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Word-to-letter inhibition: Word-inferiority and other interference effects

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Four experiments were run to determine whether the interactive activation model would more accurately reflect the effect of context in letter perception by including word-to-letter inhibition resulting from word-to-word inhibition produced when multiple word units become active. The first three experiments found less accurate target letter discrimination in word than in nonword strings when a string was altered halfway through the exposure through adding or dropping a nontarget letter. The alteration changed a word to a different word or a nonword to a different nonword. Unaltered strings produced the typical word-superiority effect. The last experiment found an inverse relationship between target discrimination performance and the number of word substrings contained in each of a set of word quadrigrams that were individually exposed.

A letter in a word can be identified more accurately than a letter in a string of letters that does not resemble a word (Reicher, 1969; Wheeler, 1970). Many possible explanations that seem simple and straightforward have been proposed, investigated, and rejected. Differences in short-term memory for word and nonword strings have been eliminated as a basis for the word-superiority effect by use of forced choice procedures in which two alternatives for the target letter are either precued or presented immediately after the word or nonword string (Reicher, 1969). Familiar string shape is not a factor since strings are usually presented as uppercase block letters, and the effect has even been shown to persist with mixed upper- and lowercase type (McClelland, 1976). Differences in processing strategies used by subjects for words and nonwords do not seem to be involved, because the word-superiority effect is found whether or not subjects expect letter strings to be words (Carr, Davidson, & Hawkins, 1978). Differences in the frequency of letter clusters between written English word and nonword letter strings do not appear to provide the basis for the difference in accuracy with which target letters are identified in the two string types (McClelland & Johnston, 1977). Nor is target recognition accuracy related to word frequency under the backward masking presentation conditions that characterize studies of context effects (Manelis, 1977; Paap & Newsome, 1980). Finally, sophisticated guessing when context letters are perceived more clearly than the target does not seem to underlie the word advantage, because there is no relationship between the magnitude of the word superiority and the amount of constraint with respect to the target's possible identity provided by the word context (Johnston, 1978).

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Because the relatively simple explanations have failed, more sophisticated models have recently been developed to account for the word-superiority effect. McClelland and Rumelhart (1981; Rumelhart & McClelland, 1982) proposed what they termed an interactive activation model of the effect of context in the perception of letters. The model uses neural analogies, with excitatory and inhibitory influences upon nodes or units in memory. According to the model, stimulus input in the form of features activates letter units, which in turn activate a word unit for that particular combination of letters if such a unit is present in the mental lexicon. Lexical access enhances letter identification through excitatory feedback from the activated word unit to its constituent letter units. A string of letters that does not resemble a word has no lexical entry to provide this feedback, and letter identification is not as accurate. Connections between word units are mutually inhibitory, since the model assumes that only one word can be present at any one place and time. The connection from a letter unit to a word unit can be either excitatory or inhibitory, depending on whether the letter is in the proper position in the word unit. In tests of the model, word-to-letter inhibition was assumed not to occur. Nevertheless, the model has been able to account for various context effects.

The purpose of the present study was to provide evidence that inhibition between word units does, in some situations, feed down to the letter level, yielding even lower identification accuracy on a letter in a word than on one among a series of letters that does not resemble a word. In the first three experiments, a discrimination task with prespecified targets was used, in which each string was modified during its exposure by adding or dropping a nontarget letter in the string. Corresponding original and modified strings were both either words or nonwords. Inhibition between lexical units when two words appeared in the same place and at almost the same time actually reversed the word-superiority effect observed when the strings were left unmodified. The final experiment involved word quadrigrams that varied in the number of word substrings they contained. Target discrimination accuracy was inversely related to the number of word substrings present.

EXPERIMENT 1

In this experiment, trigrams that were presented were or were not changed to quadrigrams by the addition of a letter. The subjects' task was to determine whether a P or an R was present at the leftmost or rightmost letter in each string. Letters in each trigram were spaced so that a letter could be inserted directly to the left or right of the middle letter without changing the location of any of the trigram's letters. A letter was never inserted beside a target. When a letter was added, it appeared halfway through the exposure of the trigram. An inserted letter changed a word trigram to a word quadrigram, or a nonword trigram to a nonword quadrigram. Trigrams and quadrigrams are shown in Table 1. The typical word-superiority effect was expected with unchanged trigrams. However, a word-inferiority effect was expected with trigrams changed to quadrigrams. The presence of different words at the same place close together in time should activate two word units in the mental lexicon with mutually inhibitory connections, with this inhibition's being passed to the letter level. Subjects, therefore, should not be able to make the target letter discriminaiton as accurately as when only one word unit has been activated and the inhibition is absent.

