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Semantic Context and the Encoding of Words: Evidence for Two Modes of Stimulus Analysis

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Earlier research with the lexical decision task led to the hypothesis that semantic context facilitates the encoding of words related to the context. In six experiments, we further investigated this issue. The experiments employed different tasks (making a lexical decision, detecting a rotated letter in a word, or detecting a gap in one letter of a word) and different experimental paradigms (tachistoscopic exposures with masking stimuli, or reaction time instructions with continuously available target stimuli). The gap detection tasks showed no effects of semantic context. For the other two tasks, the two experimental paradigms produced different effects of semantic context. In the reaction time paradigm, context facilitated performance on word targets without increasing the error rate on physically similar altered-word targets. These findings are inconsistent with the hypothesis that semantic context lowers the decision criterion in favor of related words. In contrast, the tachistoscopic paradigm yielded data favoring the decision bias hypothesis. Overall, the findings were taken to mean that semantic context does not affect the early stages of stimulus encoding. However, further stimulus analysis can occur subsequent to lexical access, and semantic context facilitates accessing the lexical entries for related words.

This study investigated the role of semantic context in the perceptual process. There are several plausible hypotheses concerning the interaction of pattern recognition processes and information in the prevailing context. In what follows, we outline some of these hypotheses as they pertain to recognizing words. We review evidence that favors the general hypothesis that semantic context affects the processes involved in encoding words. We also consider two issues concerning the way in which context interacts with encoding. One issue is whether an appropriate semantic context enhances the processing of sensory information in word recognition or, alternatively, whether the effects of context occur because of changes in the criteria associated with semantically related words in the observer's lexicon. The second issue concerns the level or levels of encoding affected by semantic context. For example, context could affect featural analysis, the analysis of letters, or the activation of word units. We begin by describing the general theoretical orientation that provides the framework for the investigation.

Theoretical Framework

In concert with several other recent analyses (e.g., Estes, 1975; McClelland, 1979; Meyer & Schvaneveldt, 1976; Morton, 1969; Schvaneveldt & Meyer, 1973; Selfridge & Neisser, 1960; Sternberg, 1969; McClelland, Note 2), we conceive of word recognition as involving several distinct processes, including the analysis of features of the stimulus, the activation of letter identities based on the feature analysis, the activation of units consisting of familiar sequences of letters, a spelling-to-sound transformation resulting in the activation of phonological units, and the activation of units corresponding to words in the subjective lexicon.

McClelland's cascade model (1979) is

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representative of current thinking about the arrangement and interaction of the component processes in word recognition. He proposes that information flows from earlier to later component processes but that, in contrast to models with independent stages, information flows continuously from each process to the next one in the sequence. At each level of analysis, there is an accumulation of information based on the accumulated output of the preceding level. For example, the activation of units in the subjective lexicon would be a continuous reflection of the activation of letter units in the preceding level. In our view, McClelland's model is a valuable formulation of the way information flows into the nervous system in feed-forward processes. We believe, however, that a more complete account would allow for feedback processes in which the information stored at deeper levels (e.g., the lexicon) could influence the analysis of more shallow levels (e.g., letter units). Also, while we are sympathetic to the idea that there are various levels of encoding (cf. Craik & Lockhart, 1972), we feel that the assumption that information flows through these levels in a strictly serial sequence may be too strong. It is quite possible that deeper levels (e.g., the lexicon) may receive information from several sources (e.g., word shape, letter features) in addition to the immediately preceding level (e.g., letter units). Our views on the nature of the subjective lexicon and the processes involved in accessing the lexicon have been strongly influenced by the pandemonium model of Selfridge (see Selfridge & Neisser, 1960) and the logogen model proposed by Morton (1969).

In the logogen model, logogens are elements in which evidence about particular words is accumulated. According to the model, a word is recognized when the evidence accumulated by the logogen corresponding to the word is sufficient to exceed the criterion currently in effect for that logogen. The evidence concerning the various logogens is determined by the extent to which features of the stimulus match the features of logogens. A process of feature analysis provides input to the logogens, incrementing those whose features match the features extracted from the stimulus and, perhaps, decrementing the logogens with mismatching features. For example, if the word BETTER occurs, the logogen for the word BUTTER would be incremented by the matching features from the B, the T's, the second E, and the R. Also, the mismatch between the first E and the U would constitute negative evidence, perhaps leading to a decrement of the logogen for BUTTER. Later we discuss how the logogen model explains semantic context effects. First, however, we review some experimental work on the effects of semantic context.

Context and Encoding

Previous research on the effects of semantic context in the lexical decision task implicates the process of encoding stimulus information as one locus of the effect of semantic context. The first study that led us to consider encoding as a possible locus of the facilitation produced by an appropriate semantic context was reported in Meyer, Schvaneveldt, and Ruddy (1974). The study was based on Sternberg's (1969) additive-factor method. Briefly, Sternberg's method requires the orthogonal manipulation of two or more independent variables in a reaction time experiment. When two variables affect the same underlying stage of information processing, the two variables should produce interactive effects on reaction time. Conversely, when two variables affect different underlying stages, the variables should produce additive effects. Meyer et al. investigated three variables: the quality of the stimulus, the nature of the response, and the semantic context preceding the target word. Stimulus quality was varied by degrading some of the target items. The degraded items were presented in a field of evenly spaced dots on a CRT screen. Overall, responses to words were 112 msec longer for the degraded displays. The response was manipulated by requiring one group of subjects to make lexical decisions about the target items and another group to pronounce the items. Subjects in both groups responded verbally, the lexical decision group by saying "yes" to words and "no" to nonwords. Responses to target words averaged 74 msec faster in the pronunciation group. Finally, the semantic context was manipulated by preceding some target words with semantically related words and others by unrelated words. Responses in the related condition were faster by 48 msec on the average. The pattern of interactions is of primary interest. Of the four possible interaction effects, only the one involving stimulus quality and semantic context was significant. The context effect was 28 msec larger for the degraded words. None of the other interactions approached significance; the largest one was 7 msec, with a standard error of 8 msec.

