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Wayne A. Wickelgren

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SHORT-TERM MEMORY FOR PHONEMICALLY SIMILAR LISTS

By WAYNE A. WICKELGREN, Massachusetts Institute of Technology

A number of recent studies indicate that short-term memory for letters, digits, and words uses an auditory or speech-motor code. Conrad and Wickelgren have shown that errors in short-term recall of verbal lists tend to have a vowel or consonant phoneme in common with the correct item.[1] Perceptual errors were eliminated from these data by slow visual presentation or scoring of only items copied correctly during presentation. Proactive and retroactive interference in short-term recall are greater for interference lists consisting of letters that have a vowel phoneme in common with the correct letter(s) in the original list than for interference letters that have no phoneme in common with the correct letter(s).[2] Finally, lists of letters that are often confused with each other in auditory recognition are more difficult to recall than lists of letters that are rarely confused with each other in auditory recognition.[3] The former letters tend to have phonemes in common, while the latter letters tend to have no common phonemes.

If short-term memory is associative and verbal items are coded in short-term memory as sequences of phonemes, then the topological structure of the associations should be very different for lists of phonemically similar items than for lists of phonemically different items. Consider the list DZGBP as opposed to the list DQJYF. The first list consists of letters, all of which contain the vowel phoneme 'ē'; the second list has no cases of letters with common phonemes. Fig. 1 describes what one phonemic-associative theory of short-term memory would predict concerning the direct phoneme-to-phoneme associations formed during presentation of each of these two lists. The only associations shown in Fig. 1 are the forward and backward intra-item associations and the forward 'direct' associations between the vowels

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[1] R. Conrad, Acoustic confusions in immediate memory, *Brit. J. Psychol.*, 55, 1964, 75-84; W. A. Wickelgren, Acoustic similarity and intrusion errors in short-term memory, *J. exp. Psychol.*, 70, 1965, 102-108.

[2] Wickelgren, Phonemic similarity and interference in short-term memory for single letters, *J. exp. Psychol.* in press; Acoustic similarity and retroactive interference in short-term memory, *J. verb. Learn. verb. Behav.*, 4, 1965, 53-61.

[3] R. Conrad, and A. J. Hull, Information, acoustic confusion and memory span, *Brit. J. Psychol.*, 55, 1964, 429-432.

and consonants of adjacent items. Many important associations have been omitted to reduce the complexity of the diagrams. Associations between serial position concepts (such as 'beginning,' 'middle,' and 'end') and phonemes have been omitted because there is no reason to suppose the structure of these associations is different in any important way for the two lists. Backward and remote inter-item associations are presumed to be weaker, on the average, than the more direct associations shown in Fig. 1, but they should be considered as competing associations which are some-

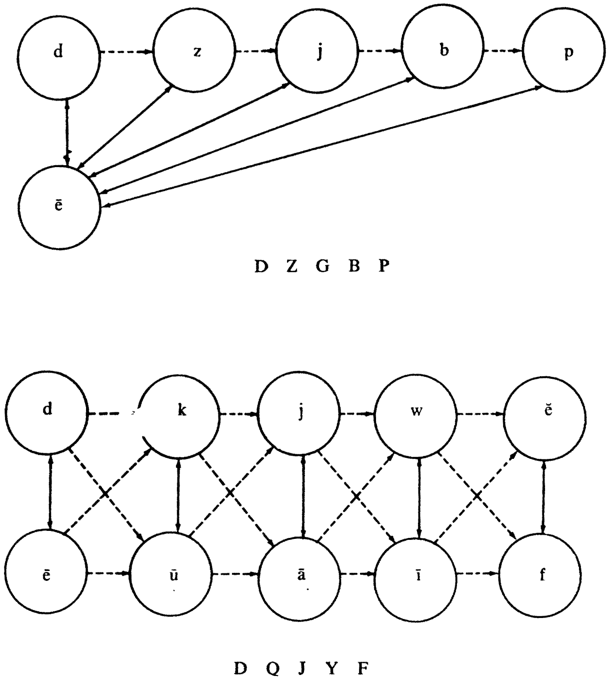

FIG. 1. PHONEMIC-ASSOCIATIVE THEORY OF SHORT-TERM MEMORY
Long-term intra-item associations between the consonant and vowel composing a letter are indicated by solid lines. Short-term associations are indicated by dashed lines.

times stronger than the direct associations because of differences in recency, amount of rehearsal, or degree of unconscious 'consolidation.'