Method

Subjects. Eight subjects served for extra credit in a general psychology course. Each reported normal or corrected-to-normal vision.

Apparatus. A four-channel Gerbrands tachistoscope, Model T-4A, was equipped with a microswitch to allow subjects to initiate exposures. Background luminance of each of the four channels was set at 5.0 cd/m², as measured with a Spectra Lumicon photometer with Photospot attachment. A tone generator with a power source separate from the tachistoscope served to generate the warning tones. The laboratory was dimly illuminated by a 40-W bulb shielded from the subject.

Stimuli. Stimuli were those shown in Table 1. Letters were traced from a Berol Rapi Design template (No. 2960) in black ink from a Pilot Razor Point Pen onto white index cards. Each letter subtended a visual angle of approximately .30° vertically and .22° horizontally. The pre- and postexposure mask was composed of a row of five superimposed Xs and Os, with horizontal lines drawn contiguous to the top and bottom of the characters. A small black fixation dot was centered approximately .1° below the bottom line of the mask. Each trigram was drawn on a separate card, with approximately .35° between the letters. Each single letter that converted a trigram into a quadrigram was drawn on a separate card. Cards were aligned on Masonite slides so that the single letter appeared between the middle letter and either the first or last letter of the trigram when both slides were illuminated, as shown in Table 1. The index cards were also positioned so that each letter in a trigram was centered behind a character in the mask if both were shown simultaneously. The single letter was centered behind the second or fourth letter in the mask and never appeared directly beside a target letter. A slide containing a blank white card was also prepared.

Design. Each subject received six blocks of 32 trials, in which all trigrams that remained trigrams and trigrams that changed to quadrigrams were exposed once each in a random order within each block. The first block given each subject was used for practice and duration setting and was not analyzed.

Procedure. Each subject was instructed to gaze at the fixation dot and initiate each exposure at any time after a .2-sec warning tone sounded to indicate that the slides were in place for that exposure. When the microswitch was pressed, the following sequence of events occurred: the mask was replaced with a trigram, and simultaneously the blank card was illuminated; on one exposure of each trigram within each block, illumination of the blank card was changed halfway through the exposure to the illumination of a single letter that converted the trigram into a quadrigram as illustrated in Table 1, whereas on the other exposure, the blank card was illuminated for the entire duration that the trigram was shown; finally, the mask reappeared to terminate the exposure of the trigram or quadrigram. The subject then responded aloud with the single letter "P" or "R" to indicate a judgment of which letter was present on that trial. The initial exposure duration of 200 msec was lowered during the practice block to allow approximately 75% overall accuracy. Thereafter, the duration was changed only between blocks when necessary to maintain this level of performance. Mean exposure duration was 87 msec. No feedback regarding accuracy was given, and trials proceeded in an uninterrupted series.

Results and Discussion

Proportions correct for each target position (leftmost or rightmost letter in the string) and target letter for word and nonword trigrams and quadrigrams for each subject were entered into an analysis of variance, with counterpart pairs analyzed as a nested variable. The interaction of whether a letter had been added (trigram vs. quadri-

Table 1
Mean Proportion of Responses Correct in Experiment 1 to Strings Appearing in Experiments 1, 2, and 3

