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FACILITATION IN RECOGNIZING PAIRS OF WORDS: EVIDENCE OF A DEPENDENCE BETWEEN RETRIEVAL OPERATIONS[1]

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Two experiments are reported in which *S*s were presented two strings of letters simultaneously, with one string displayed visually above the other. In Exp. I, *S*s responded "yes" if both strings were words, otherwise responding "no." In Exp. II, *S*s responded "same" if the two strings were either both words or both nonwords, otherwise responding "different." "Yes" responses and "same" responses were faster for pairs of commonly associated words than for pairs of unassociated words. "Same" responses were slowest for pairs of nonwords. "No" responses were faster when the top string in the display was a nonword, whereas "different" responses were faster when the top string was a word. The results of both experiments support a retrieval model involving a dependence between separate successive decisions about whether each of the two strings is a word. Possible mechanisms that underlie this dependence are discussed.

Several investigators recently have studied how *S*s decide that a string of letters is a word (Landauer & Freedman, 1968; Meyer & Ellis, 1970; Rubenstein, Garfield, & Millikan, 1970). They typically have presented a single string on a trial, measuring reaction time (RT) of the *lexical decision* as a function of the string's meaning, familiarity, etc. In one such experiment, RT varied inversely with word frequency (Rubenstein et al., 1970). When word frequency was controlled, lexical decisions were faster for homographs (i.e., words having two or more meanings) than for nonhomographs. To explain these results, Rubenstein et al. proposed that word frequency affects the order of examining stored words in long-term memory and that more replicas of homographs than of nonhomographs are stored in long-term memory.

In another experiment, Meyer and Ellis (1970) measured both the time taken to decide that a string of letters (e.g., HOUSE) is a word and the time taken to decide that it belongs to a prespecified semantic category. When the category was relatively small (e.g., BUILDINGS), the latter type of *semantic decision* was significantly faster than the former lexical decision. However, when the category was relatively large (e.g., STRUCTURES), the semantic decision was slightly slower than the lexical decision. To explain these and other results, Meyer and Ellis suggested that the semantic decision may have involved searching through stored words in the semantic category and that the lexical decision did *not* entail a search of this kind among the set of all words in memory.

The present paper provides further data about the effect of meaning on lexical decisions. To deal with this problem, we have extended the lexical-decision task by simultaneously presenting two strings of letters for *S* to judge. The stimulus may involve either a pair of words, a pair of nonwords, or a word and a nonword. In one task, *S* is instructed to respond "yes" if both strings are words, and otherwise to respond "no." In a second task, the instructions require *S* to respond "same" if the two strings are either both words or both nonwords, and otherwise to respond "different." In each task, RT for pairs of

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words is measured as a function of the associative relation between the two words.

The two tasks together are designed to give information about the nature and the invariance of underlying retrieval operations. One of their advantages is that the relation between words can be varied while keeping the overt response constant. We reasoned that the response might involve separate, successive decisions about each of the two words. By varying the degree of association between the words, we then hoped it would be possible to test for a dependence between memory-accessing components of the two decisions. Experiment I reports the results of such variation in the context of the yes–no task.

EXPERIMENT I

Method

Subjects.—The *S*s were 12 high school students who served as paid volunteers.

Stimuli.—The following test stimuli were used: 48 pairs of associated words, e.g., BREAD-BUTTER and NURSE-DOCTOR, selected from the Connecticut Free Associational Norms (Bousfield, Cohen, & Whitmarsh, 1961); 48 pairs of unassociated words, e.g., BREAD-DOCTOR and NURSE-BUTTER, formed by randomly interchanging the response terms between the 48 pairs of associated words so that there were no obvious associations within the resulting pairs; 48 pairs of nonwords; and 96 pairs involving a word and a nonword. Within each pair of associated words, the second member was either the first or second most frequent free associate given in response to the first member. Within each pair of unassociated words, the second member was never the first or second most frequent free associate of the first member. The median length of strings in the pairs of associated words and pairs of unassociated words was 5 letters and ranged from 3 to 7 letters; the median word frequency was 59 per million, and ranged from 1,747 to less than 1 per million (Kucera & Francis, 1967). A separate set of 96 words was used for the pairs involving a word and a nonword. These words were similar to the associated words in terms of frequency, length, and semantic classification. Nonwords were constructed from common words, e.g., MARK, replacing at least one letter with another letter. Vowels were used to replace vowels, and consonants were used to replace consonants. The resulting strings of letters, e.g., MARB, were pronounceable and were equal in average length to the words paired with them. A majority of the nonwords differed by only a single letter from some English word, and the differences were not systematically associated with any one letter position.