If we follow the logic of Sternberg's (1969) additive-factor method, the pattern of results suggests that stimulus quality and semantic context both affect at least one underlying stage of information processing. Further, the stage or stages affected by these variables are independent of the stage influenced by the response requirements (pronunciation vs. lexical decision), since the response factor produced a constant (additive) effect under each combination of stimulus quality and semantic context. If we suppose that both pronunciation and lexical decision involve encoding and memory retrieval prior to organizing and executing a response, the interaction of stimulus quality and semantic context leads us to conclude either that both of these factors affect encoding or that both affect memory retrieval. However, as McClelland (Note 2) has recently shown, this conclusion depends on the rather strong assumption that encoding is completed before memory retrieval begins. If we relax that assumption, an interaction between stimulus quality and semantic context could occur even when stimulus quality affects encoding and semantic context affects memory retrieval (for a detailed discussion, see McClelland, 1979).

The findings of the Meyer et al. (1974) study are consistent with the hypothesis that encoding processes are affected by semantic context, although other interpretations of the findings are clearly plausible. A study by Becker and Killion (1977) provides some constraints on explanations of the interaction of stimulus quality and semantic context. They found the same interaction when they manipulated both the intensity of target words and the semantic relationship between prime and target words. As Becker and Killion suggest, the intensity manipulation should produce effects that are more localized in encoding processes compared with the degradation employed in the earlier study by Meyer et al. To the extent that intensity effects are confined to earlier processes, the interaction of intensity and semantic context suggests that context also affects early processes. This suggestion is reinforced by the results of two additional experiments reported by Becker and Killion (1977). In these experiments, the same variation in intensity was employed together with a systematic manipulation of word frequency. While intensity and word frequency both produced reliable main effects, they did not interact ($F < 1$ in both experiments).

Taken together, the study by Meyer et al. and the experiments reported by Becker and Killion show that stimulus quality and semantic context interact while stimulus quality and word frequency do not. Under the assumptions of the additive-factor method, we can infer that stimulus quality and word frequency affect different underlying stages of information processing and that stimulus quality and semantic context affect at least one stage in common. Presumably this common stage occurs prior to the stage affected by word frequency in the sequence of stages. Even with a variety of other assumptions about the organization of information-processing activity, the pattern of results suggests that stimulus quality and semantic context affect relatively early processes while word frequency affects a later process that is immune to the effects of stimulus quality. On the basis of these studies, we seem to have sufficient evidence to consider the hypothesis that context affects encoding processes. Now we turn to some issues regarding the nature of such effects.

Sensitivity Versus Bias Effects

Basically the lexical decision task involves discriminating between words and nonwords. In one sense, this task is similar to a yes-no signal detection procedure in that signals (words) must be distinguished from noise (nonwords). In the usual signal detection task, however, the signal is a constant physical stimulus that bears a relatively fixed similarity relationship to the noise stimulus. Thus, it is reasonable to assume that both signal and noise stimuli can be mapped onto a unidimensional variable that represents the evidence in favor of the signal having occurred. In contrast, the "signals" in the lexical decision task take many different forms, as do the "noise" events. In this case, it is more difficult to appreciate the consequences of the assumption that signals and noise give rise to different distributions along a single dimension of evidence for a signal. Rather, we have several different potential signals, and a particular stimulus could lead to favorable evidence for one signal (word) and unfavorable evidence for another. For example, suppose the nonword MONIY is presented. This stimulus should give rise to favorable evidence for some signals (e.g., MONEY) and unfavorable evidence for others (e.g., FAT). Instead of a single dimension of evidence for a signal, we might assume a separate dimension of evidence for each potential signal. Thus, for each word in an observer's vocabulary there would be an element capable of registering the extent to which a stimulus produces evidence in favor of that particular word. This is essentially the logogen model proposed by Morton (1969).

Consider how the logogen model can be used to explain the effect of presenting words in a related semantic context. Morton's original proposal provided input to the logogens from a "cognitive" system as well as from the incoming sensory information. In this way, the logogens that share some semantic features with words occurring earlier would already be activated to some extent when a stimulus occurs. A stimulus word that is related to the context would then require less information from the sensory system in order to exceed a fixed criterion. Thus less information from the senses and presumably less time would be required to recognize words occurring in an appropriate semantic context compared with words occurring in isolation or in an inappropriate context. While Morton's analysis proposes a change in the starting point for logogens that are related to contextual information, the effect is identical to changing the criterion associated with the same logogens. Thus, the effects of context are essentially attributed to shifts in criteria. The consequence of a shift in the criterion associated with a particular logogen should be to increase the rate of false positive responses as well as to improve performance in recognizing the word corresponding to that logogen. In a lexical decision task, lowering the criteria associated with some of the logogens should lead to an increased error rate in classifying nonwords.

Some research recently reported by Schuberth (Note 3) addresses this problem. Schuberth required subjects to make lexical decisions about tachistoscopically presented words and nonwords. The target items were presented following context words. The target words were related to the context words for one group of subjects and unrelated for a second group. Error rates in classifying words and nonwords were used to perform a signal detection analysis to determine the level of sensitivity and bias operative in the task. The signal detection analysis showed greater sensitivity for the group with related targets. In contrast, the bias parameters for the two groups were not reliably different. Thus, it appears that semantic context enhances the sensitivity of the observer instead of inducing a shift in the criterion the observer uses in deciding whether a word has been presented. The problem with such a conclusion, however, is that there may be a different relationship between signal and noise in the two groups. In particular, the group with target words related to the context presumably has a much smaller set of potential targets on each trial compared with the group with unrelated target words. It is more probable that a randomly selected nonword will be physically similar to a word in the larger set of unrelated words than to one in the smaller set of related words. Thus, even if the criteria for related words are lower for subjects in the group shown related targets, the lower average similarity between nonwords and words in the related set could easily compensate for the criterion shift. In general, the physical similarity of potential signals and the noise events can exert unintended influences on the estimate of bias and sensitivity simply because the noise events do not give rise to sufficient evidence for the potential signals. If an experimental manipulation changes the similarity relationship, the results of a signal detection analysis could be quite misleading.