Word		Nonword		Word		Nonword	
Trigram	Mean	Trigram	Mean	Quadrigram	Mean	Quadrigram	Mean
P A N/	.850	P A H/	.625	P AIN/	.700	P AIH	.650
R A N	.625	R A H	.725	R AIN	.525	R AIH	.750
P U T	.825	P U J/	.725	P UNT/	.550	P UNJ/	.800
R U T	.750	R U J	.475	R UNT	.750	R UNJ	.650
C A P/	.875	Q A P/	.800	CHA P/	.775	QHA P/	.825
C A R	.750	Q A R	.775	CHA R	.625	QHA R	.900
C U P/	.850	Q U P/	.775	COU P/	.750	QOU P/	.925
C U R	.875	Q U R	.875	COU R	.775	QOU R	.800

gram) with string type (word vs. nonword) was significant [$F(1,7) = 10.65$, $p < .02$, $MSe = .0510$]. When trigrams remained trigrams for the entire exposure, .800 of responses were correct to words, but only .722 of responses were correct to nonwords. However, for initially exposed trigrams that changed to quadrigrams during the exposure, the corresponding proportions were .681 and .788. The only other significant effect was the interaction between target letters (P vs. R) and letter strings [$F(8,56) = 2.46$, $p < .025$, $MSe = .0464$]. Means appear in Table 1.

The significant interaction between target letters and strings indicates differential response bias for the various strings, and leaves open the possibility that the significant interaction of trigram versus quadrigram with string type was influenced by response bias. Responses to each of the 16 counterparts containing the P versus R were thus corrected for bias according to the procedure suggested by Gummerman (1972). This correction obtains the proportion of times that a given stimulus occurred, contingent upon the occurrence of the corresponding response. The correction is particularly appropriate when, as in the current experiment, the probability of each of two stimulus events is .5. The obtained proportion correct can be shown to vary less with extremes of response bias than when corrections are used to obtain the proportion of times that a given response is made, conditional upon the occurrence of the corresponding stimulus. After the correction, the variables, except for target letter, were entered into an analysis of variance as before. The only significant effect was the interaction of trigram versus quadrigram with string type [$F(1,7) = 13.98$, $p < .01$, $MSe = .0174$]. Means for the significant interaction are plotted in Figure 1. Planned comparisons confirmed a significant word-superiority effect for trigrams remaining trigrams [$t(7) = 2.66$, $p < .05$], as well as a significant word-inferiority effect for trigrams to which a letter was added to produce quadrigrams [$t(7) = 3.34$, $p < .02$].

Although adding a letter to a nonword trigram to produce a nonword quadrigram had very little effect on

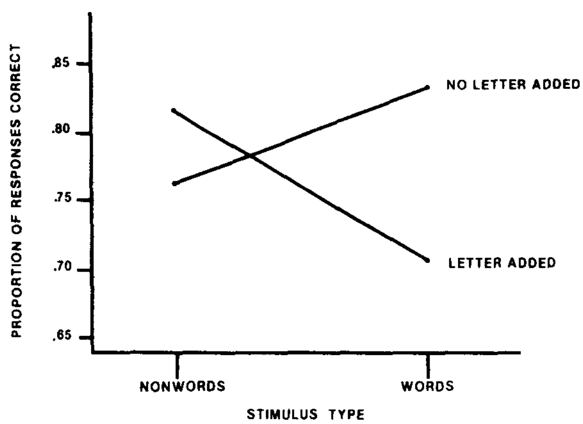

Figure 1. Mean proportion of responses (corrected for bias) correct in the significant interaction between whether a word was added and string type in Experiment 1.

target discrimination accuracy, adding a letter to a word trigram to produce a word quadrigram markedly impaired performance. In fact, performance on word quadrigrams was significantly poorer than on nonword quadrigrams. This suggests that when two words appear at the same place very close together in time, mutual inhibition between word units activated in the mental lexicon is passed down to the letter level, reducing identification accuracy of letters in the word.

Nevertheless, since word and nonword trigrams did differ by one letter, it could be that interactions between the added letter and the different shapes of the words and nonwords could produce the different patterns of accuracy observed with the trigrams and quadrigrams. It also could be that adding a letter between the middle letter of the trigram and the one at the end opposite the target isolated the target and made its position certain, thereby eliminating the word-superiority effect (for arguments attributing the word-superiority effect to positional uncertainty regarding which letter is the target in nonword but not in word strings, see Estes, 1975; Paap & Newsome, 1980; nevertheless, it is difficult to understand how removing this uncertainty would produce a word-*inferiority* effect). The following experiment was run to disconfirm these alternate interpretations of the results of Experiment 1.