The difference in topological structure of the associative network for the two lists is obvious. The memory-trace for ordered recall is much better replicated in the case of phonemically different lists than in the case of phonemically similar lists. In the simplified model described in Fig. 1, there are four associations between the representatives of adjacent letters to carry the trace for ordered recall of the phonemically different list and only one association (between adjacent consonants) to carry the trace for ordered recall of the phonemically similar list. Free recall of the phonemically similar list should not be at such a disadvantage. In fact, one might well argue that free recall of items should be better for phonemically similar lists since the 'ē' phoneme is certain to be recalled and direct associations exist from the representative of the 'ē' phoneme to the representatives of all the consonant phonemes in the list. If competition of response blocks recall of the consonants whose associations to the representative of the 'ē' phoneme are weakest, then free recall of phonemically similar lists might be poorer than free recall of phonemically different lists. But if competition of response does not prevent recall of the consonants whose associations to the representative of the 'ē' phoneme are weakest, then we might expect more items to be recalled from phonemically similar lists, though often in the wrong positions.

Conrad and Hull's study of short-term memory for acoustically similar lists did not analyze recall separately for recall of items and recall of position.[4] If the phonemic-associative theory just described is correct, then the superior ordered recall of phonemically different items should be reflected primarily in better recall of the position of an item. The number of items recalled, irrespective of position, should be less affected by phonemic similarity and might show a reversed effect.

The following two experiments were designed to test the above predictions using lists of letters and lists of consonant-vowel diagrams (*e.g.* fā, tā, kā, gā, dā, vā, bā, or fā, lē, mī, vō, nōō, zī, dē). In the latter case, only the initial consonant of each diagram was to be recalled, so there was no difference in the number of different phonemes to be recalled. Also, with diagrams there can be no cognitive strategies based on long-term associations between the consonant and vowel phonemes composing a letter.

Experiment I

Procedure. Presentation was auditory, and the entire experiment was recorded on tape. Subjects listened to a 'ready' signal followed after 1 sec. by a list of nine letters presented at the rate of three letters per sec., followed immediately by an attempt to recall the letters in the correct order (by filling-in nine boxes). Twenty seconds were allotted to recall, followed immediately by the next trial.

Design. Eight types of lists were used in the experiment. Each *S* was given every type of list, randomly ordered in 12 blocks of eight, for a total of 96 lists. All lists were 9 letters long, but ony 4 or 6 of these letters were different. Lists, however, were so constructed that there were no runs of two adjacent identical letters. The types of lists were as follows: (Pure ā—4) Random list of 'ā' letters (A, H, J, K) using each of the four letters at least once. (Pure ĕ—4) Random list using four 'ĕ' letters (selected from F, L, M, N, S, X), with the same repetition structure as the ā—4 list in the same block of eight lists. For example, if the ā—4 list was HAHJKAHJA, then the ĕ—4 list might be MSMLFSMLS. (Pure ē—4) Random list using four 'ē' letters (B, C, D, E, G, P, T, V, Z), with the same repetition structure as the ā—4 list in the same block. (Mixed ā, ĕ, ē—4) Random list using four different letters, at least one of each of the three types, with the

[4] Conrad and Hull, *op. cit.*, 429-432.

same repetition structure as the ā—4 list in the same block. (Pure ĕ—6) Random list using the six different 'ĕ' letters. (Pure ē—6) Random list using six 'ē' letters, with the same repetition structure as the ĕ—6 list in the block. (Pure ā + ū—6) Random list using six different letters drawn from the 'ā' letters and the 'ū' letters (Q, U, W), with the same repetition structure as the ĕ—6 list in the same block. (Mixed ĕ, ē, ā + ū—6) Random list using six different letters, two from each of the three types, with the same repetition structure as the ĕ—6 list in the block. The purpose of this design is to permit comparison of pure and mixed lists without confounding by differences in the difficulty of different letters or differences in the repetition structure of the lists.

Subjects. The *S*s were 31 undergraduates in psychology who participated in the experiment as a part of their course requirements. They were used in two approximately equal groups.

Results. Each *S*'s data for each condition were analyzed for ordered recall, item-recall, and position-recall for items (letters). An *S*'s report of an item is correct by an ordered recall criterion if and only if the correct item is recalled in the correct position. An *S*'s report of an item is correct by an item-recall criterion if and only if it appears anywhere in his report of the list in question. The ordered and item-recall error rates for a condition for an *S* are the ratio of the ordered or item-recall errors, respectively, to the total number of opportunities for error. Position-recall, independent of item-recall, is obtained by subtracting the item-recall errors from the ordered recall errors, reducing the total number of possible errors by the number of item-recall errors when computing the error rate for position-recall. Item-recall and position-recall are statistically independent, and ordered recall reflects the combined operation of the recall of items and the recall of the correct position for items. Ordered recall is not statistically independent of item-recall, and therefore, is not as suitable for the assessment of the recall of order as is position-recall. Position-recall is statistically independent of item-recall because only the items that are correct by an item-recall criterion are scored for position-recall.