This problem can also be viewed in another way. A bias induced at one level of analysis could lead to apparent changes in sensitivity at another level of analysis. For example, suppose that semantic context had the effect of decreasing the amount of sensory information required for reaching the thresholds of the letters in words related to the context. This amounts to a bias at the letter level of analysis. However, if we attempt to assess the bias at the lexical level by means of a lexical decision task or a tachistoscopic recognition task, we might find evidence for either a shift in bias or increased sensitivity. It depends on the nature of the foils we use to determine the false positive rate. In the lexical decision task, we would presumably find an increase in the rate of false positives if the nonwords shared a substantial number of letters in common with the words related to the context. Otherwise, performance on the nonwords would not be affected by context, and the results would appear to reflect an increase in sensitivity because of the improvement in performance on the words occurring in a related context. In short, conclusions about bias versus sensitivity effects must be carefully evaluated in light of the nature of the "noise" events.

Lapinski and Tweedy (Note 4) reported an experiment that directly controlled the similarity of the nonword foils and the word targets. They presented people with a series of letter strings and instructed them to judge the lexical status of each string. The series was organized into pairs of items such that the two letter strings in each pair were either related or unrelated. The novel aspect of their experiment was that they included specially constructed nonwords to allow relatedness to be manipulated for the nonwords as well as for the words. For example, the set of items included pairs such as DOCTOR–NURSE, LAMP–NURSE, DOCTOR–NERSE, and LAMP–NERSE, where the correct classifications are word–word, word–word, word–nonword, and word–nonword, respectively. The criterion-shift hypothesis predicts that performance on NURSE should be facilitated by the prior occurrence of a related word relative to an unrelated word and that, conversely, performance on NERSE should be worse when it follows a related word (DOCTOR) compared with an unrelated word (LAMP). While the results confirmed the prediction for the performance on words, the hypothesis can be rejected because of the performance on nonwords. Responses were faster and slightly more accurate when the nonwords followed related words. These data clearly suggest that a simple criterion shift is insufficient to account for the effects of semantic context.

Further confirmation of this conclusion has been reported by McDonald (1977), McDonald and Schvaneveldt (Note 5), and Antos (1979). These investigators, who also used lexical decision tasks with nonwords that closely resembled the word targets, found that a related context facilitated responses to words without producing an increase in the false positive rate on the similar nonwords. Again, the findings suggest that a related semantic context does not simply decrease the amount of evidence required for judging a stimulus to be a word. In some sense, context must assist in the analysis of the information in the stimulus. Word decisions can be made rapidly, but physically similar nonwords can be rejected. Our experiments are directed at a further analysis of this phenomenon.

We had several goals for the present series of experiments. First, we wished to obtain some evidence about the levels of encoding that are influenced by semantic context. To this end, we devised tasks that required people to assess visual stimuli at the featural, letter, and lexical levels of analysis. A second goal was to test the sensitivity-versus-bias hypotheses about the nature of context effects. The character of the foils (nonwords) was of particular concern to us in our attempt to untangle bias and sensitivity effects. Finally, we studied the above issues in relation to the amount of stimulus information available to the subject. In the limited-information experiments, we presented the targets briefly and followed them with a masking stimulus. Error rates provided the primary data in these experiments. In the other experiments, the target remained in view until the subject responded. We used both reaction time and error rate measures in these experiments.

Method

Altogether, we conducted six experiments, which differed in the task to be performed and the paradigm employed. Each task was studied in both reaction time and tachistoscopic paradigms. The lexical decision task required decisions about the lexical status of letter strings. The rotation detection task required decisions about the orientations of letters in target stimuli. The gap detection task required decisions about the continuity of the strokes forming the letters of target stimuli. The experiments are similar enough to allow us to describe the method for all of the experiments in this section.

Experimental Design

In each experiment, there were three types of primes (related, neutral, or unrelated) and two types of targets (word or altered word). The combination of these variables produced six basic conditions for each experiment. Latin square assignments of subjects, materials, and conditions were employed such that across subjects every target item appeared in all conditions in either its original or its altered form. No subject in any experiment saw the same string of letters more than once, nor did any subject see both a word and the altered word derived from it.

Materials

The stimulus character set was formed using a 7 (horizontal) × 9 (vertical) matrix of "dots." Patterns were selected from the Datamedia Elite 1520 uppercase character set. The letters thus formed were approximately 5.6 mm wide and 8 mm high, with a 1.7-mm space between letters. The same 192 word pairs were used in each experiment. The word pairs were selected from various free-associational norms and included additional pairs that were, in the judgment of the experimenters, semantically related. The first words of the stimulus word pairs, or primes, varied in length from three to six letters. The second words, or targets, varied in length from four to six letters, which produced a maximum visual angle of approximately 2.5°. The related word pairs were used to form the related prime conditions. New pairings of the same words were used to form the unrelated prime conditions. In addition, the targets could be paired with a string of *x*'s, which constituted a neutral prime.

Word targets were transformed to produce altered-word targets by changing a single letter. The letter selected was in any position except the first, with the added constraint that the letter could not be symmetrical about both the vertical and horizontal axes. For the lexical decision tasks, the selected letter was replaced with another letter so that the resulting letter string formed a pronounceable nonword. No effort was made to produce nonwords that were homophonic with their base words. For the rotation detection tasks, the original letter was rotated 180° about either the vertical or the horizontal axis to produce either mirror-image or inverted letters. For the gap detection tasks, the original letter was altered by removing a 2–3-mm segment from one of the strokes forming the letter.

Procedure

Subjects participated individually in a session that lasted approximately 30 min. They sat facing the video monitor with the index finger of each hand resting on a response key. In an effort to reduce variance produced by external distraction, subjects wore headphones over which low-level white noise was emitted throughout the experimental trials. Instructions were prerecorded and played for the subjects on a cassette recorder. At the completion of the instructions, subjects were encouraged to ask any questions they had concerning the task. In all experiments the key on the right was designated as correct for word targets while the key on the left was designated as correct for altered-word targets. Subjects were provided with 12 practice trials to familiarize themselves with the task. Practice in distinguishing broken from normal letters was also provided for the gap detection subjects.