EXPERIMENT 2

In Experiment 2, the stimuli from Experiment 1 were used, but a quadrigram appeared initially on each trial. On one half of the exposures of each quadrigram, the single letter that was added in Experiment 1 was dropped to produce a trigram. Pilot work indicated that masking was necessary to eliminate a lingering afterimage of the letter that was dropped. Metacontrast masking was used, since introducing patterns such as superimposed Xs and Os between letters in the strings was found to eliminate the word-superiority effect. A word-superiority effect was expected on any exposure containing only a quadrigram, but a word-inferiority effect was anticipated on an exposure in which a quadrigram was changed to a trigram. The reasoning behind these predictions is the same as for those in the preceding experiment. Different words appearing in the same place at almost the same time produce mutual inhibition between activated word units in the mental lexicon, which is then passed on to the letter units that constitute the words. A word-inferiority effect appeared with exposures containing a quadrigram in Experiment 1, yet a word-superiority effect was expected when only a quadrigram was present for the entire exposure. The word-inferiority effect can be attributed neither to different interactions among shapes in the word and nonword quadrigrams, nor to the target's being isolated in quadrigrams but not in trigrams.

Method

Except for the subjects and the sequence of events occurring during each exposure, the method was identical to that in Experiment 1.

Table 2
Sample Displays from Experiment 2

String Type	Example
Initial Quadrigram	P AIN
Changed to a Trigram	P A N
Initial Quadrigram	P AIN
Remaining a Quadrigram	P AIN

Ten new subjects, who reported normal or corrected-to-normal vision, served for extra credit in general psychology. Halfway through the exposure of a given quadrigram in each block, the letter added in Experiment 1 was dropped. A slide simultaneously appeared containing a superimposed X and O separated by approximately .05° from the top and bottom of the second and fourth positions of the string. On the other exposure, the quadrigram was left unchanged, being exposed without the slide containing the four superimposed X and O characters. Sample displays appear in Table 2. The pre- and postexposure mask was used as in Experiment 1. Mean overall exposure duration was 74 msec.

Results and Discussion

Responses were corrected for bias as in Experiment 1, and the same variables were analyzed as in that experiment. The main effect of location of the target letter was significant [$F(1,9) = 31.54, p < .001, MSe = .0351$], with .876 of responses correct to targets in the leftmost position in the string, but only .710 correct to targets in the rightmost position. The effect of strings was significant in this analysis [$F(8,72) = 2.01, p < .01$, $MSe = .0033$]; means appear in Table 3. Finally, the interaction between string type and whether or not a letter was dropped from the quadrigram to produce a trigram was significant [$F(1,9) = 9.63, p < .02, MSe = .0110$]. The significant interaction is graphically depicted in Figure 2. The relationship between the lines is very similar to that apparent in the graph of the corresponding interaction in Experiment 1.

Planned comparisons indicated (1) a significant word-inferiority effect when a letter was dropped from the quadrigrams [$t(9) = 2.69, p < .05$] and (2) a word-superiority effect when quadrigrams were left unchanged that was not quite significant [$t(9) = 1.86, .05 < p < .10$]. Inspection of Figure 2 reveals that dropping a letter had little effect on performance on nonword strings but a substantial detrimental effect on performance on word strings. The highly significant main effect of target position contributed a great deal to the significant difference between strings shown in Table 3. This table shows one pair of means that is substantially out of line with respect to the trend toward word superiority when a letter was not dropped: COUP/COUR versus QOUP/QOUR. These strings were used because they are among the few that meet the requirements for stimuli in these experiments. A simple comparison showed no significant difference between the means [$t(9) = 1.32$]. It is tempting to conclude that no word-superiority effect occurred with these pairs because COUP is an unusual word and COUR is a French word, neither of which may have been in most subjects' mental lexicons (although at least COUR probably was, because there is a well-known town in this state named Cour d'Alene). Nevertheless, when the O was dropped from these strings to produce CUP or CUR versus QUP or QUR, the means are in the direction of the predicted word-inferiority effect. This suggests that the original quadrigrams were in most subjects' mental lexicons to produce the expected inhibition.

