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FREQUENCY DISCRIMINATION AS A FUNCTION OF FREQUENCY OF REPETITION AND TRIALS

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Words were presented with varying frequency on study trials and were then presented in a paired comparison test in which the more frequent alternative was to be chosen. Over eight study-test trials, words were presented at either a 1-sec. or a 2-sec. rate on study trials and at a 2-sec. rate on test trials. In addition, the more frequent alternatives were either underlined on their first occurrence on study trials, on each occurrence on study trials, or were not underlined at all on study trials. Frequency discrimination was based on relative rather than absolute frequency differences in the no-underlining condition, and rate of study trial presentation had a significant effect only in the underlining conditions. There was improvement in performance over trials only in the underlining conditions; there was no improvement in frequency discrimination in the no-underlining condition.

The present study was concerned with *S*'s ability to make frequency discriminations of material presented with varying numbers of repetitions, and with the extent to which frequency discrimination improves over trials.

When *S* discriminates the more frequent of several presented items, the question arises as to whether he is responding to absolute or relative frequency differences between items. An absolute hypothesis simply asserts that discrimination improves as a direct function of the frequency difference between presented items. Ekstrand, Wallace, and Underwood (1966) advanced the relative frequency hypothesis, which assumes that a given frequency difference is more easily discriminated when the absolute frequency level of the alternatives is low rather than when it is high. The assumption is that Weber's law holds for frequency judgments.

In a recent study of frequency judgment, Hintzman (1969) presented words in a long series in which some words were repeated. Following presentation of the words, *S*s were given a paired-comparison test in which the more frequent of two alternatives was to be chosen. On these tests, judged frequency was a logarithmic function of actual frequency differences, supporting the relative frequency hypothesis.

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The present experiment employed a multiple-trial paired-comparison frequency discrimination task similar to that used by Hintzman. A study-test procedure was used in which words were presented with varying frequency on study trials, and on test trials word pairs were presented with *S* instructed to choose the more frequent of the two alternatives. The same list was presented for eight study-test trials with either a 1-sec. or a 2-sec. rate of presentation on study trials. Some *S*s were provided with study trial cues in addition to frequency on the basis of which to make their discriminations. Words that would be the more frequent alternatives in test trial pairs were underlined either on their first occurrence on each study trial, each time they occurred on study trials, or were not underlined at all, for different groups of *S*s.

On test trials in the present experiment, words that occurred two, three, or four times on study trials (more frequent or correct alternatives) were paired with words that occurred zero, one, or two times (less frequent or incorrect alternatives). If a word accrues frequency as a direct function of the number of times it is presented, the relative frequency difference between correct and incorrect alternatives should remain constant over trials, and, according to the relative hypothesis, there should be no improvement in frequency discrimination over trials. Consider, for example, a test trial pair in which the correct alternative occurred once. After the first trial, the frequency ratio of correct to incorrect alternatives is 3:1, and on succeeding trials it becomes 6:2, 9:3, etc. The relative difference in frequency remains the same, and, hence, there should be no improvement in frequency discrimination over trials, even though the absolute frequency difference increases from trial to trial.

An important consideration in the above analysis is that only study trial frequency is tabulated and test trial frequency is ignored. An account of the effect of the test trial on later responding would be dependent on a number of different factors, and it is not at all clear that including test trial frequencies would lead to a prediction of improvement in performance. In any case, it is recognized that the lack of knowledge of test trial effects in the present situation does create some ambiguity in the interpretation of the results of the present study.

The variation in presentation rate was also designed to provide a means of increasing the absolute frequency level of the alternatives. Assuming that *S*s use the additional time provided by the slower presentation rate for rehearsal of the presented word, the absolute frequency difference between words presented at the slower rate would be higher than the frequency difference between words presented at the faster rate. However, the relative frequency difference would be the same for words presented at the two rates of presentation. Hence, the absolute hypothesis would predict better performance at the slow rate, while the relative difference hypothesis would predict no difference in performance.

The underlining manipulation was introduced in order to determine whether providing a cue in addition to frequency on study trials would facilitate frequency discrimination and whether the addition of such a cue would produce improvement in performance over trials. It has been suggested that in the verbal discrimination task *S*s "tag" the correct alternatives, and it is this "tagging" process that produces verbal discrimination learning (Eberlein & Raskin, 1968; Kausler & Boka, 1968). In the present study, underlining would provide such a tag which might function as an associated discriminative cue for the correct alternative. Assuming that associations between correct words and the underlining cue would develop over trials, it follows that underlining should interact with trials, with performance improving over trials in the underlining conditions but not in the no-underlining condition.