When any two conditions are compared by any of the three measures of recall, the error rate in each condition for each *S* is computed and one is subtracted from the other to give a difference score favoring one condition or the other. Superiority of one condition over the other is determined by applying the Wilcoxon Matched-Pairs Signed-Ranks test to the 31 difference scores.

The error-rates for ordered recall, item-recall, and position-recall in each type of list are reported in Table I. The error-rates for ordered recall were significantly greater in pure lists than in mixed lists, replicating the results obtained by Conrad and Hull.[5] Exactly as predicted by the phonemic-associative theory, this difference resulted entirely from significantly greater error in the recall of position in the pure lists. Errors in item-recall showed small conflicting differences and were not significantly different overall.

Lists with only four different letters (and therefore more repetition of letters) were remembered better than lists with six different letters; the difference between reflected primarily in item-recall rather than position-recall. Error rates were significantly lower in ĕ—4 and ē—4

TABLE I

Error Rates (%) in Experiment I

List type	Ordered-recall	Item-recall	Position-recall
Pure ā—4	38.4	18.2	24.7
Pure ĕ—4	48.4	23.2	32.9
Pure ē—4	53.2	26.7	36.2
Total pure—4	46.7 †	22.7 *	31.0 †
Mixed ā, ĕ, ē—4	39.7	24.6	20.1
Pure ĕ—6	53.1	27.4	35.4
Pure ē—6	56.2	33.0	34.6
Pure ā+ū—6	44.3	25.2	25.5
Total pure—6	51.2 †	28.5 *	31.7 †
Mixed ĕ, ē, ā+ū—6	40.8	26.3	19.7
Total pure	49.0 †	25.6	31.4 †
Total mixed	40.2	25.5	19.9

* $p<0.05$ † $p<0.001$.

than in ĕ—6 and ē—6 in ordered recall ($p < 0.001$) and item-recall ($p < 0.001$), but there was no significant difference in position-recall.

Finally, there were some large differences between different types of letters; 'ā' letters were remembered better than 'ĕ' letters which were remembered better than 'ē' letters. With one insignificant exception, the relationship between the types of letters was the same for ordered recall, item-recall, and position-recall. Explanation of these differences between types of letters is beyond the scope of the study.

Experiment II

Procedure. Presentation was auditory and recorded on tape. The *S*s listened to a 'ready' signal, followed after 1 sec. by seven consonant-vowel (CV) diagrams presented at the rate of two diagrams per sec., followed immediately by an attempt to recall the consonants of the diagrams in the correct order (by filling-in seven boxes). Sixteen seconds were allotted to recall, followed immediately by the next trial.

[5] Conrad and Hull, *op. cit.*, 429-432.

Design. Six types of lists were used in the experiment. Each *S* was given every type of list, randomly ordered in 10 blocks of 10 lists, for a total of 100 lists. The five 'pure' types of lists occurred once each in a block of 10 and the single 'mixed' type of list occurred 5 times in a block of 10. The 7 different consonants in each list were selected randomly from the following set: b, d, f, g (as in 'go'), k, m, n, p, s, t, v, z. The 6 types of lists were as follows: (Pure ā) All 7 consonants were followed by 'ā' (*e.g.* sā, gā, vā, bā, nā, tā, fā). (Pure ē) All 7 consonants were followed by 'ē'. (Pure ī) All 7 consonants were followed by 'ī'. (Pure ō) All 7 consonants were followed by 'ō'. (Pure ōō) All 7 consonants were followed by 'ōō'. (Mixed) The 7 consonants were followed by one of the 5 vowels, with 3 of the 5 vowels being used once and the other two vowels being used twice in each list of diagrams (*e.g.* fōō, nē, bā, vō, gā, mī, zē).

Subjects. The *S*s were 28 undergraduates in psychology who participated in the experiment as a part of their course requirements. They were used in two approximately equal groups.

Results. The error rates for ordered recall, item-recall, and position-recall in each type of list in Experiment II are reported in Table II. The

TABLE II

ERROR RATES (%) IN EXPERIMENT II

List type	Ordered-recall	Item-recall	Position-recall
Pure ā	49.6	27.3	30.7
Pure ē	50.7	40.6	29.0
Pure ī	53.8	31.0	33.0
Pure ō	50.4	27.9	31.2
Pure ōō	48.2	27.7	28.3
Total pure	50.5 } *	28.9 } †	30.4 } †
Mixed	47.8 }	31.9 }	23.3 }

* $p<0.05$ † $p<0.001$.

over-all ordered recall of pure vs. mixed lists showed a significantly higher error rate in the pure lists ($p < 0.05$). Again, this difference in ordered recall resulted from a significantly higher error rate in position-recall for pure lists ($p < 0.001$), which masked a smaller, but highly significant, difference in the opposite direction for item-recall ($p < 0.001$).

