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Sequential dependencies in the lexical decision task

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Abstract Two experiments addressed whether response latency in a trial of the lexical decision task is independent of the lexical status of the item presented in the previous trial. In Exp. 1, it was found that both word and nonword responses were significantly slower when the previous trial had involved a nonword than when it had involved a word. In Exp. 2, which employed a different list composition, it was found that responses to nonwords and pseudohomophones were significantly slower when the previous trial had involved a nonword or a pseudohomophone than when it had involved a word. However, responses to words were not influenced by the nature of the previous trial. We concluded that sequential dependencies exist across consecutive trials in the lexical decision task even when there is no semantic, morphological, phonological, or orthographic relationship between the items presented during those trials.

Introduction

In the typical lexical decision experiment, one letter string is presented per trial, such as BASKET or DARMON, and the subject must decide as quickly and accurately as possible whether or not the letter string is a word. In the many years that have passed since it was introduced (Landauer & Freedman, 1968; Meyer & Schvaneveldt, 1971; Rubenstein, Garfield, & Millikan, 1970; Stanners, Forbach, & Headley, 1971), this task has assumed a remarkably prominent role in research on word recognition. Seidenberg (1990, p. 53) called lexical decision "probably the most widely used task in psycholinguistics." In light of the attention accorded to lexical decision findings, it is essential that researchers understand all factors that affect performance on the task. These factors are not restricted to characteristics of the experimental items themselves, but include such influences as the relatedness of consecutively presented items and the composition of the stimulus list as a whole.

Stimuli presented prior to trial *n* can have a specific, localized influence on the response time on trial *n*. Priming effects include semantic priming (e.g., Meyer & Schvaneveldt, 1971), rhyme priming (e.g., Meyer, Schvaneveldt, & Ruddy, 1974), short-term repetition priming (e.g., Forster & Davis, 1984), long-term repetition priming (e.g., Scarborough, Cortese, & Scarborough, 1977), and morphemic priming (e.g., Fowler, Napps, & Feldman, 1985). It is clear from the results of such experiments that sequential dependency effects exist between trials in the lexical decision task, both between consecutive trials (e.g., semantic priming and rhyme priming) and between nonconsecutive trials (e.g., long-term repetition priming and morphemic priming). The objective of the current experiments was to determine whether there is a specific, localized influence between consecutive trials in the lexical decision task when the trials are *not* related to each other.

Lexical decision experiments require that both words and nonwords be presented, and it may be the case that trials preceded by word trials exhibit systematically different response times than trials preceded by nonword trials. In the two experiments reported here, four basic types of consecutive trial sequences were examined: word–word (W–W), word–nonword (W–NW), nonword–word (NW–W), and nonword–nonword (NW–NW). In most lexical decision experiments, word responses are signaled by pressing a right-hand or dominant-hand response key, and nonword responses by pressing a left-hand or nondominant-hand key. These response key-hand mappings contribute to the virtually universal finding that word responses are quicker than nonword responses, but the lexicality effect emerges even when hand is not confounded with type of decision (e.g.,

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Chumbley & Balota, 1984; Stadler & Logan, 1989.) Thus, it is well established that the lexical status of the item presented during the current trial affects the response time on that trial. Therefore, if response times on current trials were independent of the lexical status of the *previous* trial, then the pattern of latencies would be:

W–W = NW–W < W–NW = NW–NW.

Although sequential dependencies between consecutive unrelated trials have not typically been the focus of research using the lexical decision task, sequential effects have been the focus of research using other reaction time tasks, such as choice reaction time (e.g., Laming, 1973; Remington, 1969). In general, these experiments show that reaction time on trial n is in fact not independent of reaction time on trial $n - 1$; instead, when trial $n - 1$ and trial n involve the same response, reaction time on trial n is faster than when trial $n - 1$ and trial n involve different responses. If this "same-response facilitation" effect generalizes to the lexical decision task, then the following pattern should emerge:

W–W < NW–W < NW–NW < W–NW.

