the two sources of information being moved closer in time cause some confusion between which is cue and which is target. If accessing the expected target's memory location takes _x_ msec, it is reasonable that it takes _x_ minus some number of milliseconds to access the target's memory location from the target. This assumption is independent of cue validity. These assumptions would suggest that moving the cue closer in time to the target might make the cue and target based information available at the same time. If this close temporal relationship is coupled with a loss in the source by which lexical memory was accessed, the subject may have difficulty in distinguishing cue-based lexical access from target-based lexical access. This confusion could increase the need for attention to keep responses tied to the target. As a result there would be cost in all conditions where there was incongruence between the cue and the target information, which is every word cue condition except validly primed words. The fact that subjects forget the source of the priming information (i.e., the cue word) is substantiated by Fischler and Goodman (1978). The effects at 200 msec might also be due to some general processing deficit in word targets and the lack of cost found for validly cued words might represent a benefit. Maybe, merely having to process the cue words creates a general cost which is nullified by facilitation for validly cued words.

If the second general deficit explanation were true, one would expect response latencies to the targets to be correlated with measures of the difficulty of processing difficulty. However, the correlations between response latencies for validly primed words in the 200 msec condition and word length, number of syllables, and Kucera-Francis (1967) frequencies of the cues were: -.03, .03, and .12, respectively. These correlations do not substantiate a general interference explanation.

The flow chart in Figure 5 was designed basically to help integrate the findings in Experiments 1 and 2. Other lexical decision studies in the literature have not required the completeness of target processing that was required in the present experiments. In most lexical decision studies nonwords have no valid prime and target words are not so readily predicted from valid cues. In such studies response can be tied somewhat more directly to the congruence between cue-based expectations and target-based expectations. If there is a high degree of congruence, a "YES" response will always be correct. High congruence never occurs when the target is a nonword.

If the cue word does not permit access of an exact memory, then the preliminary target information becomes more active. As stated above, invalid cues are hypothesized not to inhibit target-based lexical access. Because of this, the invalid cue may have less of an effect in studies that prime instances with category labels.

The design of this study was not conducive to the demonstration of automatic attention-free facilitation effects. Evidence was found for two different types of facilitation, increase in lexical access and response bias. These two types of facilitations are possibly orthogonal to the automatic/attentional distinction. However, facilitating lexical access has the possibility of being described by some automatic spreading-activation model and response-bias may be an attentional effect.

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Footnote

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Table 1

Average Response Latencies and Errors

for Valid, Neutral, and Invalid Cues

Condition	Cue duration					
	700 msec	500 msec	400 msec	300 msec	200 msec	Average
Words						
Valid	687 (2.00)	668 (2.33)	650 (2.08)	750 (1.90)	752 (1.86)	701 (1.86)
Neutral	716 (2.00)	688 (2.71)	674 (2.53)	754 (2.67)	755 (2.21)	717 (2.42)
Invalid	779 (5.00)	717 (5.00)	692 (3.83)	775 (2.14)	794 (2.58)	751 (3.71)
Average	727 (3.07)	691 (3.53)	672 (2.81)	760 (2.24)	767 (2.22)	723 (2.74)
Nonwords						
Valid	711 (4.84)	727 (5.11)	719 (4.65)	791 (4.17)	791 (4.55)	748 (4.66)
Neutral	729 (4.75)	734 (2.84)	707 (4.05)	783 (1.43)	762 (3.43)	743 (3.30)
Invalid	750 (2.01)	752 (3.86)	713 (3.56)	788 (3.57)	789 (2.57)	758 (3.11)
Average	730 (3.92)	738 (3.94)	713 (4.09)	787 (3.06)	781 (3.52)	750 (3.71)