In addition to the test stimuli, 24 pairs of words, 8 pairs of nonwords, and 16 pairs involving a word and a nonword were constructed as practice stimuli. Degree of association was not varied systematically among the pairs of practice words.

Apparatus.—The stimuli were generated on a Stromberg Carlson SC4060 graphics system, photographed on 16-mm. movie film and presented on a rear-projection screen by a Perceptual Development Laboratories' Mark III Perceptoscope. The *S*s responded via a panel having finger keys for the right and left hands. Reaction time was measured to the nearest millisecond by counting the cycles of a 1,000-Hz. oscillator.

Procedure and design.—The *S*s were run individually during one session involving a series of discrete RT trials. The *S* was seated in front of the darkened screen throughout the session. At the beginning of each trial, the word READY was presented briefly as a warning signal on the screen. A small fixation box, which subtended approximate visual angles of 3°40′ horizontally and 1°50′ vertically, then appeared during a 1-sec. foreperiod. Following the foreperiod, the stimulus was displayed horizontally in (white) capital letters in the middle of the box, with one string of letters centered above the other. If both strings were words, *S* pressed a key labeled "yes" with his right index finger, otherwise pressing a "no" key with the left index finger. Reaction time was measured from stimulus-onset to the response, which terminated the stimulus display. During an approximate 2-sec. interval when the screen was blank after each trial, *S* was informed of whether his response had been correct.

The session lasted about 45 min. and included a short instruction period and two blocks of 24 practice trials, followed by four blocks of 24 test trials. After each block, *S* was informed of his mean RT and total number of errors for the block, while he rested for about 2 min. This feedback was intended to encourage fast and accurate responses. To further motivate good performance, *S* was given $3 at the start of the session and then penalized 1¢ for each .1 sec. in mean RT on each trial block, and 3¢ for each error. Whatever money remained at the end of the session served as *S*'s payment for the experiment.

The entire set of practice stimuli was presented during the two practice trial blocks. During the test trial blocks, each *S* was shown 16 pairs of nonwords, 32 pairs involving a word and a nonword, 24 pairs of associated words, and 24 pairs of unassociated words from the total set of test stimuli. Half of the practice trials and test trials therefore required "yes" responses. Presentation of the test stimuli was balanced, so that each individual stimulus of a given type was presented equally often across *S*s; e.g., each pair of associated words was presented a total of six times across *S*s, while each pair of nonwords was presented a total of four times. No *S* saw any string of letters more than once. In displaying both the pairs of associated words and the pairs of unassociated words, the top string (e.g., BREAD) was always a stimulus term from the norms of Bousfield et al. (1961), while the bottom string (e.g. BUTTER) was always a response term. For the stimuli containing at least one nonword, each string was assigned equally often across *S*s to the top and bottom display positions. There were thus five types of stimuli, which are listed in Table 1 together with their relative frequencies of occurrence. Relative frequencies of these types were balanced within trial blocks to equal their relative frequencies in the total set of test stimuli. The above set of constraints on stimulus presentation was used to construct six lists of 96 test stimuli each. Subject to these constraints, two random orders of stimulus presentation were obtained for each list. Each *S* was then randomly assigned one of the lists presented in one of the orders, so that each list in each order was used for exactly one *S*.

TABLE 1

MEAN REACTION TIMES (RTs) OF CORRECT RESPONSES AND MEAN PERCENT ERRORS IN THE YES–NO TASK

Type of stimulus pair		Correct response	Proportion of trials	Mean RT (msec.)	Mean % errors
Top string	Bottom string				
word	associated word	yes	.25	855	6.3
word	unassociated word	yes	.25	940	8.7
word	nonword	no	.167	1,087	27.6
nonword	word	no	.167	904	7.8
nonword	nonword	no	.167	884	2.6

Results and Discussion

Reaction time and error data from the test trials were subjected to *S*s × Treatments analyses of variance (Winer, 1962). Prior to analysis, an arc-sine transformation was applied to each *S*'s error rates. The reported standard errors and *F* ratios were computed using error terms derived from the *S*s × Treatments interactions.