It appears that the same-response facilitation notion is so plausible that some researchers have simply *assumed* that such facilitation occurs in lexical decision experiments. For example, in one part of an investigation designed to distinguish between theories of semantic priming, McNamara (1992) found that the third item in a W–W–W sequence such as AROUND HAMMER NAIL yielded a shorter reaction time than did the third item in a NW–W–W sequence such as TELF HAMMER NAIL. He attributed this finding to a same-response facilitation artifact, but it could have arisen not because of same-response facilitation but because of the differing familiarity levels of the compounds formed of successive trials, as predicted by compound cue theory (e.g., McKoon & Ratcliff, 1992). In support of the same-response facilitation interpretation, McNamara asserted, "It is well known that responses in identical sequences are faster than responses in mixed sequences" (p. 1182). Remington (1969) was cited in support of this assertion, but Remington and others who have found same-response facilitation effects (e.g., Laming, 1973) did not use the lexical decision task. It was the aim of Exp. 1 to determine whether same-response facilitation effects do in fact occur in the lexical decision task. We believed that the purest test would be an experiment consisting of half words and half nonwords, with no sequences of repeated or related trials.

Experiment 1

Method

Participants. Thirty-two undergraduates from the University of Wisconsin-Milwaukee participated for course credit. All were right-handed native speakers of English.

Materials. Stimuli were 168 monomorphemic content words judged by the experimenters to be high in familiarity (e.g., HOUSE, PAIN, CUTE, GARLIC, SKIP, ITCH, VELVET, JUG, LIMB) and 168 pronounceable, orthographically legal nonwords that approximately matched the set of words on initial letter and length (e.g., HINK, PRAN, CHARP, GUNRIN, SIME, ITLE, VIELD, JAD, LORM). The median frequency of the words was 47 per million (Kucera & Francis, 1967), with a range of 4 to 1599 per million. The mean length of both words and nonwords was 4.5 letters, with a range of 3 to 6 letters.

Design. Two counterbalanced lists were constructed such that each item was preceded by a word in one list but a nonword in the other. The lists obeyed the constraint that no more than 4 trials in a row could require the same response (word or nonword). In both lists, the members of each pair of consecutive items were semantically, morphologically, phonologically, and orthographically unrelated to each other. Both lists contained all 336 stimulus items. On each list, there were 84 trials of each of the four types: W–W, W–NW, NW–W, and NW–NW. Half of the subjects were randomly assigned to each list.

Apparatus. Stimulus strings were displayed one at a time in lowercase letters on a computer monitor. Letters were white on a black background. An IBM-compatible microcomputer equipped with a Digitry, Inc. Cognitive Testing Station controlled the experiment and recorded responses and response latencies. The response box contained three buttons, one for initiating trials and two for indicating lexical decision responses.

Procedure. At the start of each trial, a fixation asterisk (*) appeared at the center of the screen. To initiate a trial, the subject used both thumbs to press a button centered on the lower half of the response box, causing the disappearance of the asterisk. The letter string appeared in the center of the screen 350 ms later and remained there until the subject made a response. Responses were indicated by pressing one of two buttons on the upper half of the response box with the appropriate index finger, the left-hand button for nonword responses and the right-hand button for word responses. Feedback was provided in the form of a beep whenever an error was committed. Instructions stressed both speed and accuracy.

Each participant completed 30 practice trials before proceeding to the 336 experimental trials. At the start of the experimental trials, it was necessary to present 1 filler word trial (List 1) or 1 filler nonword trial (List 2) so that all experimental trials would have a previous trial. Participants were given a break halfway through the experimental list. The first 4 trials after the break were filler trials (ending with a nonword trial for List 1 but a word trial for List 2), followed by the remaining experimental trials.

Results and discussion

The mean response latencies and error rates are presented in Table 1. Data from any trial that resulted in an error were eliminated from the response time analyses, as were data from any trial in which the previous trial had resulted in an error. The occasional extremely long response times (those more than 2.5 *SD* greater than the subject's mean for that type of trial) were replaced by the cutoff value.