Table 2

Average Cost and Benefit

in Response Latency and Percent Errors

Cue type	700 msec	500 msec	400 msec	300 msec	200 msec	Average
			Cue duration			
Words						
Benefit	29* (0.00)	20* (0.38)	24* (0.45)	4 (0.77)	3 (0.35)	16 (0.39)
minF'[a]	(1,60) 17.4	(1,21) 6.27	(1,25) 6.67	<1	<1	
n[b]	21/24	11/14	12/14	6/14	9/13	
N[c]	2,822	1,641	1,645	1,645	1,531	
Cost	63* (3.00)	29* (2.29)	18 (1.30)	21 -(0.53)	39 (0.37)	34* (1.29)
minF'[a]	(1,46) 27.1	(1,32) 4.5	(1,34) 1.8	(1,19) 1.6	(1,22) 4.5	
n[b]	23/24	10/14	11/14	11/14	10/13	
N[c]	684	391	404	411	380	
Nonwords						
Benefit	18* -(0.09)	7 -(2.27)	-12 -(0.06)	8 -(2.74)	-29 -(1.12)	-2 -(1.36)
minF'[a]	(1,51) 4.2	<1	<1	<1	(1,24) 3.8	
n[b]	18/24	8/14	3/14	5/14	3/14	
N[c]	2,742	1,594	1,602	1,610	1,506	
Cost	21* -(2.16)	18 (1.02)	6 -(0.49)	5 (2.14)	27 -(0.86)	15 -(0.07)
minF'[a]	(1,50) 4.1	<1	<1	<1	(1,36) 2.7	
n[b]	17/24	11/14	10/14	9/14	10/13	
N[c]	692	404	405	407	376	

*$p < .05$

[a] Degrees of freedom presented in parentheses rounded to nearest degree.

[b] Number of subjects showing effect/possible number of subjects.

[c] Number of observations after errors removed that the comparison is based on.

Figure Captions

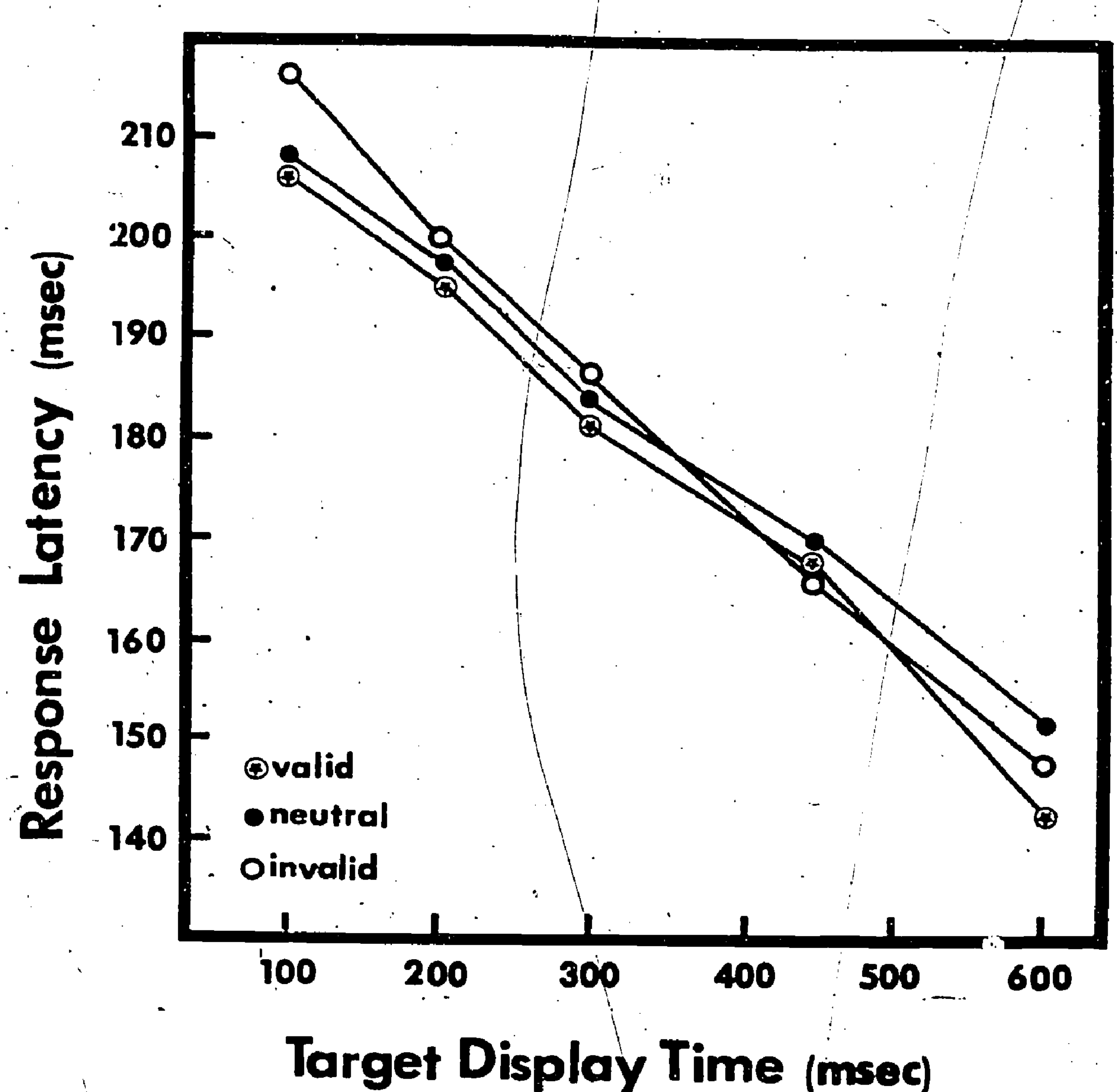
Figure 1. Mean response latency in milliseconds as a function of target display time for each type of cue. Lag times for both words and nonwords are averaged together. All six subjects are included.

