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Retrieval and Comparison Processes in Semantic Memory

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ABSTRACT

One useful procedure for studying semantic memory involves judging whether two strings of letters are both words. Decisions in the task are faster if the two strings are commonly associated words. Two classes of models could explain this effect. One class attributes the effect to processes that occur in accessing stored information about the words. A second class attributes the effect to comparing the words semantically. Such models were tested in an experiment where three horizontal strings of letters appeared simultaneously in an array from top to bottom. Subjects responded "yes" if the three strings were all words, and "no" otherwise. Both positive and negative responses were faster if two of the strings were commonly associated words. Reaction time also depended on the number and position of nonwords in the display. The results suggest that stimulus items were processed serially, that facilitation occurred in accessing stored information about associated words, and that excitation spreading between memory locations may be responsible for the association effect. Implications for a theory of semantic memory are considered.

I. Introduction: The Lexical-Decision Task

As a result of growing interest in human semantic memory, psychologists have devised a number of reaction-time (RT) tasks. One useful procedure involves judging whether a string of letters is an English word (Landauer

& Freedman, 1968; Meyer & Ellis, 1970; Rubenstein, Garfield, & Millikan, 1970). Reaction time in this *lexical-decision task* is a function of several factors, such as the frequency and number of different meanings a word has. Although the task is relatively simple, it presumably involves fundamental memory processes that occur in more complicated activities such as reading prose.

In a recent series of experiments, we used the lexical-decision task to study a dependence between retrieval operations (Meyer & Schvaneveldt, 1971). Two strings of letters were presented simultaneously on each trial. The stimuli were arranged horizontally in a visual display, with one string of letters centered above the other. Each stimulus was either a pair of nonwords (for example, PABLE–REAB), a word and a nonword (for example, KNIFE–SMUKE), or a pair of words. Half of the word pairs involved commonly associated words (for example, BREAD–BUTTER and NURSE–DOCTOR), while the remaining half consisted of unassociated words (for example, BREAD–DOCTOR and NURSE–BUTTER). In one experiment, subjects responded "yes" if both strings of letters were words, and "no" otherwise. In a second experiment, subjects responded "same" if the strings were either both words or both nonwords, and "different" otherwise.

The results of the two experiments revealed a substantial effect of association within pairs of words. In the yes–no experiment, pairs of associated words were judged an average of 85 msec faster than pairs of unassociated words. The same–different experiment produced a 117 msec association effect, which was not significantly different from the effect obtained in the yes–no experiment. The position of nonwords in the display also affected RT. In the yes–no experiment, negative responses were faster when the top item in the stimulus was a nonword than when it was a word. Given that the top item was a nonword, the lexical status of the bottom item did not affect RT significantly.

To account for these results, we proposed a two-stage retrieval model (Meyer & Schvaneveldt, 1971). According to the model, stimulus processing begins with the top string of letters in the display. The first stage involves a decision about whether the top string is a word, whereas the second stage involves a decision about the bottom string. The model presumes that if the first decision is negative in the yes–no experiment, then retrieval terminates and the subject responds "no." Otherwise, both stages are executed and the response depends on the outcome of the second decision. In the same–different task, both stages of retrieval normally are completed. The outcomes of the two decisions are then compared, and the subject responds "same" if the decisions match; otherwise, he responds "different." An outline of this model is shown in Fig. 1.