Each trial consisted of two events in the reaction time paradigm and three events in the tachistoscopic paradigm. In either case the first event was always the priming signal, which consisted of a string of *x*'s or a valid English word. If the prime was neutral (*x*'s), it was the same length (contained the same number of characters) as the related word prime for the target on that trial. The prime remained on for 750 msec and was followed by a blank interval of 500 msec. No response to the prime was required, and subjects were only told that the first event was to prepare them to respond to the target. The second event, or target, appeared in the same location on the screen and was either an English word or an altered word, as defined by the task requirements.

In the reaction time experiments, the target remained visible until the subject responded. The instructions were that the subject was to respond as rapidly and accurately as possible.

In the tachistoscopic experiments, the target was displayed for approximately 33.3 msec and was followed by a masking pattern consisting of a string of number signs (#). Subjects were instructed to make as few errors as possible, and speed was not encouraged. The interval between target and mask, or interstimulus interval, (ISI) was adjusted at the end of each block of trials in order to maintain an error rate of approximately .250. With 24 trials in each block, six errors corresponded to the desired error rate. The ISI was increased by approximately 16.7 msec for each error in excess of six in the preceding block. Similarly, the ISI was decreased by the same amount for each error under six. Thus, large error rate deviations produced large changes in ISI. The minimum allowable ISI was 0 msec and the maximum allowable was 267 msec.

All subjects received feedback on their performance. On any trial where the subject's response was incorrect, the word ERROR was displayed for 1 sec. The interval between trials was approximately 2.5 sec. After every

24 trials, subjects were provided with information about their performance on the previous group of trials. In the reaction time experiments, subjects were shown their average response time, the number of times their responses were correct, and the number of times their responses were wrong. Reaction time information was omitted for the tachistoscopic experiments. Subjects initiated each block of trials, after the word READY appeared during performance feedback, by pushing either response key.

Apparatus

Control and timing functions were performed by a Cromenco Z80 microcomputer system. Stimuli were generated with a Cromenco Dazzler graphics module. The subject station consisted of a Hitachi 9-inch video monitor and two response keys mounted on a movable box. The subject sat facing the video monitor at a distance of approximately 1 m.

Subjects

A total of 144 students volunteered to participate in six experiments in partial fulfillment of the credit requirement for introductory psychology. There were 24 subjects in each of the experiments. All subjects were native speakers of English.

Results and Discussion

In all of the experiments, each subject judged a different set of items in each condition. Thus, the interaction of subjects and conditions in an analysis of variance contains variability due to the Item × Condition interactions as well as variability due to the main effect of items. By using the Subject × Condition interactions as error terms for testing the effects of conditions, we may generalize our conclusions to both the population of subjects and the population of items from which our samples were drawn.

Reaction Time Experiments

In each of these experiments, there were two blocks of trials, three types of primes (semantically related, neutral, and semantically unrelated), and two types of targets (normal words and altered words). Reaction time from trials with correct responses and error rates were both subjected to repeated measures analyses of variance. The neutral primes were used to separate the costs and benefits associated with the effects of the unrelated and related primes (see Posner & Snyder, 1975).

Lexical decision task. This experiment was designed to replicate and extend some earlier work by Antos (1979), Lapinski and Tweedy (Note 4), Lapinski (1979), McDonald (1977), and McDonald and Schvaneveldt (Note 5).

The altered words in our experiment were formed by replacing one interior letter of each word with another letter to form a nonword. In the analysis of error rates, there was a significant effect of type of target, $F(1, 23) = 10.17$, $MS_e = .008$, $p < .005$. The error rate on words was .030 compared with .054 for altered words. The reaction time analysis showed significant effects of blocks, $F(1, 23) = 5.98$, $MS_e = 24{,}191$, $p < .025$; type of prime, $F(2, 46) = 18.01$, $MS_e = 5{,}855$, $p < .001$; type of target, $F(1, 23) = 59.16$, $MS_e = 41{,}470$, $p < .001$; and the Type of Prime × Type of Target interaction, $F(2, 46) = 12.96$, $MS_e = 8{,}412$, $p < .001$. There was a 32-msec improvement in reaction time over the two blocks. The Type of Prime × Type of Target interaction is shown in panel A of Figure 1.

Further analysis of the interaction showed that for word targets, related primes led to responses that were 79 ± 12 msec faster than responses to unrelated primes ($p < .001$).[1] For altered words, there was a nonsignificant advantage for the unrelated primes over the related primes (difference = 16 ± 11 msec, $p > .10$). The error rates are particularly relevant to the interpretation of the semantic facilitation observed for word targets. The criterion-shift hypothesis leads to the prediction that the semantic facilitation for words should be accompanied by an increased error rate on the altered words when they follow the related prime. However, the data show similar error rates for the altered words following related primes (.056) and following unrelated primes (.052). The word targets are processed more rapidly and somewhat more accurately following the related primes, while the altered-word targets may require further processing. There is a nonsignificant trend in the reaction time data, which suggests that decisions on the

[1] Where we report statistics in the form, $x \pm y$, y represents 1 *SE* of the statistic x. The probability values are based on t tests.