Figure 2. Mean proportion correct for word targets as a function of total target processing time, shown separately for each cue type. All six subjects are included.

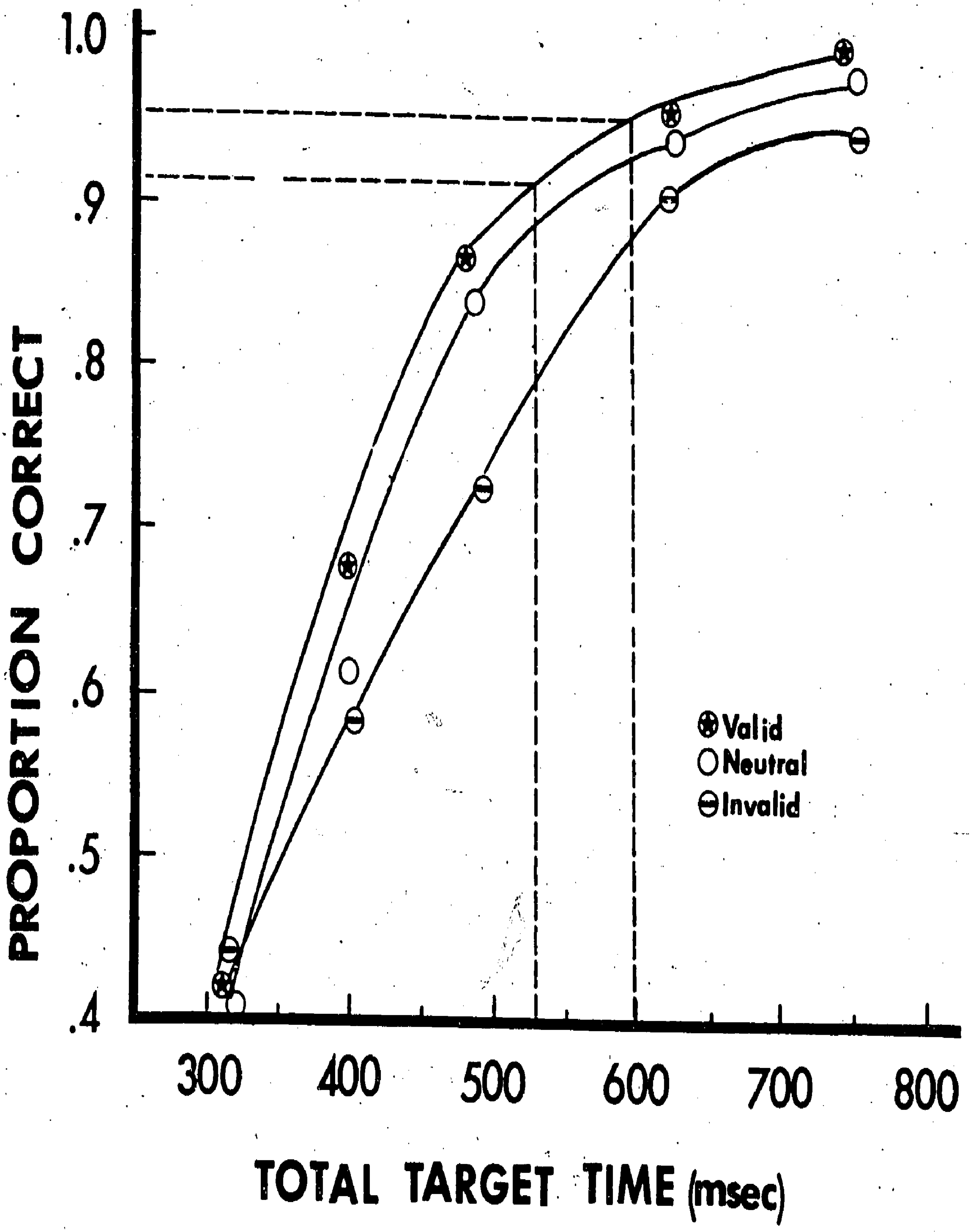
Figure 3. Mean proportion correct for nonword targets as a function of total target processing time, shown separately for each cue type. All six subjects are included.