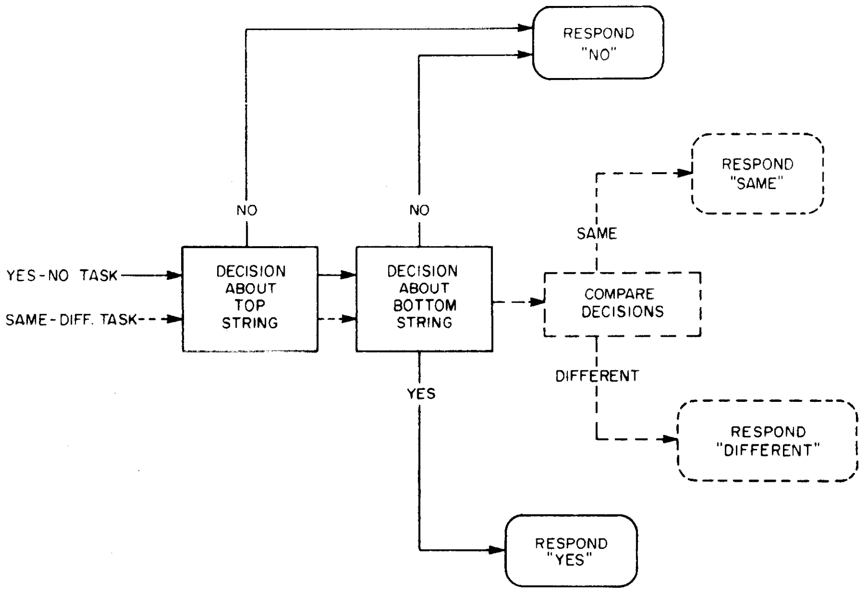

Fig. 1. A two-stage model for lexical decisions.

Our motivation for proposing the model was quite simple. The model explains two major findings in the yes–no experiment: (*a*) negative responses were faster when the top string was a nonword; (*b*) the lexical status of the bottom string had relatively little effect when the top string was a nonword. Since the association effects were similar in the yes–no and same–different experiments, there is reason to believe that the same basic retrieval operations occurred in the two experiments. The additional operation of comparing decisions for a match would then explain why "same" responses took more time than "yes" responses, and why "different" responses took more time than "no" responses.

Further elaborating the model, we suggested that the association effect occurs in accessing information for the second lexical decision. We assume that memory is organized by meaning, and that associated words are located "nearer" to each other in memory. As a result of this organization, the duration of the second retrieval stage presumably depends upon the first stage. We considered two possible mechanisms that might produce such a dependence between retrieval operations. The first is based on the concept of neural excitation. According to this view, retrieving information from a particular memory location produces a spread of excitation to nearby locations. The increase in activity at these locations facilitates retrieval, making it easier to access information stored there (see Collins & Quillian, 1970;

Warren, 1970). In addition to this *spreading-excitation model*, we suggested another alternative, which we call a *location-shifting model*. This second model assumes that stored information can be "read out" of only one memory location at any given instant, that time is required to "shift" read-out from one location to another, and that shifting time increases with the distance between locations. Thus, the association effect occurs because shifting to nearby locations is faster than shifting to more distant locations. Unfortunately, our first two experiments could not distinguish between the spreading-excitation and location-shifting models.

While our model attributes the association effect to a dependence between retrieval operations, other types of model also could explain our findings. Most semantic memory tasks include several conceptually distinct operations in addition to retrieval. For example, tasks involving two or more words often require comparing semantic information about each of the items. Effects of association (or semantic relatedness) have been observed in a number of these tasks (Collins & Quillian, 1969; Kintsch, Crothers, & Berman, 1970; Meyer, 1970; Schaeffer & Wallace, 1969). Such results have led to a view that semantic comparisons between words are responsible for association effects. One version of this *semantic-comparison model* attributes the association effect to changes in response criterion as a function of semantic similarity encountered during the comparison process (Schaeffer & Wallace, 1970). The semantic-comparison model holds that semantic similarity between words may be encountered before the stimuli have been evaluated along all critical dimensions. This semantic similarity produces a bias toward the positive response (for example, "yes," "same," "true"). Thus, positive responses are initiated more rapidly when semantic similarity is present. In contrast, negative responses (for example, "no," "different," "false") are slowed by semantic similarity. Further support for the semantic-comparison model, as well as other models attributing the association effect to response bias, comes from experiments demonstrating an inhibitory effect of association on negative responses (Collins & Quillian, in press; Schaeffer & Wallace, 1970); for example, semantic similarity slows the judgment that two words belong to different superordinate categories. Thus, it is possible that semantic comparisons produced the association effect we observed in the lexical-decision task. This possibility must be considered, even though one might argue for various reasons that the semantic-comparison model does not apply to lexical decisions (see Meyer & Schvaneveldt, 1971).