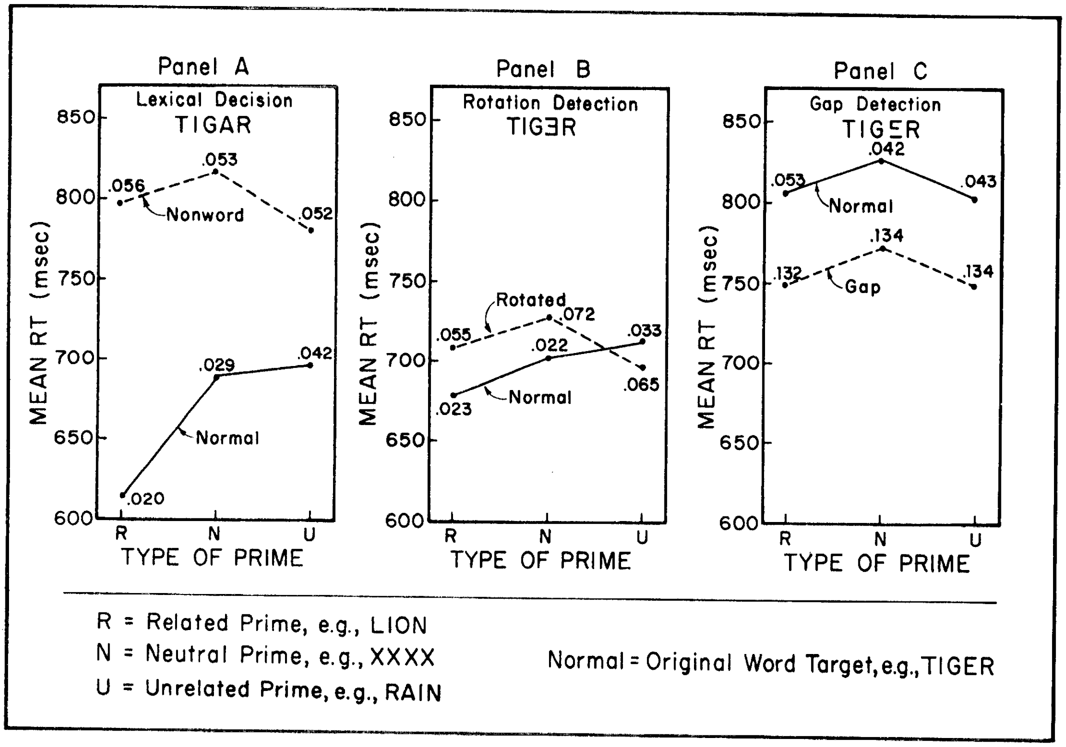

Figure 1. Mean reaction time as a function of type of prime and type of target for the reaction time experiments. (Error rates are shown for each data point. Data from the normal-word targets are plotted with solid lines. Data from the altered-word targets are plotted with dashed lines. An example of an altered word is shown in each panel.)

altered words may be delayed by a related prime compared with an unrelated prime, but since the error rate is not affected by the prime, the delay for altered words must reflect processes occurring after it has been determined that the target is not the physically similar word. In short, the data from the lexical decision task are not consistent with the criterion-shift hypothesis. Rather, a semantically related context facilitates the processing of word targets without producing a higher error rate on the physically similar altered-word targets.

An analysis of the benefits associated with related primes showed a significant advantage for word targets (related primes led to responses that were 72 ± 12 msec faster than responses to neutral primes, $p < .001$). There was also a reliable benefit for altered-word targets, where responses to altered words were 20 ± 8 msec faster following related primes than following neutral primes ($p < .05$).

Analysis of the costs associated with the unrelated primes showed no reliable effect for word targets (695 msec for unrelated primes vs. 689 msec for neutral primes). However, responses to the nonword targets were 36 ± 12 msec faster with unrelated primes than with neutral primes ($p < .01$). Thus, we found that nonwords were classified more rapidly following word primes than following neutral primes regardless of the semantic relationship between the word prime and the nonword. Neely (1976, 1977) also reported an advantage for nonword decisions following a word prime compared with a neutral prime. Neely's findings as well as our own led us to perform some experiments investigating this issue (McDonald, Schvaneveldt, & Thorpe, Note 6). The upshot of these experiments is that there appear to be priming effects that are independent of the semantic priming, which is normally the topic of priming studies. Our current hypothesis is that the priming event can lead to the general activation of linguistic information-processing mechanisms. If we are correct in this, then the advantage of word primes for responding to nonword targets may simply reflect this general priming effect and have nothing to do with the semantic relationships involved.

In summary, the results of the first experiment lend support to the hypothesis that semantic context enhances the sensitivity of the observer for recognizing semantically related words. The central basis for this claim is the facilitation for responding to words in a semantically related context without a corresponding decrement in error rate on altered words that are physically very similar to the words. The lack of an effect of priming on the error rate for nonwords suggests that related primes facilitate the process of accessing related words and that these words are distinguished from similar nonwords before a response is made.

We designed the next experiment to determine whether the effects of context would extend to the task of detecting the presence of a rotated letter in a word.

Rotation detection task. In this experiment the altered words were formed by rotating the same letter that had been replaced in the first experiment. In the error analysis, there were significant effects of blocks, $F(1, 23) = 6.89$, $MS_e = .002$, $p < .025$, and type of target, $F(1, 23) = 19.01$, $MS_e = .011$, $p < .01$. People made fewer errors in the second block of trials and were more inclined to miss a rotated letter than to indicate that a normal letter was rotated. In the analysis of reaction time, there were significant effects of blocks, $F(1, 23) = 18.22$, $MS_e = 16{,}632$, $p < .001$, and an interaction between blocks and type of target, $F(1, 23) = 7.57$, $MS_e = 8{,}452$, $p < .005$. In the first block, response time (RT) was approximately the same for normal words and altered words, but in the second block, the normal words were classified 35 msec faster than the altered words. There was also a significant main effect of type of prime, $F(2, 46) = 3.57$, $MS_e = 9{,}503$, $p < .05$, and a significant Type of Prime × Type of Target interaction, $F(2, 46) = 3.98$, $MS_e = 9{,}674$, $p < .05$. The nature of the interaction is shown in panel B of Figure 1.

Further analysis of the interaction showed that the related primes led to faster responses than did the unrelated primes for the word targets (difference = 34 ± 12 msec, $p < .01$), but there was a nonsignificant trend in the opposite direction for the altered words (difference = 12 ± 17 msec). The error rates showed small advantages for the related primes over the unrelated primes for both word targets and altered-word targets. As in the first experiment, the facilitation on word targets occurred without a corresponding decrement in the error rate for the altered-word targets. These results suggest that a criterion shift is not responsible for the semantic facilitation observed for word targets.