In general, the predicted effects were observed in Experiment 2, along with some that were not predicted. Dropping a letter produced a word-inferiority effect, suggesting that the results of Experiment 1 were not an artifact of interactions among letter shapes in the quadrigrams or of the target letter's being isolated when the fourth letter was added rather than dropped. However, the word-superiority effect was not quite significant in this experiment, and one set of means was substantially out of line with predictions. In addition, a highly significant effect of target position appeared that was not observed in Experiment 1. This position effect suggests that subjects were making a left-to-right scan across letter strings in search for a target letter. The following experiment was therefore run to resolve these inconsistencies.

EXPERIMENT 3

Experiment 3 replicated Experiment 2 except that there was no metacontrast masking of the single letter that was dropped. A word-superiority effect was expected whether or not a letter was dropped from quadrigrams, because the trace of the dropped letter should have persisted until the postexposure mask appeared. Obtaining a word superiority was a main point of interest since the word-

Table 3
Mean Proportion of Responses (Corrected for Bias) Correct in Experiment 2 to Strings Appearing in Experiments 1, 2, and 3

Word		Nonword		Word		Nonword	
Quadrigram	Mean	Quadrigram	Mean	Trigram	Mean	Trigram	Mean
P AIN/ R AIN	.917	P AIH/ R AIH	.874	P A N/ R A N	.857	P A H R A H	.892
P UNT/ R UNT	.898	P UNJ/ R UNJ	.863	P U T/ R U T	.855	P U J/ R U J	.850
CHA P/ CHA R	.817	QHA P/ QHA R	.590	C A P/ C A R	.623	Q A P/ Q A R	.733
COU P/ COU R	.688	QOU P/ QOU R	.778	C U P/ C U R	.696	Q U P/ Q U R	.753

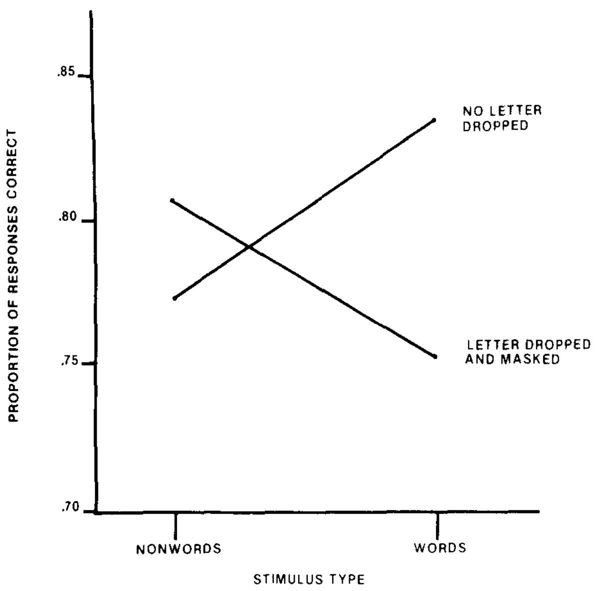

Figure 2. Mean proportion of responses (corrected for bias) correct in the significant interaction between whether a letter was dropped and string type in Experiment 2.

superiority effect when quadrigrams were presented for the entire exposure in Expeiment 2 was not quite significant. Other interests included determining whether the target position effect observed in Experiment 2 would be maintained, and whether the mean performance on the COUP/COUR versus QOUP/QOUR stimuli would be out of line with that on the other quadrigrams when no letter was dropped.

Method

Since the method was similar to that in the preceding experiment, only the differences will be mentioned. Sixteen new subjects, whose essential characteristics were identical to those of subjects in the preceding experiments, were chosen. When a letter was dropped, illumination of the slide containing it was replaced with illumination of a blank slide rather than one containing a metacontrast mask. Mean overall exposure duration was 77 msec.

Results and Discussion

Correction for response bias and analysis of variance was performed, as in Experiment 2. The main effect of string type was significant [$F(1,15) = 28.37, p < .001$, $MSe = .0131$], with .805 of responses correct to words but only .729 to nonwords. The main effect of target position was likewise significant [$F(1,15) = 12.88, p < .01$, $MSe = .0838$]. Proportion correct for targets in the leftmost position was .832 and for those in the rightmost position was .702.