The present study has three purposes. First, it provides a test between the spreading-excitation and location-shifting models. Second, it provides evidence about the applicability of the semantic-comparison model to lexical-decision tasks. Third, it provides additional data about the serial nature of retrieval operations in lexical decisions. The experiment uses a procedure where three horizontal strings of letters are presented simultaneously in an array from top to bottom. Stimuli consist of either three words, or a combination of words and nonwords. The subjects respond "yes" if all three strings of letters are words, and "no" otherwise. Reaction time is measured as a function of two factors: (*a*) degree of association between words in the stimulus; and (*b*) position of the words and nonwords in the stimulus display. An important feature of the procedure is that degree of association varies orthogonally with the required response.

Each of the models makes firm predictions about RT of positive responses. We should emphasize that the predictions assume that the strings of letters are processed serially from top to bottom. This assumption can be tested directly from variations of RT with the position of nonwords in the display. When a single nonword is present in the stimulus display, the RT of negative responses should increase linearly as the position of the nonword changes from top to bottom.

If the strings of letters are processed serially beginning with the top item in the array, then the location-shifting model implies that degree of association should affect RT, and that this effect will depend upon the position of the associated words in the display. For example, suppose that the stimulus includes two associated words like BREAD and BUTTER, together with an unassociated word like STAR. Then the unassociated word can appear in one of three stimulus positions: top, middle, or bottom. When the unassociated word is in the top or bottom position, the associated words will be processed in immediate succession. In this case, the location-shifting model predicts that the associated words will facilitate retrieval, thereby making RT faster. However, when the unassociated word is in the middle position, there should be no association effect. The reason for this is quite simple. Between accessing information from the memory locations of the two associated words, retrieval must be shifted elsewhere in memory to the location of the unassociated word. Thus, the shorter distance separating the associated words in memory becomes irrelevant to retrieval time.

On the other hand, the spreading-excitation model ordinarily would predict that the associated words should facilitate retrieval, regardless of the position of an unassociated word. Because excitation may decay, facilitation could be less when the unassociated word is in the middle position. However, unless the decay is very rapid, the effect should not disappear completely. Similarly, the semantic-comparison model would predict that facilitation should occur for positive responses whenever associated words are present in the stimulus.

Each of the models also makes predictions about negative responses. For example, suppose that the stimulus includes two associated words and a nonword, and that the nonword is in the bottom stimulus position. Then the spreading-excitation and location-shifting models predict that association should facilitate retrieval and shorten RT. If the nonword is in the middle or top position, both models predict that there should be no association effect. This happens because the assumed serial retrieval-process would terminate before information is accessed about the associate in the bottom stimulus position. In contrast, the semantic-comparison model predicts that association slows negative responses (Collins & Quillian, in press; Schaeffer & Wallace, 1970). Association effects on negative responses therefore provide a test of the retrieval versus comparison models in this experiment.

As a convenient shorthand for referring to the different stimulus types, we shall adopt the following notation. Let *A* represent a word that is associated with at least one other word in the stimulus, let *U* represent a word that is unassociated with all other words in the stimulus, and let *N* represent a nonword. Then three letters such as *AUA* will refer to a stimulus like BREAD–STAR–BUTTER, where the words are arrayed from top to bottom and the top word is associated with the bottom word.

To summarize, Table 1 outlines the predictions of the various models. The predictions are for positive and negative stimuli involving associated words, as compared with corresponding stimuli in which none of the words are associated. For example, the semantic-comparison model predicts that RT of "no" responses should be slower for stimuli of type *AAN* than for those of type *UUN*.[1]

II. Method

The subjects were ten technical assistants at Bell Laboratories and ten high school students. Each subject was tested individually in a single session lasting approximately 1 hr. The subject was seated in a darkened room throughout the experiment, which was controlled by a General Automation 18/30 computer.

A session was divided into ten blocks of 21 trials each. During the first two blocks, the subject practiced the task. The remaining eight blocks consisted of test trials. A small fixation point was presented on the screen of a cathode ray tube at the start of each trial. The fixation point served as a

[1]The model's predictions for stimuli of types *ANA* and *NAA* depend on temporal properties of the semantic-comparison process. With various assumptions about these properties, one would predict that association either inhibits or does not affect negative responses to stimuli *ANA* and *NAA*.