In the analysis of benefits for the normal word targets, related primes demonstrated an advantage of 24 ± 13 msec over neutral primes ($p < .05$); for the altered words, the advantage was 29 ± 18 msec ($p > .10$). The facilitation we found with the rotation detection task was similar to that in the lexical decision task, but the effects were considerably smaller.

The costs associated with an unrelated prime were small for the word targets, as they were in the lexical decision task. For normal words, there was a small (10 ± 14 msec) advantage for the neutral primes compared with the unrelated primes, but the altered words showed an advantage of 41 ± 15 msec for the unrelated primes compared with the neutral primes ($p < .02$). As in the lexical decision experiment, responses to words showed differences as a function of the semantic relationship between the prime and the target, while the altered words showed an advantage of word primes over neutral primes regardless of the semantic relationship between the prime and the target. The magnitude of the semantic effect in the rotation detection task was considerably smaller than it was in the lexical decision task, but the data still suggest that semantic context affects the processing of the normal words. The altered words show only the general, nonsemantic priming effect.

In the next experiment, we attempted to push the required level of analysis even further. The gap detection task required subjects to determine whether one letter of a word had a missing segment. Presumably, this task required analysis of the features of letters.

Gap detection task. In this experiment, the altered words were formed by removing a small segment from the letter that had been replaced in the first experiment. In the analysis of error rates, there were significant effects of blocks, $F(1, 23) = 12.18$, $MS_e = .007$, $p < .005$, and type of target, $F(1, 23) = 30.16$, $MS_e = .036$, $p < .001$. The error rate in the first half of the experiment was .102 compared with .077 in the second half. The intact words showed a considerably lower error rate (.046) than the altered words (.133). The reaction time analysis showed significant effects of blocks $F(1, 23) = 34.04$, $MS_e = 51{,}117$, $p < .001$; type of target, $F(1, 23) = 16.82$, $MS_e = 25{,}979$, $p < .001$; and a Blocks × Type of Target interaction, $F(1, 23) = 6.06$, $MS_e = 6{,}650$, $p < .025$. Type of prime also produced a reliable effect, $F(2, 46) = 3.20$, $MS_e = 10{,}672$, $p < .05$. There was a 110-msec improvement in reaction time over the two blocks. Overall, the altered words were classified 55 msec faster than the intact words, but this difference was 72 msec in the first block and 38 msec in the second block. The neutral primes were slower than the other two, which did not differ from each other (777, 799, and 776 msec for related, neutral, and unrelated primes, respectively). The pattern of differences was virtually identical for intact words and altered words. The means of the (nonsignificant) interaction of Type of Target × Type of Prime are shown in panel C of Figure 1 for comparison with the first two experiments.

In the gap detection task, there were no effects of semantic context, but the nonsemantic priming effects we encountered in the altered-word conditions of the first two experiments were found for both words and altered words. Thus, the semantic effects appeared to extend to the processing of letter orientation, albeit to a lesser extent than for the processing of the identity of letters in a word. Semantic effects were absent, however, when the subject was required to make judgments about the individual features of letters in a word. The tachistoscopic experiments should help us to determine whether the observed effects of semantic context are occurring in the early encoding processes. Next we turn to the results of those experiments.

Tachistoscopic Experiments

The interval between the target stimulus and the masking stimulus was adjusted after every block of trials with the aim of holding the error rate at approximately .250. The data we report represent performance on all trials following the short practice block. In each of the tachistoscopic experiments, the design included three types of primes (semantically related, neutral, and semantically unrelated) and two types of targets (normal words and altered words). The error rates were subjected to an analysis of variance for each experiment.

Lexical decision task. In this experiment, we tested two groups of subjects with different masking stimuli to determine whether the type of mask would influence the pattern of results. One mask was patterned (a series of #'s), and the other mask was a solid white field covering the area where the white letters of the target stimulus had appeared on a black ground. Since we manipulated the target mask interval to maintain a .25 error rate, the main effect of type of mask was artificially eliminated. However, there were also no significant interactions involving type of mask. Thus, the pattern of results was the same for the two masking conditions.

There was a significant effect of type of target, $F(1, 22) = 27.91$, $MS_e = .001$, $p < .001$, and a significant Type of Prime × Type of Target interaction, $F(2, 44) = 21.91$, $MS_e = .012$, $p < .001$. The error rate for words was .141 compared with .267 for the altered words. The interaction is shown in panel A of Figure 2.

Detailed analysis of the Type of Prime × Type of Target interaction showed that the error rate for word targets was .123 ± .020