Responses to nonwords averaged 754 ms, compared to 641 ms for words; the 113-ms difference was significant, $F_1(1,31) = 150.45$, $p < .0001$ and $F_2(1, 334) =$

Table 1 Mean response latencies (in milliseconds) and error rates for words and nonwords as a function of previous trial type (Exp. 1)

Trial type	Previous trial type	
	Word	Nonword
Word		
RT	630	651
Percentage errors	3.98	3.98
Nonword		
RT	740	768
Percentage errors	4.84	4.97

248.01, $p < .0001$. More interestingly, there was a significant effect of the lexical status of the item that had appeared during the previous trial. Responses on trials following word trials averaged 685 ms, 25 ms less than responses of trials following nonword trials (710 ms), $F_1(1,31) = 36.00$, $p < .0001$ and $F_2(1,334) = 39.22$, $p < .0001$. Although the effect of the previous trial was slightly larger for current nonword trials than for current word trials, the interaction between the lexical status of the current trial and that of the previous trial did not approach significance.

Although effects of the lexical status of the current trial and that of the previous trial were observed in the response time data, no such effects were observed in the error rate data. Overall, error rates were low, averaging 4.44%, with a somewhat higher rate for nonword trials (4.91%) than for word trials (3.98%). The difference of 0.93% did not approach significance in either analysis. Also, there was no significant error rate difference between trials that had been preceded by word trials (4.41%) and trials preceded by nonword trials (4.48%), and no significant interaction between lexical status of the current trial and lexical status of the previous trial.

It is evident, therefore, that although there were no appreciable differences in accuracy in the four conditions of the experiment, response times did vary systematically as a function of the lexical status of the immediately previous trial. The observed pattern of latencies was:

W–W < NW–W < W–NW < NW–NW,

indicating that trials following nonword trials, regardless of their own lexical status, tended to have greater latencies than trials following word trials.

Note that this finding is not only inconsistent with the hypothesis that reaction times on current trials are independent of those on previous trials, but is also inconsistent with the same-response facilitation hypothesis developed from research on the choice reaction time task (e.g., Laming, 1973; Remington, 1969), which predicted the pattern:

W–W < NW–W < NW–NW < W–NW.

Experiment 2

In Exp. 2, two types of nonwords were used: (1) pseudohomophones and (2) nonhomophonic but pronounceable and orthographically legal nonwords. Response times on pseudohomophone trials tend to be longer than response times on nonhomophonic nonword trials (e.g., McCann, Besner, & Davelaar, 1988; Rubenstein et al., 1970). Therefore, the inclusion of pseudohomophones in Exp. 2 allows a test of one explanation of the effects observed in Exp. 1, namely, that response times on trials following nonword trials were greater than those on trials following word trials because decisions following slow responses are slower than decisions following faster responses. If this explanation is correct, then in Exp. 2 it should be found that decisions on trials following pseudohomophone trials are slower than decisions on trials following nonhomophonic nonword trials. If this explanation is not correct, and it is the negativity of the prior trial that causes the sequential dependency effect, then trials following pseudohomophone trials should not exhibit increased response times relative to trials following nonhomophonic nonword trials.

Method

Participants. Thirty undergraduates from the University of Wisconsin-Milwaukee participated for course credit. All were right-handed native speakers of English. None had participated in Exp. 1.

Materials. Experimental stimuli consisted of 45 monomorphemic content words (W) that were judged by the experimenters to be high in familiarity, 45 pronounceable, orthographically legal nonwords (NW) that were not homophonic with any English word, and 45 pronounceable, orthographically legal nonwords that are homophonic with a familiar English word (pseudohomophones, PH). Examples of each of the three types of items are JELLY, POLITE, BANG, FLOAT, TRUNK, LACE, WANDER, BLAZE, FOLD (W); JERIN, PISHON, BLAPE, FUMP, TARELL, LIDAL, WHOD, BRELK, FISE (NW); and JURNEL, PEECE, BREAZE, FOAN, THRET, LOKAL, WATE, BRANE, FITE (PH). No attempt was made to equate the nonwords and pseudohomophones on orthographic similarity to words, because we were not studying explanations of the pseudohomophone effect but rather were using pseudohomophones as a means of lengthening response times on negative trials. The median frequency of the words was 7.0 per million (Kucera and Francis, 1967; range = 3–8). The three types of stimuli were approximately matched on initial letter and on length ($M = 5.3$ letters, range = 4–6). In addition, 155 filler items were gathered, consisting of 100 monomorphemic content words similar in judged familiarity to the experimental words and 55 nonhomophonic, pronounceable, orthographically legal nonwords.