No other main effect or interaction was significant. In particular, neither the main effect of letter strings ($p > .10$) nor the interaction between string type and whether a letter was dropped ($F < 1.0$) approached significance. The fact that the significant effect of target position did not spill over to produce a significant difference in performance among letter strings may be due to the fact that the position effect was not nearly as strong in the present experiment as it was in Experiment 2. An examination of means revealed that, as in Experiment 2, when no letter was dropped, mean proportion correct on QOUP/QOUR was higher than on COUP/COUR [.689 vs. .674, $t(7) = .27$, n.s.], whereas means on each of the other quadrigram word versus nonword combinations were in the expected direction in this condition. The explanation for this anomaly may be that COUR is not an English word and COUP is a word that may have been unfamiliar to many subjects. The lack of word superiority with these pairs was consistently observed in Experiments 2 and 3.

The word-superiority effect appeared both when a letter was dropped and when it was not. Planned comparisons indicated a significant effect in both the former [$t(15) = 2.86, p < .05$] and the latter instances [$t(15) = 2.63$, $p < .05$]. Apparently when the single letter was removed, its afterimage persisted for an average of approximately 40 msec until the postexposure mask arrived, so that two word entries in the mental lexicon were not activated to produce mutual inhibition. And as in Experiment 2, the main effect of target position was significant, suggesting a left-to-right scan across the letter string.

The current experiment accomplished its purposes in demonstrating a significant word-superiority effect when a quadrigram was initially presented, confirming the target position effect observed in Experiment 2, and showing that the means for one of the word versus nonword strings were consistently out of line with those for the others.

Experiment 4 was run to demonstrate that inhibition between word units in the mental lexicon is transferred to the letter units, but presentations were used in which all letters in each string appeared simultaneously for the entire exposure.

EXPERIMENT 4

Some words contain one or more substrings of letters that form other, shorter words. Perhaps each of these substrings would activate its own word unit, which would have mutually inhibitory connections with the word unit formed by the whole string and with other substring word units, if present. The inhibition generated might then feed down to the letter level, producing impairment in a target discrimination task that would be proportional to the number of word units activated. Taft and Forster (1976) found that lexical decisions are slowed when the first several letters of a longer nonword string form a word, and more relevant to the current issue is Taft's (1979) later finding of the same effect with words (e.g., BEARD or PAINT took longer to classify than STORM or GUEST).

Stimuli in the current experiment were all four-letter words. One group of subjects discriminated M from N as targets, and the other group discriminated P from R. Stimulus strings are shown in Table 4. There were four types, with four pairs representing each type in both the M/N and the P/R discriminations. For these types, only

Table 4
Mean Proportion of Responses (Corrected for Bias)
Correct for Types and Words Analyzed in Experiment 4

Group	Type 1	Mean	Type 2	Mean	Type 3	Mean	Type 4	Mean
1	MODE/NODE	.802	MILE/NILE	.793	MICE/NICE	.778	MESS/NESS	.901
	SPAM/SPAN	.626	SCAM/SCAN	.610	FIRM/FIRN	.596	CLAM/CLAN	.668
2	PANT/RANT	.770	PANG/RANG	.785	PAID/RAID	.680	PAIN/RAIN	.852
	PATE/RATE	.707	PUNT/RUNT	.734	PAIL/RAIL	.767	PEST/REST	.868
Mean		.726		.731		.705		.822

three-letter substring series forming content words were considered as candidates to activate a word unit that might have inhibitory connections with other word units and with the four-letter word string. In Type 1, each word contained two word substrings, one of which included the target letter (e.g., PAN or PAT) and the other of which did not (e.g., ANT or ATE). In Type 2, each word contained only one word substring that included the target letter (e.g., PAN or PUN). Each word in Type 3 contained only one word substring that did not include the target letter (e.g., AID or AIL). Finally, a Type 4 word contained no word substring. Performance was predicted to increase monotonically across the four types, since inhibition should consistently decrease. The notion that a word substring containing the target letter would provide more inhibition than one not containing it seemed a reasonable speculation that deserved testing. Targets could be in either the leftmost or rightmost position in a word, since always placing targets in the same position has been found to eliminate the influence of context letters (Johnston, 1981; Johnston & McClelland, 1974; but see Chastain, 1981; Purcell & Stanovich, 1982; and, for a possible resolution of this issue, Chastain, 1982). Words available for the M/N and P/R discriminations were not equally favorable for this manipulation. Although it was possible to find words of all four types allowing M or N to be in each position, only the initial position was conducive to producing four types with P and R. With the latter, eight word counterpart pairs were used in which the rightmost position contained the target, although these stimuli did not vary systematically in the number of word substrings they contained. Examples of those that were used are DEEP/DEER, SOUP/SOUR, and HEAP/HEAR. Responses to these words with the target in the rightmost position were not analyzed.