In terms of frequency theory, underlining could induce increased attention to and rehearsal of underlined words, thus producing additional frequency counts for the correct words. This would lead to a greater absolute and relative frequency difference between correct and incorrect alternatives in the underlining conditions, and better frequency discrimination. However, the relative frequency difference would remain constant over trials, and, according to the relative hypothesis, frequency discrimination should not improve over trials in the underlining conditions even though the absolute frequency difference would be increasing.

The slower presentation rate would provide more of an opportunity for rehearsal of underlined words, so that underlining would facilitate performance more at the slow rate than at the fast rate of presentation. Since *S*s were required to verbalize each item as it was presented on study trials, the 1-sec. rate would likely preclude a significant amount of additional rehearsal in the underlining conditions. Hence, frequency theory would predict an interaction between rate of presentation and underlining such that underlining would have less of an effect at the fast presentation rate. However, even at the fast rate, associations between correct words and underlining cue would develop over trials. A consideration of underlining as providing an associated discriminative cue would lead to the prediction of a facilitative effect of underlining even at the fast presentation rate.

Method

Materials.—A total of 36 four- and five-letter high-frequency nouns (A and AA Thorndike-Lorge frequency count) were selected as experimental items. Interitem associations were minimized. Eighteen words were randomly selected to be correct items, i.e., the more frequently occurring alternatives of test trial pairs, and 18 were selected as incorrect items, or less frequently occurring alternatives of test trial pairs. Correct items occurred two, three, or four times on each study trial, and incorrect items occurred zero, one, or two times. The design for the frequency manipulation was a 3 × 3 factorial with two correct and two incorrect items in each of the nine cells. Ten additional words served as primacy and recency buffers, with 4 of the words presented at the beginning and 6 at the end of the list. Thus, there were 82 items on each study trial. Across 3 between-*S* replications of the list, each correct and incorrect item occurred at each of the 3 appropriate frequency levels. Within each list, repetitions of the same word were separated by an average of 9 other words (range from 7 to 12). Three random orders of each list were constructed with the restriction that the above-mentioned separation for repetitions of the same word was maintained. In addition to the inclusion of buffer items, primacy and recency effects were controlled in the random orders by counterbalancing the initial occurrence of half of the words at each frequency level and the final occurrence of the other half of the words at each frequency level. By necessity, this procedure resulted in words of high frequency levels occurring more often in the middle of the list.

Each of the 18 test trial pairs consisted of a correct and an incorrect item. There were three different random orders of test trial pairs. Correct items were paired with different incorrect items of the appropriate frequency level in each random order, so that each incorrect item at a given frequency was paired with correct items of each frequency level.

Procedure.—Study trial items and test trial pairs were presented individually on a memory drum. Study trial presentation was at either a 1-sec. or a 2-sec. rate for different groups of *S*s, and test trial pairs were presented at a 2-sec. rate. There was a 4-sec. interval between successive study and test trials. For *S*s in one condition, the correct words were underlined on their first occurrence on study trials (U_1). In another condition each occurrence of the correct item was underlined (U_2), while in a third condition there was no underlining (U_0).

The *S*s were required to pronounce each item aloud when it was presented on study trials. They were informed that words would occur with varying frequency on study trials and that on test trials they were to select the most frequently occurring member of each pair and pronounce it aloud. The *S*s in the underlining conditions were informed that the words which would be the most frequently occurring alternatives of test trial pairs would be underlined either on their first occurrence or on each occurrence of the word. Each *S* was run individually for eight study-test trials on the same list, with the start order for each *S* being randomly determined.

Ninety introductory psychology students served as *S*s. Fifteen *S*s were assigned in randomized blocks of 6 to each of the six presentation rates by underlining conditions, with 5 *S*s in each condition receiving each list replication.