Table 1 summarizes mean RTs of correct responses and mean percent errors averaged over *S*s. "Yes" responses averaged 85 ± 19 msec. faster for pairs of associated words than for pairs of unassociated words, $F(1, 11) = 20.6$, $p < .001$. "No" responses to pairs involving a word and a nonword averaged 183 ± 14 msec. faster when the nonword was displayed above the word, $F(1, 11) = 171.7$, $p < .001$. "No" responses for pairs of nonwords were not significantly faster (20 ± 14 msec.) than "no" responses for pairs where a nonword was displayed above a word, $F(1, 11) = 2.0$, $p > .10$.

The error rates for pairs of unassociated words versus pairs of associated words did not differ significantly, $F(1, 11) = 2.1$, $p > .10$. The error rate for pairs involving a word and a nonword was significantly greater when the word was displayed above the nonword, $F(1, 11) = 18.9$, $p < .005$. The error rate for pairs of nonwords was significantly less than that for pairs where a nonword was displayed above a word, $F(1, 11) = 5.5$, $p < .05$.

Error rates were relatively low except for pairs where a word was displayed above a nonword. A possible reason for this exception is considered in later discussion. The pattern of errors suggests that a speed-accuracy trade-off did not cause the observed differences in mean RTs; i.e., mean error rates tended to correlate positively with mean RTs.

The results of Exp. I suggest that degree of association is a powerful factor affecting lexical decisions in the yes–no task. For example, the effect of association appears to be on the order of two or three times larger than the average effect of homography reported by Rubenstein et al. (1970). This effect of association occurred consistently across *S*s, and 11 of the 12 *S*s showed it in excess of 30 msec. In Exp. II, another group of *S*s performed the same–different task to further study the generality of the effect.

EXPERIMENT II

Method

Subjects.—The *S*s were 12 high school students who served as paid volunteers. They had not been in Exp. I, but were drawn from the same population.

TABLE 2

Mean Reaction Times (RTs) of Correct Responses and Mean Percent Errors in the Same–Different Task

Type of stimulus pair		Correct response	Proportion of trials	Mean RT (msec.)	Mean % errors
Top string	Bottom string				
word	associated word	same	.125	1,055	2.4
word	unassociated word	same	.125	1,172	8.7
nonword	nonword	same	.25	1,357	8.9
word	nonword	different	.25	1,318	11.6
nonword	word	different	.25	1,386	12.0

Stimuli.—The same set of test stimuli was used as in Exp. I. In addition, 16 pairs of words, 16 pairs of nonwords, and 32 pairs involving a word and a nonword were constructed as practice stimuli. Most of these practice stimuli also had been used in Exp. I.

Apparatus.—The same apparatus was used as in Exp. I.

Procedure and design.—The procedure and design were similar to those used in Exp. I, except for the following modifications. The *S* pressed a "same" key with his right index finger if the stimulus involved either two words or two nonwords, otherwise pressing a "different" key with the left index finger. The complete session lasted about 1 hr. and included a short instruction period, two blocks of 32 practice trials, and six blocks of 32 test trials. Two lists of 192 test stimuli each were constructed. For each list, two random orders of presentation were obtained, subject to constraints like those used in Exp. I. Each of these List × Order combinations was then used for three of the *S*s. During the test trial blocks, each *S* was presented 48 pairs of nonwords, 96 pairs involving a word and a nonword, 24 pairs of associated words, and 24 pairs of unassociated words from the total set of test stimuli. Half of the trials therefore required "same" responses. Because the same–different task was somewhat more difficult than the yes–no task, each *S* was given $3.50 at the start of the session.