Method

Subjects. Two groups of 8 new subjects per group served as in the preceding experiments.

Apparatus. Two channels of the four-channel tachistoscope described earlier were used. Background luminance of each channel was 5.0 cd/m^2.

Stimuli. Stimuli were those shown in Table 4, plus 16 additional four-letter words with the target in the rightmost position in the string for the group receiving P and R as targets. Letters were traced from the same template in the same manner as in Experiment 1-3. Letters were normally spaced with a visual angle of approximately .05° between them. The pre- and postexposure mask was composed of a row of four superimposed Xs and Os, with a horizontal line drawn contiguous to the top and bottom of the characters. A small black fixation dot was centered approximately .1° below the bottom line of the mask. Cards were aligned on Masonite slides so that each letter of a word would be centered behind a character in the mask if both were shown simultaneously.

Design. Each subject discriminating M from N received 14 blocks of 16 trials, and the other subjects received 7 blocks of 32 trials, in which all words were exposed once each in a random order within each block. The first 32 trials given each subject were used for practice and duration setting and were not analyzed.

Procedure. The general procedure was that used in the first three experiments. The appearance of a word interrupted the otherwise continuous presence of the mask.

Results and Discussion

Responses were corrected for bias as before. Word counterparts were analyzed as a nested variable within each group and type. The effect of type was significant [$F(3,42) = 6.51, p < .005, MSe = .0133$]. The effect of word counterparts was also significant [$F(8,56) = 4.47, p < .001, MSe = .0186$]. Means for the significant effects are shown in Table 4.

Although the interaction between groups and type was not significant, the data from each group were analyzed separately to ensure that the effect of type was consistent. The performance of subjects receiving M and N as targets differed across types [$F(3,21) = 4.29, p < .02, MSe = .0069$]. Means are shown in Table 4. An orthogonal comparison showed that performance on Type 4 words differed significantly from that on the other types [$F(1,21) = 5.95, p < .05$], whereas planned comparisons indicated no significant difference between any of the other types (all ps $> .10$). Target position was analyzed and found to have a significant effect [$F(1,7) = 24.24, p < .005, MSe = .0247$]. Proportion correct on counterparts containing targets in the leftmost position was .818, and in the rightmost position was .625. This difference suggests that the subjects, like those in the two preceding experiments, were making a left-to-right scan across the strings. Subjects in the other group also displayed a significant difference in performance across types [$F(3,21) = 3.10, p < .05, MSe = .0196$]. Means are shown in Table 4. An orthogonal comparison showed that performance on Type 4 words differed significantly from that on the other types for this group also [$F(1,21) = 4.38, p < .05$], whereas planned comparisons indicated no significant difference between any of the other types (all $ps > .10$).

Mean overall exposure durations did not differ between the groups ($p > .10$). The overall mean was 61 msec.