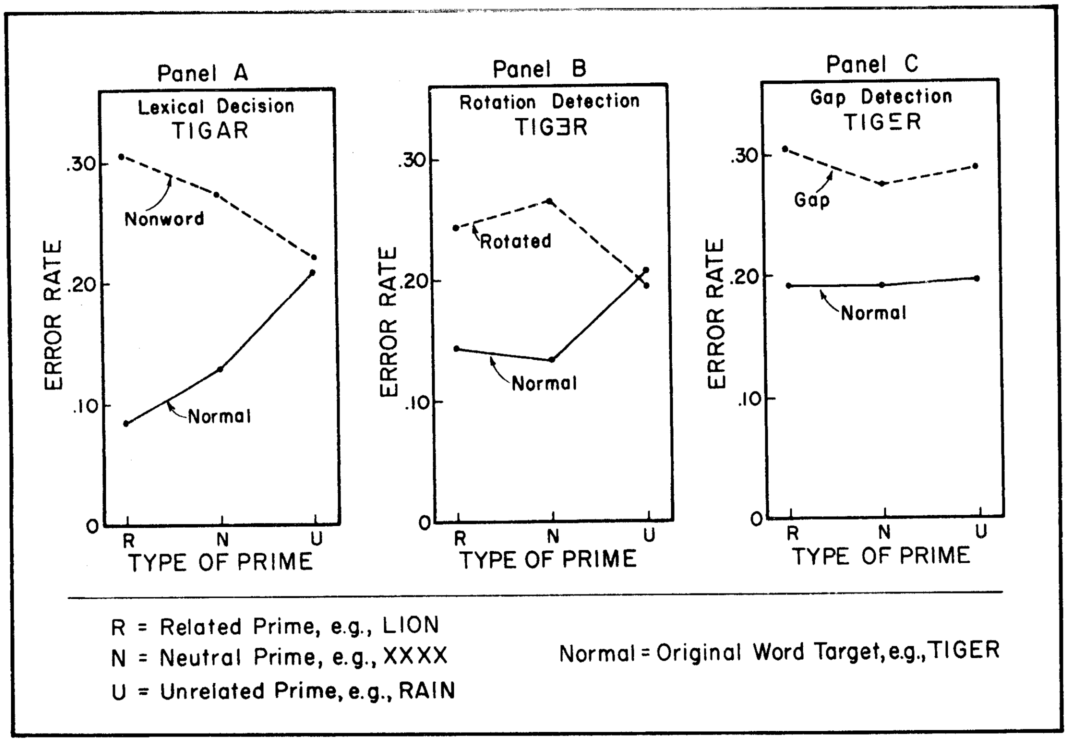

Figure 2. Mean error rates as a function of type of prime and type of target for the tachistoscopic experiments. (The data from the normal-word targets are plotted with solid lines. The data from the altered-word targets are plotted with dashed lines. An example of an altered word is shown in each panel.)

less for the related primes than for the unrelated primes ($p < .001$). For the altered-word targets, the difference was .086 ± .024 in the opposite direction ($p < .01$). Thus, the facilitatory effect of a related prime on the words is offset by an inhibitory effect of related primes on the altered words. This pattern suggests that a related semantic context simply increases the likelihood of a word decision.

Similar trade-offs for word and altered-word decisions are found in the pattern of benefits and costs. For word targets, the error rate was .043 ± .019 smaller for related primes compared with neutral primes ($p < .05$). The difference, .033 ± .024 ($p > .10$), was in the opposite direction for the altered-word targets. As for costs associated with unrelated primes, the error rate on word targets was .079 ± .020 larger with unrelated primes than with neutral primes ($p < .001$). Again, the effect was in the opposite direction for the altered-word targets, .053 ± .025 ($p < .05$).

In contrast to the findings from the lexical decision task in the reaction time paradigm, the tachistoscopic procedure yielded data that favored the criterion-shift interpretation of the effects of semantic context. The error rates showed systematic trade-offs between the word targets and the altered-word targets. When performance on word targets changes, performance on the altered-word targets changes in the opposite direction. Semantic context influences the choice of a response, but it does not affect people's ability to discriminate between words and physically similar nonwords when the stimulus information is limited.

Rotation detection task. In this experiment, the effect of type of target, $F(1, 23) = 9.87$, $MS_e = .078$, $p < .005$, and the Type of Prime × Type of Target interaction, $F(2, 46) = 8.67$, $MS_e = .031$, $p < .001$, were significant. The error rate for the word targets was .161, compared with .234 for the altered-word targets. The interaction is shown in panel B of Figure 2.

As in the last experiment, the word targets and the altered-word targets showed opposite effects of priming. The error rate on word targets was .064 ± .022 smaller with related primes than with unrelated primes ($p < .01$). An opposite difference of .048 ± .022 occurred with the altered-word targets ($p < .05$). The differences between neutral primes and related primes were small and nonsignificant for both target types. The comparison of unrelated and neutral primes again showed opposite effects for the two target types. For words, unrelated primes led to a .070 ± .024 larger error rate than did the neutral primes ($p < .01$). For altered words, the neutral primes produced a .072 ± .023 larger error rate ($p < .01$).

This pattern of results is similar to that of the last experiment. There is a consistent trade-off of error rates for the word targets and the altered-word targets. Again, semantic context effects appear to be entirely due to shifts in decision criteria.

Gap detection task. The only effect to reach significance in this experiment was the effect of type of response, $F(1, 23) = 10.94$, $MS_e = .101$, $p < .005$. The error rate on intact-word targets was .194 compared with .289 on the altered-word targets. For comparison with the other tachistoscopic experiments, the (nonsignificant) Type of Prime × Type of Target interaction is shown in panel C of Figure 2.

Discussion

In the gap detection experiments, we attribute the effect of priming to the general advantage of word primes over neutral primes. There is no evidence that semantic priming has any influence. With tachistoscopic exposures, there were no effects of priming at all. The response bias effect was not present, as it was with the lexical decision and rotation detection tasks.

The absence of a semantic effect in the gap detection tasks supports the hypothesis that semantic context effects do not extend to the level of analyzing individual features of letters in words. However, it is important to emphasize that the evidence for such a conclusion rests on accepting the null hypothesis, which requires some caution. Of even more concern is the possibility that the task to be performed on the target stimulus affects the way in which the priming stimulus is processed. Smith (1979) has shown that semantic priming effects depend on how the prime is processed. In our experiments, we required no overt response to the prime. Under similar conditions, Smith found semantic priming effects in a letter search task. Still, we cannot be certain that the prime is not processed differently when the objective of the task is to detect a gap in one letter of the target stimulus. Thus, we should take the data from the gap detection experiments as suggestive rather than conclusive on the question of the level at which semantic context operates.