Results

The basic data subjected to analysis of variance were the number of correct identifications of the more frequent alternative, which could range from zero to two for each condition for each *S*. For ease of interpretation and comparison with other studies, the data will be presented as percent correct responses. The analysis revealed that the replications effect and several interactions involving replications were significant. Inspection of the data for each replication, however, indicated that the significant effects reported below were consistently replicated and that the significant interactions with replications stemmed from differences in the magnitude rather than the direction of the effects of the major experimental variables.

The main effects of rate of presentation, $F\ (1,\ 72) = 8.10$, $p < .005$, and underlining, $F\ (2,\ 72) = 23.16$, $p < .001$, were significant, with better performance at the slow presentation rate and in the conditions in which the correct alternative was underlined on study trials. Percent correct at the 1-sec. presentation rate were 73, 80, and 84 for U_0, U_1, and U_2, respectively, while the corresponding values for the 2-sec. presentation rate were 74, 86, and 91. The Rate × Underlining interaction was not significant, $F\ (2,\ 72) = 1.31$, although it is apparent that rate of presentation had little if any effect in U_0.

Table 1 contains the percent correct responses collapsed over the eight trials as a function of frequency of correct and incorrect alternatives for each of the underlining conditions. Frequency of correct, $F\ (2,\ 144) = 15.86$, frequency of incorrect, $F\ (2,\ 144) = 91.19$, and their interaction, $F\ (4,\ 288) = 7.90$, all ps $< .001$, were all highly significant. Since the triple interaction of underlining with frequency correct

TABLE 1

PERCENT CORRECT RESPONSES AS A FUNCTION OF FREQUENCY OF CORRECT AND INCORRECT ALTERNATIVES AND UNDERLINING

Frequency incorrect	U_0				U_1				U_2			
	Frequency correct											
	2	3	4	$\bar{X}$	2	3	4	$\bar{X}$	2	3	4	$\bar{X}$
0	87	83	90	86	92	91	94	92	92	92	95	93
1	68	74	80	74	80	83	86	82	86	86	88	86
2	50	62	65	59	66	77	73	72	78	86	84	82
$\bar{X}$	68	72	78	73	80	84	84	82	85	88	88	87

and frequency incorrect was not significant, and since the effect of frequency per se should be most clearly represented in the no-underlining condition, the results of the frequency manipulation may best be viewed in the no-underlining section of Table 1. As can be seen, the effect of frequency correct increases with increasing frequency incorrect, and, conversely, the effect of frequency incorrect decreases with increasing frequency correct. A comparison of the cells on the left-to-right diagonals, where the absolute differences between frequency of correct and incorrect alternatives are the same (e.g., the 2-0, 3-1, and 4-2 cells), reveals decreasing percent correct identifications with decreasing relative differences in frequency between correct and incorrect alternatives, even though the absolute differences remain the same. In addition, a comparison of the cells with the same relative frequency difference but different absolute frequency differences (Cells 2-1 and 4-2) reveals very similar percent correct identification, 68% versus 65%. In general, the no-underlining condition supports the hypothesis that frequency discrimination is based on relative rather than absolute frequency differences between the alternatives. This holds over a considerable frequency range since the cumulative frequency of presentation over the eight study trials was as high as 32 for correct alternatives and 16 for incorrect alternatives. It is of interest to note that in the cell where frequency of correct and incorrect alternatives was identical (2-2), the percent correct responses was exactly 50%, which was the expectation, assuming that *S*s were using only frequency cues. There is one slight reversal in the 3-0 cell where the 83% correct is lower than the 87% correct in the 2-0 cell, when it should have been higher. Other than that, the data are very consistent with the relative frequency discrimination hypothesis.

Turning to the effects of underlining in Table 1, there was a significant Frequency Incorrect × Underlining interaction, F (4, 144) = 6.29, $p < .001$. As can be seen in Table 1, the effect of frequency of incorrect alternatives was considerably reduced by underlining the correct alternative on study trials. Viewed in another way, underlining had its major effect in more difficult discriminations, i.e., with higher frequencies of incorrect. The Frequency Correct × Underlining interaction was not significant, F (4, 144) = 1.68.

