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REHEARSAL GROUPING AND HIERARCHICAL ORGANIZATION OF SERIAL POSITION CUES IN SHORT-TERM MEMORY

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Lists of 8, 9, or 10 digits were presented at the rate of 1 digit/sec. to subjects instructed to rehearse silently the digits in non-overlapping groups of 1, 2, 3, 4, or 5 digits, after hearing each digit. Subjects were instructed not to rehearse any digits outside the group currently being presented. Rehearsing in 3's was optimal, irrespective of list length. Both recall of items and recall of the correct positions of items improved from 1's to 2's to 3's. Recall of items declined very little from 3's to 4's to 5's, but recall of position declined sharply. Errors in positioning digits tended, above chance, to be in the same group or the same position in a different group. The results suggest that both item-to-item associations and serial position-to-item associations are formed in short-term memory, that only two or three serial position cues are used, but that these serial position cues can be hierarchically organized into a beginning, middle, and end group and a beginning, middle, and end position within a group.

INTRODUCTION

What is learned by a subject who is presented with a list of items depends, in the final analysis, upon what he thinks about during presentation of the list, that is, upon what internal representatives are activated in what sequence. If the items in the list are highly intelligible, the list not too long, the subject co-operative, and instructed to attend to each item, it is reasonable to suppose that the internal representative of each item of the list is activated at about the time it is presented. If the rate is fast enough (2 to 4 syllables a sec. or faster), this is very likely to be close to all that is activated, and in such cases the analysis of learning is vastly simplified (e.g. Wickelgren and Norman, 1966; Wickelgren, 1967), though we are still far from a complete understanding of acquisition, storage, and retrieval even in these "simple" situations.

However, when the list is presented at slower rates (1 syllable a sec. or slower), it is introspectively clear that internal representatives are activated which do not correspond to items in the list (partly by association to the internal representatives of one or more items on the list) and, furthermore, the internal representatives of previous items on the list are activated *after* one or more subsequent items have been presented (i.e. more than the present item is rehearsed). Under these circumstances, the analysis of what is learned (what associations are strengthened) is a very difficult problem.

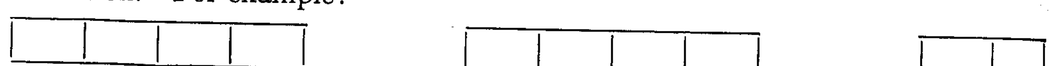
One way to attack the problem is to attempt to control, by instruction, the active rehearsal process. If the instructional manipulation is effective, there should be differences in the rates and types of errors among groups instructed to rehearse in different ways. Furthermore, the exact nature of these performance differences should indicate some characteristics of man's active rehearsal and recoding capacities in list-learning tasks.

The present study is directed to one dimension of rehearsal strategy, namely, the size of the groups in which the subject rehearses a list. The concern is not with determining what grouping methods subjects will choose, but rather with the consequences for performance of adopting different grouping methods. The study is restricted to the rehearsal of non-overlapping groups of different size. This means that a subject is instructed to rehearse, after each item is presented, all previously presented items of the group to which the present item belongs. Furthermore, he is explicitly instructed not to rehearse items from any other group. Thus, if a subject is rehearsing in 4's, after hearing the eighth digit of a list of 10 digits, he is to rehearse the fifth through eighth items of the list in order and no other items. When the ninth item is presented, he is to rehearse only that item (because now he is starting on the third group).

Under ordinary circumstances when one says that he is grouping in 4's, he does not mean that he follows this rigid method of rehearsal. He means that he "thinks" of the list in groups of four items each (four, four, and two in the case of a list of 10 items). Under ordinary circumstances subjects rehearsing in 4's would not refrain from rehearsing a previous group while being presented with the second group, nor is there any reason to think this would be desirable for memory performance. However, it is very desirable for ease of theoretical analysis to control as carefully as possible the exact method of rehearsal, and this is the reason for doing it. Instructing a subject to rehearse in non-overlapping groups of four items induces a subject to "think" of the list in groups of four, whatever that might mean, and also provides explicit instruction regarding what is to be rehearsed at each moment. The hope is that the analysis of performance under different rehearsal instructions will suggest what it means to "think" of a list in groups of four.