Design. Three counterbalanced lists were constructed such that each item was preceded by a word in one list, a nonword in a second list, and a pseudohomophone in a third list. In all lists, the members of each pair of consecutive items were semantically, morphologically, phonologically, and orthographically unrelated to each other. All three lists contained all 135 experimental items and all 155 filler items, for a total of 290 items. Thus, each list contained equal numbers of positive trials (145 words, 45 of which were experimental Ws) and negative trials (100 nonwords, 45 of which were experimental NWs, plus 45 experimental PHs). Pseudohomophones therefore comprised 15.5% of each list. In each list, there were 15 trials in each of the 9 conditions formed by factorial combination of the type of previous trial with the type of current trial (W–W, W–NW, W–PH, NW–W, NW–NW, NW–PH, PH–W, PH–NW, and PH–PH). One-third of the subjects were randomly assigned to each list.

Apparatus and procedure. Apparatus and procedure were the same as in Exp. 1, except that after completing 30 practice trials, participants completed 290 trials.

Results and discussion

Table 2 presents the response time and error rate data from each of the 9 conditions.

Response times

As in Exp. 1, response time data from incorrect trials and from trials that followed incorrect trials were excluded from the analyses, and outliers were replaced by the predetermined cutoff value of 2.5 *SD* units plus the subject's mean for that trial type. ANOVAs indicated a significant main effect of type of current trial, $F_1(2,58) = 110.89$, $p < .0001$ and $F_2(2,132) = 32.51$, $p < .0001$. Mean response times for each of the three types of trials were 673 ms for words, 749 ms for nonwords, and 786 ms for pseudohomophones. Thus, as expected, pseudohomophones were responded to more slowly than nonhomophonic nonwords; sub-analyses of the subject and item data indicated that the 37-ms difference between PHs and NWs was significant, $F_1(1,29) = 45.61$, $p < .0001$ and $F_2(1,88) = 7.94$, $p < .01$.

Table 2 Mean response latencies (in milliseconds) and error rates for words, nonwords, and pseudohomophones as a function of previous trial type (Exp. 2)

Trial type	Previous trial type		
	Word	Nonword	Pseudo-homophone
Word			
RT	674	673	672
Percentage errors	4.22	4.89	4.89
Nonword			
RT	715	764	767
Percentage errors	4.22	4.22	3.56
Pseudohomophone			
RT	752	804	802
Percentage errors	7.78	11.78	11.33

Turning to the effect of the previous trial, trials following word trials averaged 714 ms, compared to 747 ms for trials following nonword trials and 747 ms for trials following pseudohomophone trials; the main effect of previous trial was significant in the overall ANOVAs, $F_1(2,58) = 13.86$, $p < .0001$ and $F_2(2,264) = 14.44$, $p < .0001$. This main effect arose because trials following negative trials were appreciably slower than trials following positive trials, although the size of the effect did *not* vary at all as a function of whether the prior negative trial had been a NW trial or a PH trial. Given that the PH trials themselves had been responded to more slowly than the NW trials, it is evident that it was the negativity (nonlexicality) of the previous trial, rather than the amount of time spent on the previous trial, that exerted an effect on the current trial's response time.