Percent correct responses are plotted in Fig. 1 as a function of trials and underlining. The main effects of trials, F (7, 504) = 3.16, $p < .005$, and, more importantly, the Trials × Underlining interaction, F (14, 504) = 2.89, $p < .001$, were both significant. On the first trial, the effect of underlining was small and nonsignificant,

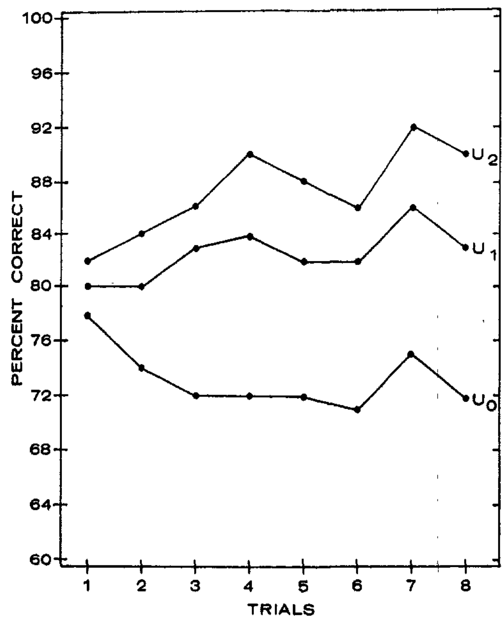

FIG. 1. Percent correct identifications as a function of underlining and trials.

but over trials, the curves for the underlining and no-underlining conditions diverge. Analyses of the simple main effects of trials for each underlining condition indicated significant improvement in performance over trials for U_2, $p < .001$, no significant trials effect for U_1, and a marginally significant decrease in performance over trials for U_0, $p < .05$. The decrement in correct frequency discrimination for U_0 occurred on the first three trials, with performance being relatively stable thereafter. The high points in the curves at Trials 4 and 7 are probably attributable to the reoccurrence of the first trial ordering and pairings.

The Trials × Frequency of Incorrect Alternatives interaction, F (14, 1008) = 1.87, $p < .05$, was marginally significant, as was the Trials × Frequency Correct interaction, F (14, 1008) = 1.83, $p < .05$. In general, these interactions reflect the fact that performance improved over trials only when the discrimination was relatively difficult, i.e., when frequency correct was low and frequency incorrect was high. Although the triple interaction of frequency correct or of frequency incorrect with underlining and trials was not significant, it was apparent from inspection of the curves that any improvement in performance was restricted to the conditions in which the correct alternative was underlined, U_1 and U_2; in no case was there any improvement in performance in U_0.

Discussion

It is clear from the present data that discrimination was based on relative rather than absolute frequency differences between items. That is, discrimination was a function of the ratio of the frequency of correct to the frequency of incorrect alternatives rather than being a function of the absolute differences in frequency between correct and incorrect alternatives.

There were three specific comparisons of differential predictions made by the relative and absolute frequency difference hypotheses. All of these involved the U_0 condition in which frequency was the only appropriate discriminative cue. First, when absolute frequency differences were held constant but relative frequency differences varied (Cells 2-0, 3-1, and 4-2), percent correct responses varied directly with the relative frequency difference between alternatives. When relative differences were held constant and absolute differences varied (Cells 2-1 and 4-2), performance was virtually identical. Second, the failure to find an effect of rate of presentation in the U_0 condition supported the relative hypothesis. Under the assumption that there was more rehearsal of the presented word at the slow rate than at the fast rate, absolute frequency differences would be greater at the slow rate than at the fast rate, although the relative frequency differences would be the same. Note also that this result was contrary to the total-time hypothesis, which, like the absolute-difference hypothesis, asserts that the amount learned is a direct function of study time (Cooper & Pantle, 1967).

The third source of evidence for the relative hypothesis was the lack of improvement in performance over trials. Assuming that study trial frequencies accumulate over trials, the absolute frequency differences would increase over trails, while the relative frequency differences would remain constant. Thus, the absolute hypothesis would predict improvement in performance, while the relative hypothesis would predict no change in performance over trials.

It should again be emphasized that only study trial frequencies were considered in the preceding discussion, and test trial frequencies were ignored. This does not imply that test trial frequencies have no effect (Underwood & Freund, 1970b), but it is not clear what effect test trial frequencies would have in the present situation. Assuming that test trial frequencies were not discriminably different from study trial frequencies and that additional frequency accrued to the alternative which was selected and verbalized, test trial frequencies should have progressively enhanced the absolute frequency difference between alternatives. When relative frequency differences are considered, however, the effect of the test trial would depend on the frequency accruing on test trials as compared with study trials, and on the relative frequency difference between alternatives on test trials as compared with study trials. If the test trial relative difference were greater than the study trial relative difference, discrimination would be facilitated; if less than, discrimination would be hindered; and if equal relative frequency differences occurred on study and test trials, performance would not change as a function of test trial frequency. Considering relative frequency differences, it is not at all clear that a consideration of test trial frequencies would lead to a prediction of improvement in performance over trials.