Results

The results were analyzed in the same way as Exp. I. Table 2 summarizes mean RTs of correct responses and mean percent errors averaged over *S*s. "Same" responses averaged 117 ± 18 msec. faster for pairs of associated words than for pairs of unassociated words, $F\ (1,\ 11) = 42.6$, $p < .001$. "Same" responses averaged 185 ± 29 msec. slower for pairs of nonwords than for pairs of unassociated words, $F\ (1,\ 11) = 40.7$, $p < .001$. "Different" responses averaged 68 ± 25 msec. faster when the word was displayed above the nonword, $F\ (1,\ 11) = 7.3$, $p < .025$.

The error rate for pairs of associated words was significantly less than the error rate for unassociated words, $F\ (1,\ 11) = 16.6$, $p < .01$. The difference between error rates for pairs of unassociated words and pairs of nonwords was not significant, $F\ (1,\ 11) < 1.0$. For pairs involving a word and a nonword, the error rate did not depend significantly on whether the word was displayed above or below the nonword, $F\ (1, 11) < 1.0$.

A comparison of mean RTs in the yes–no task (Exp. I) versus mean RTs in the same–different task revealed the following: "Yes" responses to pairs of words averaged 216 ± 68 msec. faster than "same" responses to pairs of words, $F\ (1,\ 22) = 10.2$, $p < .01$. The effect of association on "same" responses to pairs of words did not differ significantly from its effect on "yes" responses, $F\ (1,\ 22) = 1.4$, $p > .20$. "No" responses to pairs involving a word and a nonword averaged 357 ± 74 msec. faster than "different" responses, $F\ (1,\ 22) = 23.6$, $p < .001$. For pairs involving a word and a nonword, the effect of the word's display position on RT interacted significantly with the task, $F\ (1,\ 22) = 76.4$, $p < .001$.

Discussion

As a framework for explaining our results, we tentatively propose a model involving two separate, successive decisions. According to this model, stimulus processing typically begins with the top string of letters in the display. The first decision is whether the top string is a word and the second is whether the

bottom string is a word. If the first decision is negative in the yes–no task, we presume that processing terminates without the second decision and *S* responds "no." Otherwise, both decisions are made and *S*'s response corresponds to the second decision's outcome. It is assumed that in the same–different task, both decisions are normally made regardless of the outcome of the first. After both decisions, their outcomes are compared. If the outcomes match, *S* responds "same"; otherwise, he responds "different."

Now let us consider the RTs and error rates of yes–no responses. The *serial-decision model* explains why "no" responses are faster when the top string is a nonword. This happens because only the first decision is made, whereas both decisions are made when the top string is a word. The model also explains why "no" responses are about equally fast for pairs where only the top string is a nonword, as compared to pairs where both strings are nonwords; i.e., for either kind of pair, only the first decision is ordinarily made. An occasional reversal in the order of stimulus processing, beginning with the bottom rather than top string, might account for the slightly faster responses to pairs of nonwords.

The relatively high error rate for pairs involving a word above a nonword suggests that processes preceding "yes" responses sometimes terminate prematurely after the first decision. In these cases, *S* may feel that discovering a word in the top position is sufficient evidence for responding "yes," without making the second decision. This behavior would not be too unreasonable, given the relative frequencies of the various types of stimuli. Such premature termination of stimulus processing, together with an occasional reversal in the processing order, would also explain why "no" responses were most accurate for pairs of nonwords.

The RTs from the same–different task do not provide direct evidence for testing the proposed serial-decision model because both lexical decisions are assumed to be made before all same–different responses. However, the relative invariance of the association effect across the yes–no and same–different tasks suggests that similar processes occur in both tasks. An additional operation, which compares the outcomes of the two lexical decisions for a match, would explain why responses were somewhat slower in the same–different task than in the yes–no task.

Several factors in the present experiments may have induced *S*s to process the strings of letters serially. For example, *S*s were encouraged to perform with high accuracy and were allowed to move their eyes in examining the stimulus display. Under other circumstances, e.g., with brief stimulus presentation and/or a more relaxed error criterion, *S*s might process two or more words in parallel.

If the serial-decision model is valid for the present experiments, then one can use the yes–no data to estimate the time taken in deciding that a string of letters is a word. In particular, let T_{nw} represent the mean RT to respond "no" to a nonword displayed above a word. Let T_{wn} represent the mean RT to respond "no" to a nonword displayed below a word. Then with certain assumptions (cf. Sternberg, 1969), the difference $T_{wn} - T_{nw}$ is a measure of the mean time to decide that the top string is a word. From the results of Exp. I, an estimate of this difference is 183 ± 14 msec. An occasional reversal in the order of stimulus processing would make this difference an underestimate of the true mean.