Unlike the results of Exp. 1, the results of Exp. 2 yielded an interaction of current trial type with previous trial type; this interaction was significant by subjects, $F_1(4,116) = 4.22$, $p < .005$ and nearly significant by items, $F_2(4,264) = 2.37$, $p = .053$. The interaction indicates that word response times were unaffected by the previous trial, but that both nonword and pseudohomophone response times were greater when the previous trial had been negative that when it had been positive. Whereas W trials averaged almost exactly 673 ms regardless of the nature of the previous trial, NWs following negative trials were processed 51 ms more slowly than NWs following word trials, and PHs following negative trials were also processed 51 ms more slowly than PHs following word trials. Therefore, although pseudohomophones were processed more slowly than nonwords, they were not more affected by the nature of the previous trial than nonwords were. Notice again that the type of negative prior trial exerted no effect: Response times on PH–PH trials were virtually identical to those on NW–PH trials, and response times on NW–NW trials were virtually identical to those on PH–NW trials.

Error rates

Analyses of error rates of Exp. 2 indicated no significant main effect of previous trial type but a significant main effect of current trial type, $F_1(2,58) = 26.02$, $p < .0001$ and $F_2(2,132) = 7.76$, $p < .001$, which was due to elevated error rates on PH trials ($M = 10.30\%$) compared to NW ($M = 4.00\%$) and W ($M = 4.67\%$) trials. The interaction of current trial type with previous trial type reached significance in neither ANOVA. Newman-Keuls tests on the subject data revealed that although somewhat more errors were made in the NW–PH (11.78%) and the PH–PH (11.33%) conditions than the W–PH condition (7.78%), the differences were not significant. Therefore, although pseudohomophones were processed less accurately than other nonwords, the reduction in accuracy was not significantly affected by the trial before the pseudohomophone trial.

General discussion

Participants tended to respond more slowly to an item when the previous trial had involved a nonword than when it had involved a word. These results demonstrate that there can exist sequential dependencies in lexical decision data even when consecutive trials involve items that are unrelated to each other in meaning, spelling, and sound. Notice that in both experiments, it was found that when sequential dependencies existed, they took the form of slower responses following negative responses. Although previous work with choice reaction time tasks (Laming, 1973; Remington, 1969) might suggest that NW–NW trials should be faster than W–NW trials, the opposite pattern was observed in both experiments: NW–NW trials were consistently slower than W–NW trials, regardless of whether the nonwords were pseudohomophones or not. The observed pattern is consistent with a general inhibition hypothesis, which states that processing an unfamiliar letter string (a nonword) during trial $n-1$ can cause a temporary inhibition effect that lengthens the decision stage on trial n.

The reason for the different pattern of results in lexical decision as compared to choice reaction time tasks probably lies in the fact that choice reaction time tasks typically have one-to-one stimulus-response mappings, such that two consecutive trials requiring the same response also involve repetition of the exact same stimulus. In contrast, two consecutive trials in the present experiment requiring the same response *never* involved repetition of the exact same stimulus. Therefore, it appears that stimulus repetition, and not mere response repetition, underlies the same-response facilitation patterns reported in choice reaction time experiments such as Remington's (1969).

Consistent with Remington's (1969) findings, repetition priming effects between consecutive presentations of the exact same letter string have been reported in lexical decision experiments (e.g., Forbach, Stanners, & Hochhaus, 1974). Both repeated nonwords and repeated words typically show facilitation compared to unrepeated nonwords or words. The results of the current experiments, in which no stimuli were repeated, show that repetition of the same response *category* between consecutive trials does not in itself produce facilitation relative to non-repetition of the response category.

In Exp. 1, which employed words and pronounceable, orthographically legal nonwords, it was found that both words and nonwords were responded to more slowly when they followed nonword (negative) trials than when they followed word (positive) trials. The composition of the list had a strong influence on which type of trials would be slowed by prior negative trials, however; the addition of pseudohomophones to the list (Exp. 2) eliminated the sequential dependency when the current trial was a word trial. Interestingly, despite the finding that pseudohomophones were processed more slowly than other nonwords, trials following pseudohomophones were not slower than trials following other nonwords. Similarly, pseudohomophones were not more slowed down by prior negative trials than were other nonwords. Thus, it appears that negative trials are generally susceptible to influences from the previous trial, but positive trials are influenced by the previous trial under some circumstances but not others.