Table 1. *Predicted Effects of Association on Reaction Time: Retrieval versus Comparison Models*

Stimulus[a]	Example	Correct response	Predicted reaction time: Location shifting	Spreading excitation	Semantic comparison
AAU	BREAD BUTTER STAR	"Yes"	Faster	Faster	Faster
AUA	BREAD STAR BUTTER	"Yes"	No effect	Faster	Faster
UAA	STAR BREAD BUTTER	"Yes"	Faster	Faster	Faster
AAN	BREAD BUTTER SATH	"No"	Faster	Faster	Slower
ANA	BREAD SATH BUTTER	"No"	No effect	No effect	Slower or no effect
NAA	SATH BREAD BUTTER	"No"	No effect	No effect	Slower or no effect

[a] *A* = associated word; *U* = unassociated word; *N* = nonword.

warning signal and remained visible throughout a 1 sec foreperiod. At the end of the foreperiod, the fixation point was removed and a stimulus was presented that subtended approximate visual angles of 2.2° horizontally and 2.0° vertically. The stimulus consisted of three horizontal strings of letters displayed visually in an array from top to bottom, with the top word centered at the same position as the fixation point. The subject pressed a key labeled "yes" with his right index finger if the three strings were all words, otherwise pressing a "no" key with the left index finger. The subjects were instructed to examine the stimulus from top to bottom, and to respond as quickly and accurately as possible. The RT was measured in milliseconds from the onset of the stimulus to the response. The response terminated the display, and the screen remained blank for 2 sec before the next trial. If the subject made an error, this interval was extended to 4 sec, during which a display appeared to indicate the occurrence of an incorrect response. After the trial block, the subject was informed of his mean RT, total number of correct responses, and total number of errors for the block.

Each subject was paid an initial sum of $1.25 for participating in the experiment. In addition, subjects were paid a bonus for responding quickly and accurately. This bonus was computed from a system whereby 1 point was awarded for each correct answer, *n* points were deducted for the *n*th error that occurred on each trial block, and 1 point was deducted for each .1 sec in mean RT on a block. The subject was paid 1.5¢ for each point in the net total he scored under the system, and the average bonus was approximately $1.25.

Separate sets of stimuli, which consisted of various combinations of words and nonwords, were presented during the practice and test blocks. Words in the test stimuli were chosen from standard association norms and included the stimulus and response members from 80 pairs of frequently associated words (Bousfield, Cohen, Whitmarsh, & Kincaid, 1961; Palermo & Jenkins, 1964). Nonwords in the test stimuli were constructed from the 160 words of the paired associates. This procedure involved two steps. First, the initial letter of each word was altered by replacing vowels with other vowels and consonants with other consonants. Second, for those strings that involved two or more syllables, the modified initial syllable of each string was interchanged randomly with the initial syllable from one of the other multisyllable strings. The resulting nonwords were matched with the words in length and general orthography.

This collection of words and nonwords then was used to form 13 different types of test stimuli. The test stimuli varied in three respects: (*a*) level of association between the words in the stimulus, (*b*) the number of nonwords contained in the stimulus, and (*c*) the display positions of the words and nonwords in the stimulus. Two levels of association were possible between any two words in a stimulus. Either the two words were *associated* in that they occurred together in the association norms, or the words were *unassociated.* The unassociated words did not occur together in the norms, and were obtained by randomly permuting the words belonging to the paired associates.