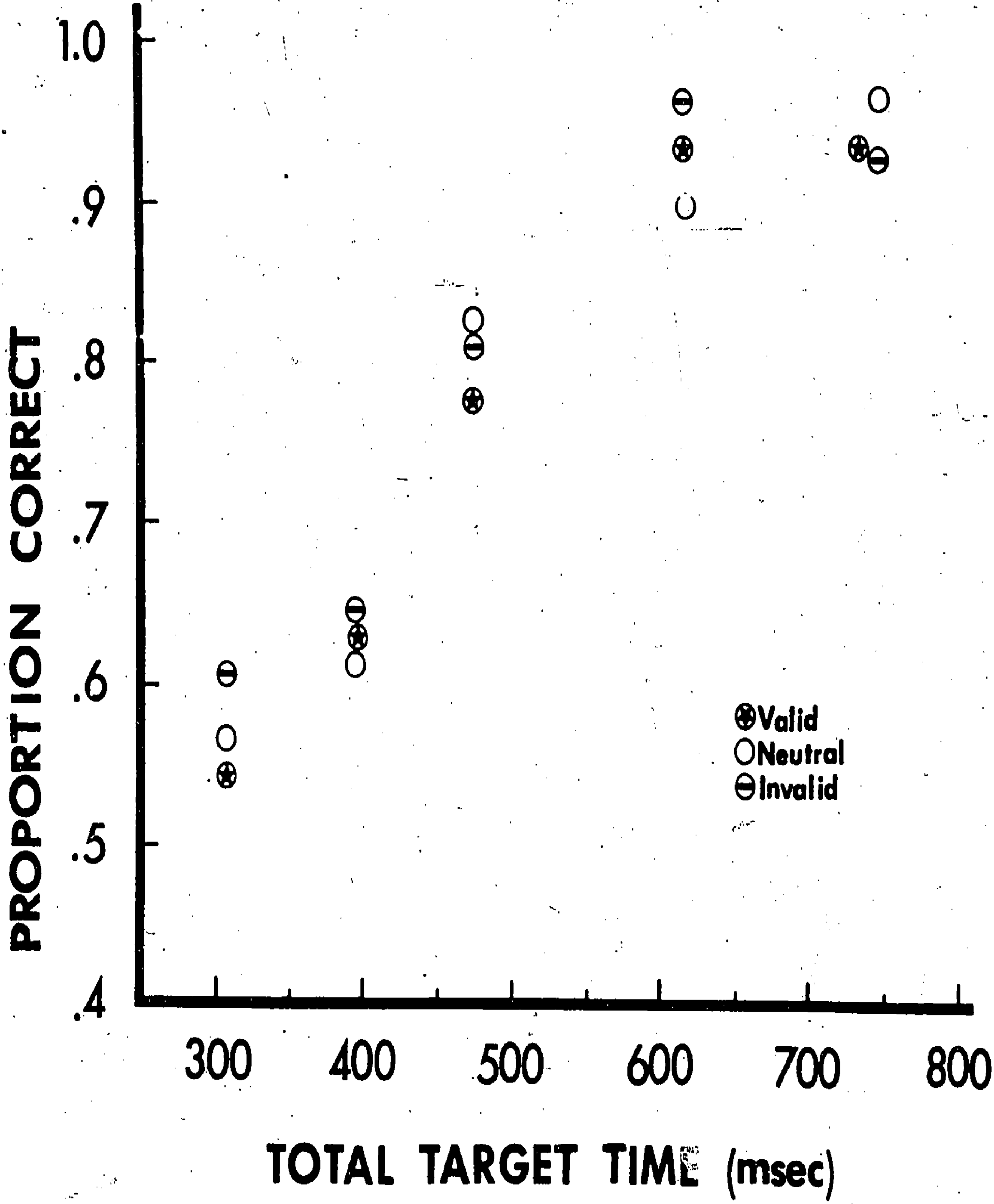
Figure 4. d' shown as a function of milliseconds of cue processing time. All six subjects are included.