The findings of Exp. 2 are in general agreement with findings from Meyer et al.'s (1974) rhyme priming studies. Unlike the present experiments, Meyer et al.'s studies included pairs of items that were orthographically related (e.g., COUCH TOUCH) or orthographically and phonologically related (e.g., BRIBE TRIBE). For purposes of comparison with the present experiments, the most interesting conditions of Meyer et al. are the four control conditions involving consecutively presented *unrelated* items, the results from which were as follows: W–W, 599 ms; NW–W, 601 ms; W–NW, 716 ms; and NW–NW, 795 ms. Thus, like the results of the present experiments, the Meyer et al. results showed that nonword responses were slower when the previous trial involved a nonword compared to when it involved a word. As in the present Exp. 2, words were not noticeably affected by the nature of the previous trial. It appears likely that the results of the present Exp. 2 and the results of Meyer et al. are similar to each other because both experiments included items that activate potentially misleading phonological representations (pseudohomophones such as BRANE in our experiment and nonrhyming orthographic neighbors such as COUCH TOUCH in the experiment of Meyer et al.)

The lack of sequential dependency effects on word trials in Exp. 2 may have arisen because pseudohomophones introduced a generally high level of task difficulty that interfered with processing of easier trials. It has often been found that when difficult conditions (in this case, pseudohomophone trials) are added to an experiment, easier conditions (in this case, the word trials) tend to show lengthened reaction times and reduced differences among themselves. Such a pattern was observed, for example, in an experiment by Kahneman and Henik (1981), who used a variation of the Stroop task to investigate preattentive and attentive processes. Participants viewed pairs of words, one of which was always in black ink, and the other of which was always in ink of another color. Three conditions were included: (1) a black neutral word and a colored neutral word, (2) a black incompatible word (e.g., GREEN in black ink) and a colored neutral word, and (3) a black neutral word and a colored incompatible word (e.g., RED in blue ink). The task was to name the ink color of the word not printed in black ink. It was found that Conditions 1 and 2 yielded equivalent reaction times, whereas Condition 3 yielded elevated reaction times. However, van der Heijden, Hagenaar, and Bloem (1984) found that by essentially removing the difficult condition (Condition 3), a difference between the remaining, easier conditions emerged, such that Condition 2 yielded longer reaction times than Condition 1. Analogously, in the present lexical decision experiments, word trials exhibited sequential dependencies only when there were no difficult nonwords (pseudohomophones) included in the experiment.

The present studies join others which suggest that lexical decision responses are sensitive to a number of influences beyond those involved in accessing the mental lexicon (e.g., Balota & Chumbley, 1984; Dorfman & Glanzer, 1988; Shulman, Hornak, & Sanders, 1978; Stone & Van Orden, 1992). Many of these studies have focused on global list composition effects. The implication of the present results is that the decision stage can be influenced not only by list composition but also by the lexical status of the trial immediately before the current trial, implying a dynamic model of the lexical decision task in which subjects continually adjust their decision criteria in a momentary, trial-by-trial fashion. These momentary adjustments are modulated by a global adjustment based on list composition as a whole, as indicated by the finding that the inclusion of pseudohomophones in Exp. 2 eliminated response time elevation on word trials following negative trials.

The momentary adjustments occurred even though there was no basis for subjects to generate expectancies or to employ semantic matching processes of the sort discussed by Neely, Keefe, and Ross (1989), who manipulated nonword ratios and relatedness proportions in order to study the role of expectancies and retrospective semantic matching on semantic priming. In our stimulus lists, the probability that a stimulus was a word or a nonword was set at 50%, and there were no pairs of related consecutive trials. It appears that even under such apparently "baseline" conditions, in which subjects should behave in as neutral a fashion as possible, there is a tendency to delay responding to the next trial if the current trial is a negative one.

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