In actuality, there was a slight, but significant decrease in frequency discrimination for U_0 over the first three trials. This may have been due to the fact that over test trials, incorrect alternatives of a given frequency level were paired with correct alternatives of each frequency level. An incorrect alternative of Frequency Level 2, for example, occurred with correct alternatives of Frequency Levels 2, 3, and 4 within a block of three test trials. When an incorrect alternative was in the 2-2 cell, the probability was .50 that it would be erroneously selected and verbalized. On the next trial, when that incorrect alternative would have been in the 3-2 or 4-2 cells, it may more likely have elicited an erroneous response than the incorrect alternatives in the 3-2 or 4-2 cells on the first trial. Tracing incorrect alternatives in a Trial × Trial conditional probability analysis did reveal that an error following an error was more likely than an error following a correct response on test trial items involving the same incorrect alternative, especially for twice-occurring incorrect alternatives.

Underwood and Freund (1970a) have suggested that as the cumulative frequency of incorrect alternatives increases, frequency discrimination becomes more difficult. The increase in cumulative frequency of incorrect alternatives over the first three trials may also account for the initial drop in discrimination over trials. However, Underwood and Freund (1970a) found that with frequency of incorrect levels over three, discrimination was degraded to essentially a chance level. In the present data, cumulative frequencies of incorrect over trials were well above the frequencies investigated by Underwood and Freund (1970a), but discrimination remained at a fairly high level as long as the relative frequency differences between alternatives were maintained. Underwood and Freund (1970a) controlled absolute rather than relative frequency differences, and as the frequency incorrect increased, the relative frequency differences decreased. This may well be the reason for their finding such poor discrimination at higher levels of frequency of incorrect. Also, their frequency discrimination data were markedly variable, whereas the present data, like those of Hintzman (1969), were much less variable and were very consistent with the relative frequency discrimination hypothesis.

Underlining the correct alternative on study trials did increase frequency discrimination on test trials. Providing the additional discriminative cue may either have increased rehearsal of the underlined words, thus increasing the relative frequency difference between correct and incorrect alternatives, or it may have served as an associatively learned discriminative cue which, if recalled, would facilitate discrimination. The latter explanation seems most appropriate for two reasons. First, the Underlining × Trials interaction, which indicated improvement over trials for the underlining conditions but no improvement for U_0, supported the associative cue explanation. As already indicated, *S*s appear to respond to relative frequency differences, and it can be demonstrated that even if underlining produced additional rehearsal of correct alternatives, the relative frequency difference between correct and incorrect alternatives should not increase over trials. Second, there was no significant interaction between underlining and rate of presentation. Although not as pronounced as at the slow rate, there was a significant improvement as a function of underlining at the 1-sec. presentation rate. While the time demands were not so great that *S*s had to strain to pronounce the words at the 1-sec. rate, they paced their verbalization so as to effectively fill the 1-sec. intervals, precluding any significant amount of additional rehearsal. Therefore, there would have been little accrual of additional frequency, and, on the basis of frequency theory, there should have been little or no improvement in performance. For these reasons it is suggested that underlining provided an associated discriminative cue which was learned over trials, enhanced discriminability, and produced improvement in discrimination over trials.

These results also have some implications for the frequency theory of verbal discrimination learning (Ekstrand et al., 1966). Ekstand et al. substantiated that *S*s can make fairly accurate discriminations based on situational frequency and that *S*s do discriminate on the basis of relative frequency differences. However, the failure to find improvement over trials in the U_0 condition together with the improvement in performance for the underlining conditions suggest that some associative mechanism may also be functioning to produce improvement in performance in the verbal discrimination situation. Underlining, or the raising of the shutter of a memory drum are frequently used feedback devices to indicate the correct response in verbal discriminative learning. These may be learned as associated discriminative cues and may account for the demonstrated improvement in performance over trials in the verbal discrimination situation.

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