The left half of Table 2 uses the notation of Section I to summarize the 13 stimulus types, together with their frequencies of occurrence in the experiment. To represent the various types, a different set of 144 test stimuli was assigned to each subject. The peculiar characteristics of individual words were controlled by balancing the presence of each word in all possible stimulus types and in all possible display positions. A similar balancing procedure was used for the nonwords. During the test blocks, each subject was also presented an additional eight stimuli of type *AAA*, eight stimuli of type *UUU*, and eight stimuli of type *NUU*. These "filler stimuli" were constructed from a separate set of words (Bilodeau & Howell, 1965) and non-

Table 2. *Stimuli and Data from the Three-String Experiment*

Stimulus type[a]	Correct response	Relative frequency	Mean RT (msec)	Mean errors (%)
AAU		.095	1093	3.4
AUA	"Yes"	.095	1090	4.4
UAA		.095	1073	3.1
UUU		.048	1175	3.8
AAN		.048	1151	13.1
ANA	"No"	.048	1029	6.3
NAA		.048	827	5.0
UUN		.095	1222	12.5
UNU	"No"	.095	1010	4.4
NUU		.048	864	3.1
UNN		.048	992	1.3
NUN	"No"	.048	814	2.5
NNU		.048	769	1.3

[a] *A* = associated word; *U* = unassociated word; *N* = nonword.

words, and served to balance a number of conditional stimulus probabilities. For example, the level of association between any two words in a stimulus was eliminated as a cue about the correct response. The various types of stimuli were presented on each test block in proportion to their frequency over the entire stimulus set. Stimuli of type *NNN* were not included in the experiment. Approximately 43% of the stimuli required a "yes" response. Given these constraints, the order of stimulus presentation was randomized for each subject.

III. Results and Discussion

The right half of Table 2 summarizes mean RTs of correct responses and mean error rates for the various types of test stimuli. The data from the filler stimuli are excluded because they involved a different set of words and nonwords than used in the test stimuli.

A. Evidence of Serial Processing

Let us first consider the mean RTs for stimuli that included two unassociated words and a single nonword (*UUN*, *UNU*, and *NUU*). These data reveal that the position of the nonword in the display had a significant effect;

$F(2, 38) = 69.7, p < .001$. When the nonword was the top item in the displa negative responses were relatively fast, and there was an approximate line increase in RT as the position of the nonword varied from top to botto This linear increase accounts for approximately 99% of the variation in me RT with position of the nonword, and the residual variation was not signi icant. The slope of a least-squares line fit to the data was 179 msec per ur change in position of the nonword. This estimate is quite similar to the valu of 183 msec per unit change that we obtained earlier for stimuli involvi two strings of letters (Meyer & Schvaneveldt, 1971).

The data for stimuli involving two unassociated words and a nonwo suggest that processing included a substantial serial component. In particul the data appear as if the subject processed the stimulus items sequential from top to bottom, stopping as soon as a nonword was discovered. W therefore shall assume that the processing order was consistent enough f testing the retrieval models discussed in Section I.

B. Effects of Association on Positive Responses

The mean RTs for positive responses revealed a significant effect association; $F(1, 19) = 27.1, p < .01$. Reaction time averaged 90 ± 17 ms faster for stimuli that included two associated words and one unassociate word (*AAU*, *AUA*, and *UAA*) than for stimuli with three unassociated wor (*UUU*).[2] The magnitude of the association effect did not depend significant on the position of the unassociated word in the stimulus. In particular, th effect was not attenuated significantly when an unassociated word wa displayed in the middle position, separating associated words in the top an bottom display positions. These results are summarized in Fig. 2.

As we argued previously, each of the models predicts that associatio should speed positive responses. The spreading-excitation and semanti comparison models imply that some effect should occur regardless of th position of the words in the display. Our data are therefore consistent wit these models. However, the location-shifting model predicts that the associa tion effect should be eliminated when an unassociated word is displayed be tween two associated words. Since the effect was not even attentuate significantly in this case, we have substantial evidence against locatio shifting.

[2]Here and elsewhere we are reporting RT differences plus or minus one standard erro Error terms were derived from treatments-by-subjects interactions computed in an analys of variance.