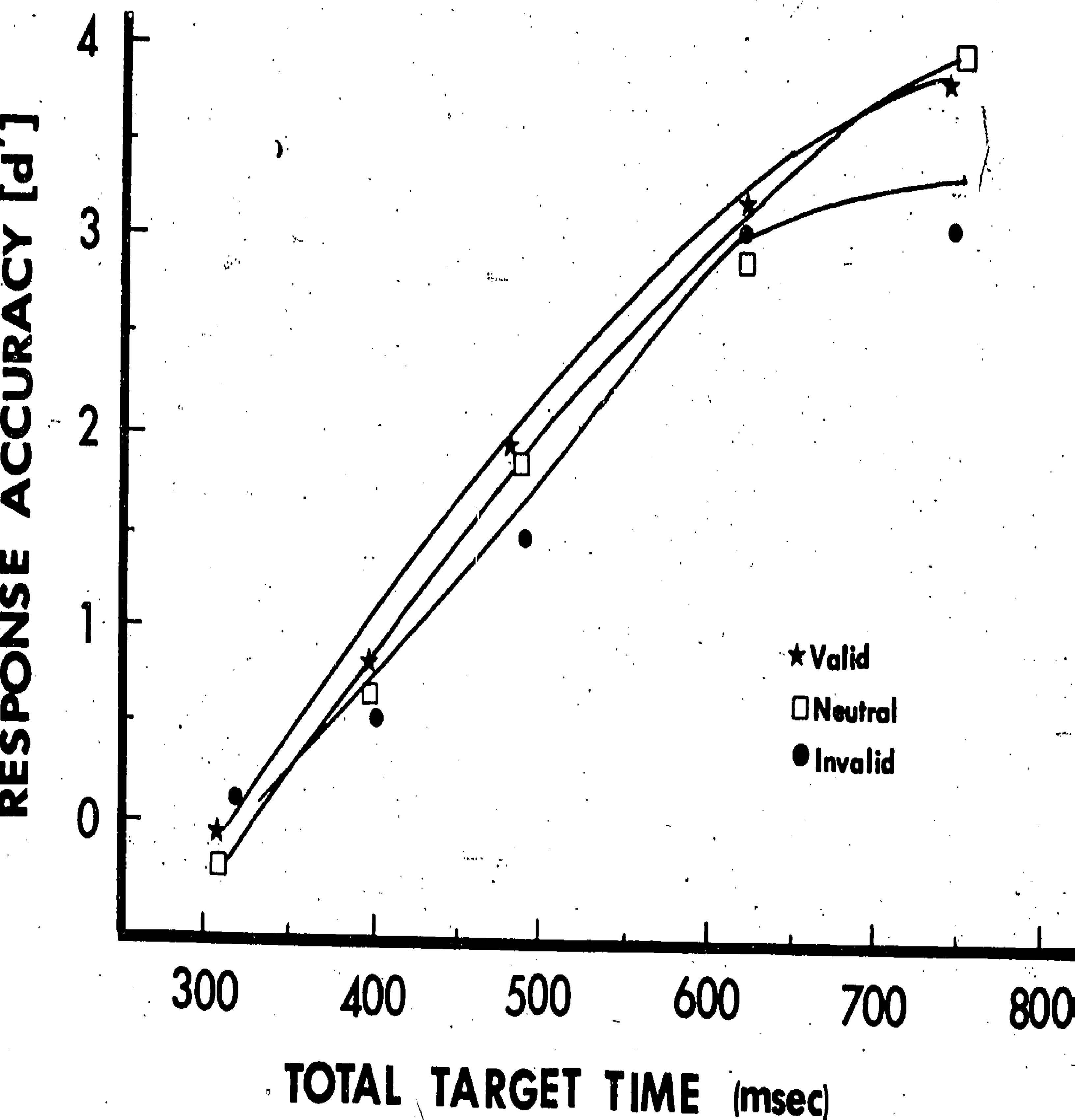
Figure 5. Flow chart of hypothesized information processing routine used to make word-nonword decisions.