The present study is a replication, under slightly different conditions, of a previous study (Wickelgren, 1964) which demonstrated the following: (*a*) the probability of correct ordered recall is greater for grouping in 3's than for grouping in 1's, 2's, 4's, or 5's; (*b*) while the increase in correct performance from 1's or 2's to 3's is in both recall of items and recall of the correct position of the item in the list, the decrease from 3's to 4's and 5's is primarily in recall of the correct position of items, not the recall of items; and (*c*) errors in positioning items tend, beyond chance, to be in the same group or in the same position of a different group. The results were interpreted as indicating that subjects form associations from serial position cues (such as "beginning," "middle," and "end") to items and that these serial position cues can be hierarchically organized into a beginning, middle and end group, and a beginning, middle and end position within a group.

In the previous experiment, each subject was run in only two different rehearsal conditions (first half of the session in one condition, second half in the other), for fear that subjects could not rapidly switch from one rehearsal strategy to another. In the present study, each subject was run under all rehearsal instructions, with the rehearsal method changing every five trials. To facilitate the shift, the boxes in which a subject wrote his answers were grouped in correspondence with the rehearsal instruction. For example:



In the previous experiment, subjects were run on a small number of trials with all list lengths from 6 to 10 digits. It was not possible to analyse the results separately ach list length. In the present experiment, separate experiments were done list lengths of 8, 9, and 10 digits to determine whether the conclusions of the ous study held for each list length or whether there was an interaction between ial group size and list length. For example, it seems "natural" to group a f eight items into two groups of four, a list of nine items into three groups of , etc.

Method

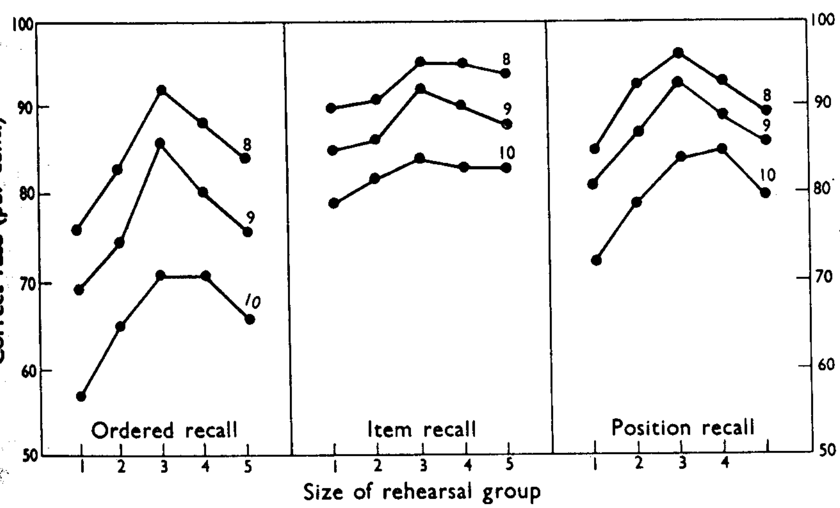
n each trial a subject got a ready signal, followed in about half a sec. by a list of or 10 digits presented at the rate of 1 digit/sec., followed by 10 sec. in which to the list in order by filling in boxes on an answer sheet. There were three experiments, ing lists of 8 digits, one using lists of 9 digits, and one using lists of 10 digits. were no digits repeated in any list, so the lists of 10 are essentially permutations o 10 digits, 0–9. Within each experiment, subjects used each of the five different ing methods (rehearsing in 1's, 2's, 3's, 4's, or 5's), changing the grouping method five trials. In every 25 trials subjects used each of the grouping methods once for ials in a block, with the order of the grouping methods randomized. Furthermore, bjects in each experiment were divided roughly in half and one half had the order grouping methods exactly reversed from the other half.

bjects were M.I.T. undergraduates taking psychology courses, who participated in xperiment as part of their course requirements; 23 took the length-8 lists, 24 the th-9 lists, and 30 the length-10 lists.