Again there were some differences between different types of pure lists, but the differences were smaller than those in Experiment I. By and large, any difference of 3% or larger in Table II indicates a significant difference at the 0.05 level using the Wilcoxon Matched-Pairs Signed-Ranks test.

Discussion. Both of the present experiments support the phonemic-associative theory of verbal short-term memory. Phonemically similar lists are more difficult to recall in order than phonemically different lists primarily because the items from phonemically similar lists are much more likely to be recalled in the wrong positions than are the items from phonemically different lists. The number of items recalled correctly, irrespective of position, generally shows a small advantage in favor of the phonemically similar lists. The most pronounced dissociation of item-recall and position-recall was obtained in short-term recall of the initial consonant of diagrams. Thus, it is not possible to argue that long-term associations (such as those involved in our knowledge of the phonemic characteristics of letters in the alphabet) are responsible for the superior item recall of phonemically similar lists.

It seems difficult to account for the present findings and previous findings on phonemic similarity without assuming that items are coded in short-term memory as sequences of phonemes, at some level of analysis. Naturally, we cannot say from these data whether the phoneme is the ultimate unit of coding in short-term memory. The results of Miller and Miller and Nicely indicate that in auditory recognition of vowels and consonants there is a level of analysis beyond the phonemic level, namely distinctive feature analysis.[6] It may be that the distinctive feature is also a more basic unit of coding in short-term memory, and perhaps there are levels of analysis even more basic than distinctive features. The present findings indicate only that, whatever the most basic units are, these basic units combine to represent phonemes, which in turn combine to represent letters, digits, words, etc.

It also seems difficult to account for the present findings with a non-associative theory of short-term memory. Non-associative theories of short-term memory are those in which an ordered set of cells (boxes, locations, registers, etc.) are set aside as temporary ('buffer') storage and any item can be encoded into any cell. Ordered recall is possible because a list of items is generally or always stored in the cells in a fixed order and generally or always retrieved from the cells in the same order. To account for the present findings a non-associative theory must make additional assumptions like the following: (1) The correspondence between storage order and retrieval order is poorer for lists with greater phonemic similarity. (2) The rate of trace decay for an item within a cell is slower when phonemically similar items are stored in other cells than when phonemically different items are stored in these other cells. Both assumptions are completely *ad hoc,* and the second assumption seems incompatible with the greater retroactive interference in item-recall produced by phonemically similar interpolated items.[7]

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[6] G. A. Miller, The perception of speech, in *For Roman Jakobson,* 1956, 353-359; G. A. Miller, and P. E. Nicely, An analysis of perceptual confusions among some English consonants, *J. acoust. Soc. Amer.,* 27, 1955, 338-352.

[7] Wickelgren, *op. cit., J. verb. Learn. verb. Behav.,* 53-61; Phonemic similarity and interference in short-term memory for single letters, *J. exp. Psychol.,* in press.

An associative theory of short-term memory requires no additional assumptions to account for the greater interference of similar interpolated items and the greater item-recall in similar lists. Whether the similar items are in the list to be recalled or in an interpolated list, they produce competing responses to the common phonemes. When the comparison is between similar and different *interpolated* items, these competing responses are not correct by an item-recall criterion since they are not in the original list. When the comparison is between similar and different items in the original list, the competing responses are all correct by an item-recall criterion. The present findings indicate that in short-term memory, competing associations to a common phoneme have little tendency to block the weaker associations, so long as one is allowed to recall as many items as there are competing responses. Whatever blocking of weaker associations does exist, its effect on item-recall is generally less than the advantage of having a cue that is associated to all the correct responses.

SUMMARY

In the first experiment 31 *S*s attempted ordered recall of two types of 9 letter lists: phonemically similar lists in which all letters had a common vowel phoneme (ā, ē, or ĕ) and phonemically different lists whose letters had no common phoneme. Ordered recall was poorer for similar lists ($p < 0.001$), but this resulted entirely from poorer recall of the position of similar letters ($p < 0.001$). Item-recall, by a free recall criterion, was not significantly different for the two types of lists. In the second experiment 28 *S*s attempted ordered recall of the consonants only, from two types of lists of seven consonant-vowel diagrams: phonemically similar lists in which the vowel was identical for all seven diagrams (ā, ē, ī, ō, o͞o) and phonemically different lists whose seven vowels were a mixture of the above five vowels. Position-recall was significantly poorer for phonemically similar lists ($p < 0.001$), but item-recall was significantly better for similar lists ($p < 0.001$).