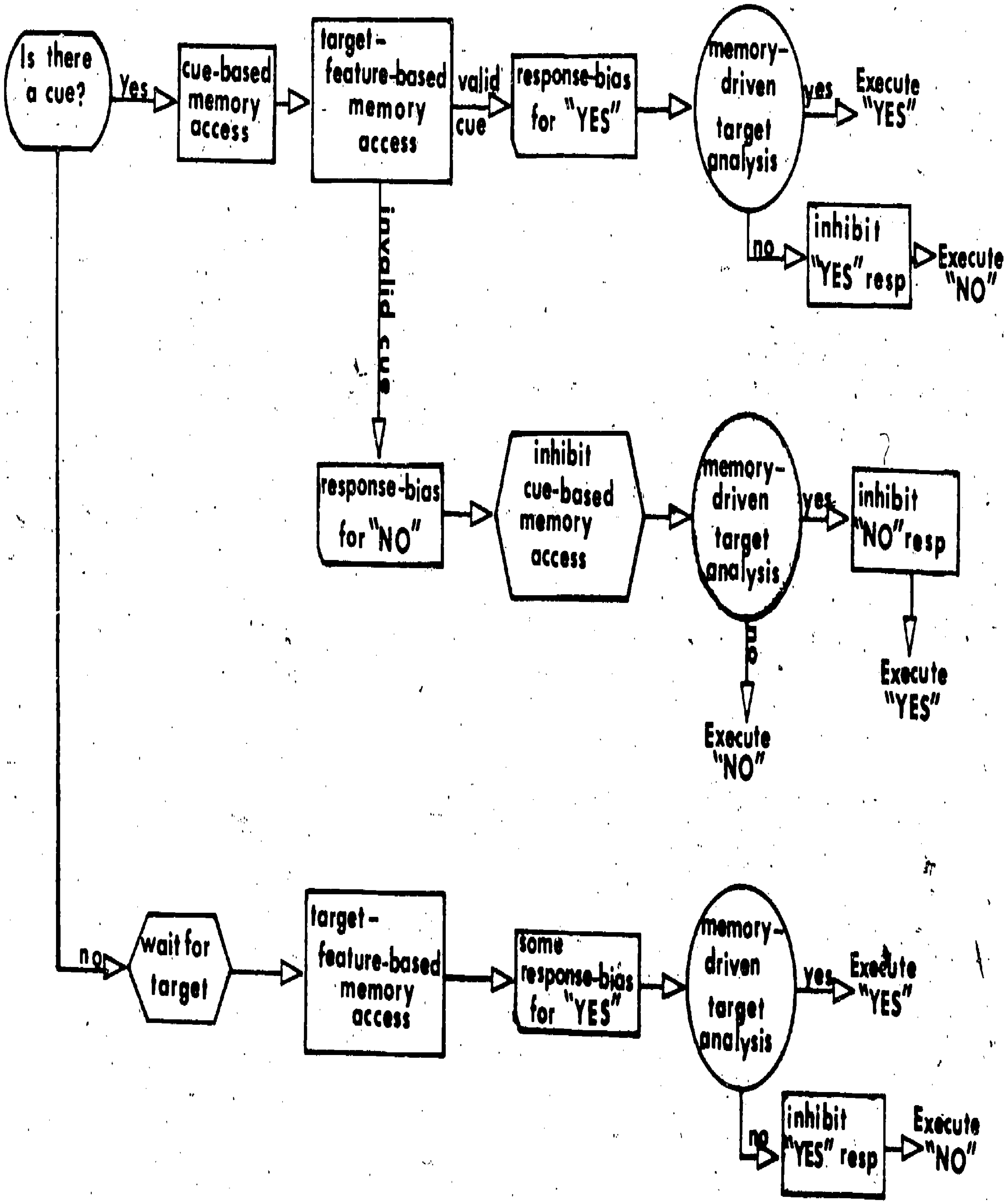


Response Latency (msec)
210
200
190
180
170
160
150
140
valid
neutral
invalid
100
200
300
400
500
600
Target Display Time (msec)


1.0
.9
.8
.7
.6
.5
.4
PROPORTION CORRECT
300
400
500
600
700
800
TOTAL TARGET TIME (msec)
Valid
Neutral
Invalid


1.0
.9
.8
.7
.6
.5
.4
PROPORTION CORRECT
Valid
Neutral
Invalid
300
400
500
600
700
800
TOTAL TARGET TIME (msec)


RESPONSE ACCURACY [d']
4
3
2
1
0
300
400
500
600
700
800
TOTAL TARGET TIME (msec)
Valid
Neutral
Invalid


Is there a cue?
Yes
cue-based memory access
target-feature-based memory access
valid cue
response-bias for "YES"
memory-driven target analysis
yes
Execute "YES"
no
inhibit "YES" resp
Execute "NO"
invalid cue
response-bias for "NO"
inhibit cue-based memory access
memory-driven target analysis
yes
inhibit "NO" resp
Execute "YES"
no
Execute "NO"
no
wait for target
target-feature-based memory access
some response-bias for "YES"
memory-driven target analysis
yes
Execute "YES"
no
inhibit "YES" resp
Execute "NO"

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