One can also estimate approximately how much time is required to compare the outcomes of the two decisions before same–different responses. For example, suppose the mean RT of "yes" responses (Exp. I) is subtracted from the mean RT of "same" responses to pairs of words (Exp. II). Then with certain assumptions, the difference of 216 ± 68 msec. is an estimate of the comparison time when the two decisions match. On the other hand, suppose the mean RT of "no" responses to a word displayed above a nonword is subtracted from the corresponding mean RT for "different" responses. Then the difference of 231 ± 76 msec. is an estimate of the comparison time when the two decisions do not match.

What kind of operation occurs during each of the two proposed decisions? One possibility is that visual and/or accoustic features of a string of letters are used to compute an "address" in memory (Norman, 1969; Schiffrin & Atkinson, 1969). A lexical decision about a string might then involve accessing and checking some part of the contents of the string's computed memory location (cf. Rubenstein et al., 1970). Given this model, memory locations would be computed for both words and nonwords, although the contents of nonword locations might differ qualitatively from those of word locations. In essence, we are therefore suggesting that both words and nonwords may have locations "reserved" for them in long-term memory.

The effect of association on RT does not necessarily imply that the meaning of a word is retrieved to make a lexical decision. To understand why, consider the following elaboration of the serial-decision model, which may explain the effect. First, suppose that long-term memory is organized semantically, i.e., that there is a structure in which the locations of two associated words are closer than those of two unassociated words. Evidence from other studies of semantic memory suggests that this assumption is not totally unreasonable (Collins & Quillian, 1969; Meyer, 1970). Let L_1 and L_2 denote the memory locations examined in the first and second decisions, respectively. Second, suppose that the time taken to make the second decision depends on where L_2 is relative to L_1. In particular, let us assume that the time taken accessing information for the second decision varies directly with the "distance" between L_1 and L_2. Then responses to pairs of associated words would be faster than those to pairs of unassociated words. This follows because the proximity of associated words in the memory structure permits faster accessing of information for the second decision. The argument holds even if the accessed information is (*a*) sufficient *only* to determine whether a string is a word and (*b*) does not include aspects of its meaning.

If our second assumption above is correct, then any retrieval operation R_2 that is required sufficiently soon after another operation R_1 will generally depend on R_1. This would mean that human long-term memory, like many bulk-storage devices, lacks the property known in the computer literature as *random access* (cf. McCormick, 1959, p. 103). Recently, Meyer (1971) has collected data in other tasks that are consistent with this notion.

There are several ways in which this dependence between retrieval operations might be realized. One possibility is that retrieving information from a particular memory location produces a passive "spread of excitation" to other nearby locations, facilitating later retrieval from them (Collins & Quillian, 1970; Warren, 1970). A second speculative possibility is that retrieving information from long-term memory is like retrieving information from a magnetic tape or disk. In this latter model, facilitation of retrieval would occur because (*a*) information can be "read out" of only one location during any given instant, (*b*) time is required to "shift" readout from one location to another, and (*c*) shifting time increases with the distance between locations.

The present data do not provide a direct test between this *location-shifting model* and the *spreading-excitation model.* However, the location-shifting model may explain one result that is difficult to account for in terms of spreading excitation. In particular, consider the following argument about the finding that "different" responses were faster when a word was displayed above a nonword. We previously have argued that processing normally begins with a decision about the top string and then proceeds to a decision about the bottom one. Let us now assume that memory is organized by familiarity as well as by meaning, with frequently examined locations in one "sector" and infrequently examined locations in another sector. Recently, Swanson and Wickens (1970) have collected data supporting a similar assumption that Oldfield (1966) has made. Suppose further that before each trial, a location is preselected in the sector where familiar words are stored, which would be optimal under most circumstances (cf. Oldfield, 1966). Then the response to a word displayed above a nonword would require only one major shift between memory locations in the familiar and unfamiliar sectors. This shift would occur after the first decision, changing readout from the familiar to the unfamiliar sector.[3] In contrast, the response to a nonword displayed above a word would require two major shifts, i.e., one from the familiar to the unfamiliar sector before the first decision and one returning to the familiar sector before the second decision. This would make "different" responses slower when the nonword is displayed above the word. Moreover, the assumption that the starting location is in the familiar sector fits with the finding that lexical decisions are generally faster for familiar than for unfamiliar words (Rubenstein et al., 1970); i.e., a major shift between locations is required to access potential information about an unfamiliar word, whereas such a shift would not be required for a familiar one.