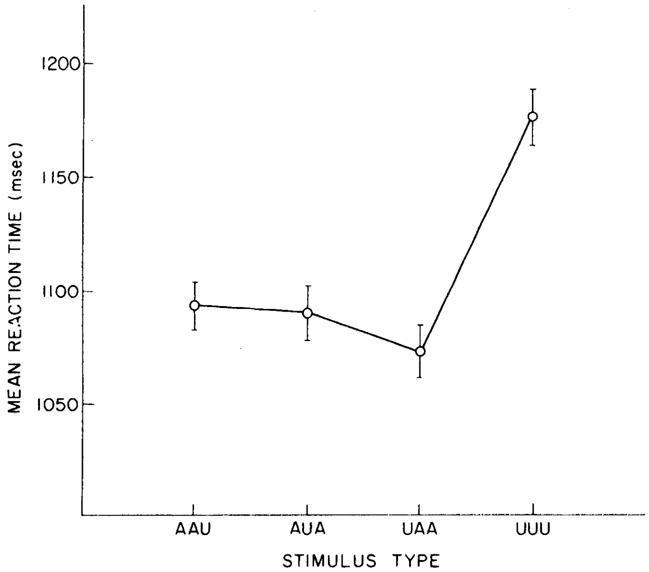

Fig. 2. Mean RT (± 1 standard error) for positive responses to stimuli involving associated and unassociated words.

C. Effects of Association on Negative Responses

In contrast to positive responses, the negative responses revealed association effects that depended upon the position of items in the display. When two words were displayed above a nonword, RT was 71 $\pm$ 23 msec faster if the two words were associated (*AAN* versus *UUN*); $F(1, 19) = 9.86$, $p < .01$. Thus, the effect was comparable to the association effect for positive responses (*AAN-UUN* versus *AAU-UUU*); $F(1, 19) < 1.0$. However, when the nonword appeared in the middle display position, the association effect was -19 ± 20 msec (*ANA* versus *UNU*), which was not significant; $F(1, 19) < 1.0$. Finally, when the nonword was in the top position, the effect was 37 $\pm$ 25 msec (*NAA* versus *NUU*), which also was not significant; $F(1, 19) = 2.05$, $p > .10$. Thus, the association effect with a nonword in the bottom position was significantly larger than the average effect with a nonword in the middle or top position; $F(1, 19) = 4.6$, $p < .05$. Furthermore, the association effect with a middle nonword was not significantly different from the effect with a top nonword (*ANA–UNU* versus *NAA–NUU*); $F(1, 19) = 2.6$, $p > .10$. A summary of these results is shown in Fig. 3.

The effects of association on negative responses give evidence against the semantic-comparison model. As discussed earlier, this model predicts

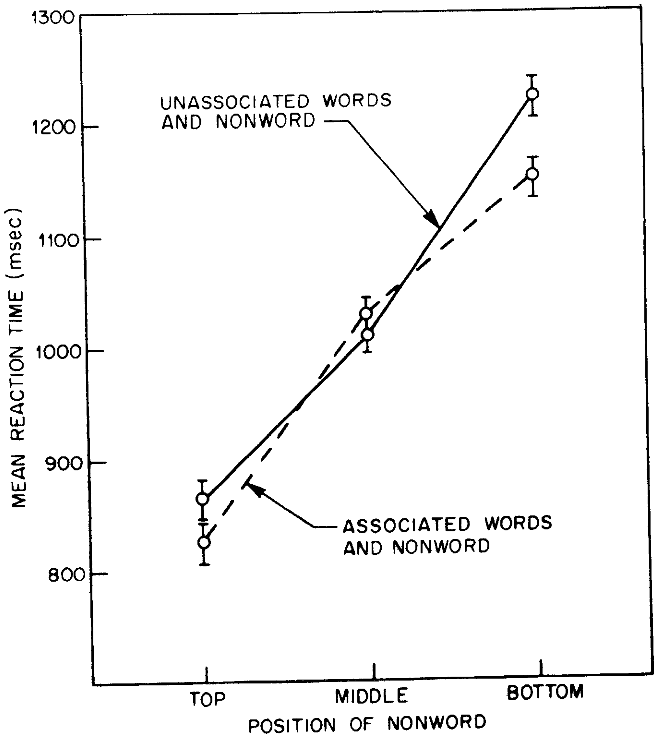

Fig. 3. Mean RT (±1 standard error) for negative responses to stimuli involving one nonword.

that association should inhibit negative responses (Schaeffer & Wallace, 1970), whereas our data show a net facilitation for the negatives. In addition, the results rule out several response-bias explanations of the association effect (see Trabasso, Rollins, & Shaughnessy, 1971). The effect is consistent with predictions of both the location-shifting and spreading-excitation models, assuming that the stimulus items were processed serially. The serial-processing assumption is further supported by the fact that a significant association effect occurred only when the nonword was in the bottom display position.