The significant effect of counterparts in the overall analysis and inspection of the means in Table 4 suggest that the words may not have contributed equally to the main effect of type. Short function words, such as A, AN, and AT, were not considered as word substrings when the words for the four types were selected. In addition, no test was made to ensure that subjects in the sampled population recognized as words the stimuli analyzed as words or word substrings. Fifteen students in general psychology classes were therefore shown each of the four-letter words that had been presented in the experiment. Words were exposed in the four-channel tachistoscope with unlimited viewing time. Each subject was asked to analyze each stimulus, indicate whether it was actually a word, and name each word substring it contained. Single letters, such as A or I, were not considered words, because research has shown that they do not enjoy the same status in the mental lexicon as do other words (Samuel, van Santen, & Johnston, 1982; Wheeler, 1970). Of the words originally analyzed, three were not considered to be words by most of the subjects: NESS, FIRN, and PATE. An additional analysis was performed on the remaining words as follows: A Pearson product-moment correlation was computed between the total number of errors made on each word by the original subjects and the mean number of word substrings that each word was judged to contain by the subjects who made that judgment. However, for those stimuli that tended not to be considered words, their counterparts (MESS, FIRM, and RATE) were excluded from the analysis. The exclusion was made because, in all three instances, responses were biased such that many more errors had been made on the counterpart that was not considered to be a word. Before being entered into the analysis, the number of errors on words in which P or R was the target was doubled, since there were only half as many exposures of each of these as of words in which M or N was the target. The correlation for the remaining 26 words was significant [$r = .45$, $t(24) = 2.44$, $p < .05$], and a subsequent analysis showed no significant departure from linearity. The number of word substrings ranged from 0 to 3.467 and the number of errors ranged from 10 to 38.

The foregoing correlational analysis is probably a better indication of the inhibitory effect of word substrings on target identification in word strings than is the analysis by type that was originally performed. Whereas the first analysis merely showed a difference in performance on words that contained no substring and those that did, the second directly related the number of substrings of all lengths within each word to performance on that word. However, rather than being a function of the number of substrings within each word, performance might instead have been due to at least one other factor that could be related to the number of substrings within each word. McClelland and Rumelhart (1981) found that accuracy in identifying a target letter within a word was positively related to the number of one-letter-different lexical "neighbors" that the word has. Words containing many substrings might happen to have fewer such neighbors than words containing few substrings. The number of one-letter-different lexical neighbors for each word in the correlation analysis was determined, and a correlation between the number of neighbors and the number of word substrings was computed for the 26 words. The correlation was not significant ($r = -.05, p > .40$). The number of neighbors ranged from 6 to 14.

The logic underlying Experiment 4 was similar to that of the first three experiments, but the test was perhaps even more direct. Presenting words containing varying numbers of words as substrings allows multiple word units in the mental lexicon to be simultaneously active. A direct relationship between the number of word units activated and the likelihood of an error on a target discrimination task demonstrates clearly that inhibition between word units can pass down to the letter level to inhibit the activity there.

SUMMARY AND CONCLUSIONS

The first three experiments showed that adding a letter to or dropping a letter from an originally presented word produces lower target discrimination accuracy than does similarly altering a string that does not resemble a word. Trigrams were changed to quadrigrams, or vice versa. Since both word and nonword string types were treated in the same manner, the results cannot be attributed to differential lateral interference on the target letter. Leaving the original strings unaltered yielded superior performance on the word strings; therefore, the word-inferiority effect evident with the altered strings cannot be attributed to differential uncertainty regarding which letter was the target (which otherwise would be a possibility, because word and nonword strings differed only by the letter in one of the two possible target positions). In the last experiment, target discrimination accuracy was shown to be inversely related to the number of word substrings contained in the stimulus word. Whether a substring included the target letter did not appear to be related to the adverse influence of the substring on target discrimination. All of these results converge to suggest that word entries in the mental lexicon have mutually inhibitory connections. If more than one word appears in the same place and at about the same time, multiple word entries are activated. The resulting inhibition is channeled down to the letter level, impairing identification of letters in the words. Although other explanations may be possible on the basis of other models with different assumptions, the present results are nicely explained by proposing minor modifications to McClelland and Rumelhart's (1981) interactive activation model of context effects in letter perception.

The current experiments seem unique in demonstrating a word-inferiority effect in a target discrimination task, with the corresponding implications for McClelland and Rumelhart's model. Healy, Oliver, and McNamara (1982) presented subjects with a passage of text, either one or four words at a time, on a computer terminal screen in a target detection task. A word-superiority effect was observed when words were presented one at a time, whereas a word-inferiority effect occurred when four words were presented at once. The basis for the difference may have been the same as for the effects observed in the experiments presented here: when multiple word units in the mental lexicon were activated close together in time, the resulting inhibition moved down to the letter level to make target detection difficult. Evidence is therefore accumulating that modifications to the interactive activation model that would add inhibitory connections from the word to the letter level are in order.

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