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[3] Here we are invoking our earlier proposal that both words and nonwords may have locations reserved for them in memory. We are assuming that from the viewpoint of retrieval, a nonword that is similar to English may be treated as a very unfamiliar word whose location is examined infrequently.

The effect of association on "same" responses to pairs of words (Exp. II) is also relevant to a recent finding by Schaeffer and Wallace (1969). In their study, *S*s were presented with a pair of words and required to respond "same" if both words belonged to the semantic category LIVING THINGS or if both belonged to the category NONLIVING THINGS. Otherwise, *S*s responded "different." Reaction time of "same" responses varied inversely with the semantic similarity of the words in the pair; e.g., "same" responses to a stimulus like TULIP-PANSY were faster than "same" responses to a stimulus like TULIP-ZEBRA. In contrast, Schaeffer and Wallace (1970) found that the RT of "different" responses varied directly with semantic similarity. They attributed the effects of similarity on both "same" and "different" responses to a process that compares the meanings of the words in a stimulus.

The effects of association in Exp. I and II possibly could have been caused by such a comparison process, rather than by the retrieval mechanisms discussed above. However, if the "meaning" of a word is represented by the semantic categories to which it belongs, then there seemingly is a difference between the same–different task of Exp. II and the one studied by Schaeffer and Wallace (1969, 1970). Logically, Exp. II did not require *S*s to compare the meanings of the items in a stimulus; i.e., *S*s did not have to judge whether both strings belonged to the same semantic category, e.g., LIVING THINGS. Instead, Exp. II only required comparing the items' lexical status. Moreover, a comparison of meanings would have been impossible for those pairs involving at least one nonword, since the nonword would have no meaning in the usual sense. One might therefore argue that *S*s did not compare the meanings of items in Exp. II. The argument is reinforced by the fact that Exp. I (yes–no task), which logically did not require comparing the strings in any way, produced an effect of association like the one observed in Exp. II.

Our reasoning suggests, furthermore, that the findings of Schaeffer and Wallace (1969, 1970) may not have resulted solely from a comparison of word meanings. Rather, their findings could have been caused at least in part by a retrieval process like the one we have proposed. This point is supported by the magnitudes of the similarity effects they observed, which averaged 176 msec. for facilitating "same" responses (Schaeffer & Wallace, 1969) and 120 msec. for inhibiting "different" responses (Schaeffer & Wallace, 1970). In particular, consider the following detailed argument. Suppose that judgments in their task involved two components: an initial retrieval process similar to the one we have proposed, which might be necessary to access word meanings, and a process that compares word meanings (cf. Schaeffer & Wallace, 1970). Suppose further that our experiments required only the first process. One might then expect that whenever both of these processes are used in "same" judgments, they would both be facilitated by semantic similarity. However, when they are used in "different" judgments, similarity would inhibit the comparison process while still facilitating the retrieval process. This would explain why the effect of association on "same" responses in Exp. II (117 msec.) was less than the effect of similarity on "same" responses in the study by Schaeffer and Wallace (1969). Moreover, it would also explain their finding that semantic similarity inhibited "different" responses less than it facilitated "same" responses. Unfortunately, the argument is partially weakened by at least one fact; i.e., their results for "same" versus "different" responses were obtained in separate experiments using somewhat different semantic categories and test words.

Regardless of whether spreading excitation, location shifting, comparison of meanings, or some other process is involved, the effects of association appear limited neither to semantic decisions nor to same–different judgments. At present we do not have ways to test all the possible explanations of these effects. However, procedures like the ones we have described may provide a way to study relations between retrieval operations that are temporally contiguous. We may therefore be able to learn more about both the nature of individual memory processes and how they affect one another.

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