D. Reaction Time for Stimuli Including Two Nonwords

Although we have argued for serial processing, some of the data leave open questions about the exact nature of processing. There is little doubt that a substantial serial component was present in the processing of the three strings of letters. However, inconsistencies appear in the RTs to stimuli with two nonwords. When two nonwords were presented in the top and middle display positions, the mean RT was 95 ± 35 msec faster than when a single nonword appeared in the top position (*NNU* versus *NUU*); $F(1, 19) = 7.5$, $p < .025$. If processing was strictly serial from top to bottom, then there should have been no difference between these two stimulus types. The occurrence of a difference suggests that a nonword in the middle position was processed at least occasionally when a nonword was also present in the top position, contrary to the serial processing assumption.

A comparison between stimulus types *NUN* and *NUU* yields a smaller difference of 50 ± 33 msec; $F(1, 19) = 2.3$. While this difference is not significant, it might be interpreted as further evidence that stimulus processing was not strictly serial from top to bottom. The data suggest that if there was a nonword in the top position, then a nonword in the bottom position was processed less often than a nonword in the middle position. It is interesting that an even smaller difference (18 ± 14 msec) occurred for stimuli of type *UNN* versus *UNU*.

E. Errors

Error rates in the experiment averaged approximately 5% over the various stimulus types, and tended to correlate positively with RT. Error rates were significantly higher ($p < .01$) for stimuli of types *UUN* and *AAN*. This suggests that processing of the stimuli occasionally terminated before the bottom display position had been examined. Such a strategy is not surprising, since "yes" was the correct response for approximately 75% of the stimuli with words in the top and middle positions (see Meyer & Schvaneveldt, 1971). In general, the other stimulus types did not differ significantly in error rates.

IV. Conclusions

Taken as a whole, the data for negative responses support a belief that stimulus processing was not strictly serial from top to bottom. This suggests at least two possible conclusions. First, processing may have been strictly serial, but may have varied in the stimulus position at which it started. For example, the subject sometimes could have begun processing with the middle string and only later processed the top string. Second, processing may have occurred from top to bottom, but with some overlap in the execution of operations for each string of letters.

Despite these conclusions, there is little doubt that stimulus processing was substantially serial from top to bottom, as indicated by the data for stimuli that included two unassociated words and a single nonword. The uniform effects of association on positive responses therefore suggest a rejection of the location-shifting model. At the same time, the effects of association on negative responses rule out the semantic-comparison model as discussed here. Thus, of the theories proposed in Section I, only the spreading-excitation model is completely consistent with our findings. Because association affected positive responses without regard to the position of the associated words, it appears that excitation may not decay significantly over a period of 200–400 msec. This inference follows from three considerations: (*a*) the estimated time to process a word is approximately 200 msec; (*b*) substantial facilitation occurred for stimuli where an unassociated word was displayed between two associated words; (*c*) for stimuli of this type, the middle unassociated word was usually processed before the bottom associate.

Assuming our conclusions are correct, one might speculate about the way in which spreading excitation facilitates retrieval. For example, suppose that serial retrieval-operations occurred in processing the stimulus from top to bottom, but that these operations overlapped temporally to some extent. Then one could argue that excitation affected the starting times of these operations, as well as perhaps influencing their durations. In particular, excitation may have permitted the operations to begin sooner and also may have lessened the times they took. It is conceivable that initiation of the operations is "linked" to some extent, so that the starting time of one operation determines how soon thereafter another operation begins.

Our results, of course, do not permit dismissing contributions of comparison processes or response bias in other semantic memory tasks. A comprehensive model of semantic memory may have to incorporate more than one type of processing operation to explain the entire spectrum of association effects. However, the present findings suggest that retrieval processes must play a central role in such a theory.

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