The findings from the lexical decision and rotation detection tasks permit somewhat stronger conclusions about the role of semantic context in encoding. With both of these tasks, the semantic relationship between the prime and the target reliably affected performance. However, the nature of the effect was quite different for the tachistoscopic paradigm compared with the reaction time paradigm. With the tachistoscopic procedure, variations in context led to nearly perfect trade-offs in error rate for words and altered words.[2] Thus, context effects can be explained simply by the hypothesis that decision criteria are lower for semantically related words. This hypothesis implies that physically similar altered words are mistaken for the original word more often when they occur in a related context than when they occur in an unrelated context—which is what we found. When we consider the data from the reaction time experiments, the decision bias hypothesis does not fare so well. The reaction time data show enhanced speed

[2] We extracted both parametric and nonparametric estimates of the bias and sensitivity parameters of signal detection theory using the data from the tachistoscopic experiments. As Figure 2 would suggest, there were no differences in sensitivity as a function of type of prime. The bias parameters, however, varied reliably with type of prime in the lexical decision and rotation detection tasks.

and accuracy on words occurring in a related context without a corresponding decrement in error rate on the altered words. Apparently the confusion between altered words and normal words that occurred in the tachistoscopic experiments was correctly resolved when the stimulus remained available for further analysis. Thus, the reaction time data show increased sensitivity when items occurred in a semantically related context in the sense that decisions were made with slightly more accuracy and were substantially faster.

Taken together, the present experiments provide support for the existence of two modes of processing sensory information. One mode involves the initial analysis of sensory information and is not directly affected by semantic context. This initial processing may involve analysis of the features of the stimulus or such holistic properties as word shape. Our tachistoscopic experiments show that semantic context can affect the response selected on the basis of the initial stimulus analysis, perhaps by lowering the criteria for words related to the context in the manner suggested by the logogen model. The data for our tachistoscopic experiments can be explained quite well with the logogen model.

A second mode of processing sensory information is suggested by our reaction time experiments. This mode can be characterized as a "second look" at the stimulus. This second look can resolve some of the confusion that arises from the initial processing of the stimulus. Our view is that the secondary analysis of stimulus information is basically a memory-driven process in which "hypotheses" about the identity of the stimulus are tested by comparing actual stimulus characteristics with those predicted by the hypothesis. The hypotheses are generated by a combination of sensory information (from the first mode of processing) and contextual information.

For example, when an altered word such as NERSE is presented, the second mode of analysis determines whether the stimulus is NURSE. The first mode provides considerable positive evidence for the hypothesis that the stimulus is NURSE. If the stimulus occurs in a semantically related context (e.g., following the word DOCTOR), the NURSE hypothesis would generally occur faster and would result in faster responses when the stimulus actually is the hypothesized word. When it is a nonword, however, the secondary analysis simply establishes that it is not the particular hypothesized word, and the recognition process must continue. According to this explanation, nonword responses follow an exhaustive analysis of all entries in the lexicon that are sufficiently similar to the stimulus to be entertained as hypotheses in the secondary analysis of stimulus information. Of course, the second mode of analysis depends on the continued availability of stimulus information. With tachistoscopic exposures and masking stimuli, there is little opportunity for the second mode to operate.

Several writers have proposed theories that include a succession of processes which depend to varying degrees on "bottom up" and "top down" modes of organization. Compare, for example, the notion of perceptual cycles (Neisser, 1976) and the verification model (Becker, 1976; Becker & Killion, 1977; Schvaneveldt, Meyer, & Becker, 1976; Becker, Schvaneveldt, & Gomez, Note 7). Similar views have been expressed by Rumelhart (1977) and by Rubenstein, Lewis, and Rubenstein (1971). In the language of perceptual cycles, our data suggest that the initial cycle is not affected by semantic context but, rather, that later cycles are directed by hypotheses about the stimulus, and because the hypotheses are partially determined by semantic context, the later cycles of stimulus analysis are also affected by semantic context.

There are some interesting parallels between the research reported in the present article and some recent studies on the word superiority effect. Massaro (1979) and Krueger and Shapiro (1979) have presented evidence against the proposition that orthographic context influences the extraction of features from the letters in words and nonwords. Krueger and Shapiro found that people do not detect flaws in the letters of words with any greater accuracy than they do in the letters of nonwords. This finding parallels our finding with gap detection, although Krueger and Shapiro found that word context induces a response bias toward missing the flaws in letters. Our own findings with semantic context do not show an analogous bias. It would seem that neither orthographic nor semantic context affects the process of extracting features. However, the work on orthographic context was done using brief presentations of stimuli. It would be useful to investigate the issue further with a paradigm that does not limit the stimulus information. If orthographic context can influence the secondary analysis of stimulus information, as semantic context appears to do in our reaction time experiments, the effects would not be revealed by experiments using brief stimuli.

It could be argued that some of the effects we observed in our experiments occurred only because of the tasks we employed. Of course, we cannot be certain that the phenomena we observed would occur in other tasks. Each of our tasks required attention to the visual detail of the stimuli. In a task more like reading, where fine visual details may be less important, a logogen-based system would possibly be sufficient to account for performance. There may be no need to invoke explanations that involve "top down" components. While this is a reasonable position to hold, we are not in accord with it. We propose that the secondary analysis of stimulus information that occurred in our reaction time experiments is a general process. Basically, the process is concerned with the verification of hypotheses about the identity of the stimulus, and since it is a verification, the process is guided by the hypothesis to be tested. Thus, secondary analyses of stimulus information can be directed to particular details as defined by the characteristics of the hypothesized stimulus.

Eye movement data recently reported by Zola (Note 8) suggest that context effects in reading are similar to the effects we observed in our reaction time experiments, providing some support for the contention that similar processes are involved. Zola manipulated the degree of contextual constraint provided by the text preceding a critical word and then observed eye fixations on the critical words. Sometimes the critical word was misspelled (cf. the altered words in our lexical decision experiments). While the number and distribution of fixations on the critical word were not affected by contextual constraint, the fixations were of shorter duration when the critical word occurred in the highly constrained context. Also analogous to the finding in our reaction time experiments, the highly constrained context that Zola used did not reduce the probability of fixating a misspelled critical word. Thus, context appears to produce a speed advantage in reading without increasing the probability of overlooking a spelling error.

In summary, the present series of experiments supports the hypothesis that context can influence the processing of stimulus information, but the influence is via a secondary analysis occurring subsequent to accessing the lexicon. Semantic context facilitates accessing the lexical representations of words related to the context; consequently, context influences the secondary-stimulus analysis. Apparently, the initial analysis of the stimulus is not affected by semantic context.

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