Results

The data were analysed for ordered recall, item recall, and position recall of idual items in the list. An item is correct by an ordered recall criterion if it rs in the correct box on the answer sheet. An item is correct by an item recall ion if it appears in any box on the answer sheet. The correct position recall s obtained by dividing the number of items correct by an ordered-recall ion by the number of items correct by an item-recall criterion. Thus, item and position recall are statistically independent, and ordered recall combines two factors into an overall score. This analysis was done separately for each

FIGURE 1



ect of size of rehearsal group on ordered recall, item recall, and position recall, for f 8, 9, and 10 digits.

subject for each rehearsal grouping method to permit comparison of performance under different grouping methods by the Wilcoxon Matched-Pairs Signed-Ranks test.

The average probabilities of correct ordered, item, and position recall for each rehearsal grouping method for each list length are shown in Figure 1. The results agree in almost every detail with the previous study (Wickelgren, 1964). Furthermore, the efficacy of different grouping methods is remarkably invariant over different list lengths. Rehearsing in 3's is optimal regardless of list length, although it is no better than 4's for length-10 lists. Accuracy in both item and position recall increases from 1's to 2's to 3's for all three list lengths. Accuracy in position recall then declines from 3's to 4's to 5's for all list lengths, with one small reversal at length-10. However, item recall remains roughly constant from 3's to 4's to 5's for lengths 8 and 10, and declines slightly for length 9.

By the Wilcoxon test, R1 < R2 in ordered recall ($p < 0{\cdot}01$ for all three list lengths), in item recall (correct direction but insignificant for all three lengths), and in position recall ($p < 0{\cdot}01$ for all three lengths). R2 < R3 in ordered recall ($p < 0{\cdot}01$ for all three lengths), in item recall ($p < 0{\cdot}01$ for all three list lengths), and in position recall ($p < 0{\cdot}01$, 0·01, and 0·05 for lengths 8, 9, and 10, respectively). R3 > R4 in ordered recall (0·05, 0·01, and n.s.), item recall (n.s., 0·05, n.s.), and position recall (0·01, 0·01, n.s.). R4 > R5 in ordered recall (0·01, 0·05, 0·05), item recall (n.s., n.s., n.s.), and position recall (0·01, 0·01, 0·05).

To obtain more information about the curvilinear relationship between size of rehearsal group and position recall, every item that was recalled correctly by an item-recall criterion, but recalled in the wrong position, was classified into one of three position-error categories. *Within-group* errors refer to items recalled in the correct group, but at the wrong position within the group. *Within-position* errors refer to items recalled in the wrong group, but in the correct position within the group. *Other* errors refer to items recalled in the wrong group and wrong position within the group.

To obtain an independent measure of the relative frequency of within-group and within-position errors for Conditions R2, R3, R4, and R5, the frequency of each type of error was compared to the frequency of all *other* errors. In order to determine if the relative frequency of within-group or within-position errors was affected by rehearsal group size, it was necessary to compare the relative frequency of each type of error in any rehearsal condition to the same relative frequency computed for a standard "ungrouped" condition, in this case R1. Computation of the comparable relative frequency in R1 involves breaking R1 into the same groups as in the condition with which it is being compared.

Table I presents the relative frequency of within-group and within-position errors in each condition for each list length and the comparable relative frequency in R1.

For all list lengths and for all rehearsal conditions, there is clearly a tendency for errors to be in the same group or in the same position within a group. As in the previous study, the tendency to make within-group errors increases with the number of positions in a group and the tendency to make within-position errors increases with the number of groups.

The findings of the previous study are completely replicated. Subjects appear to have little difficulty in rapidly changing rehearsal set. Furthermore, there appears to be no significance for memory performance of the greater "naturalness" of dividing a list of eight items into two groups of four or of dividing a list of 10 items into two groups of five.

TABLE I

ERRORS IN POSITIONING ITEMS

Condition	List length	Within-Group/Other		Within-Position/Other	
		Error ratios in R2 to R5	*Comparable error ratio in R1*	*Error ratios in R2 to R5*	*Comparable error ratio in R1*
R2	8	0·66*	0·47	1·19**	0·53
	9	0·49	0·49	1·55**	0·65
	10	0·51	0·46	2·11**	0·81
R3	8	0·71	0·80	0·62	0·22
	9	1·18**	0·93	1·04**	0·37
	10	1·30*	0·88	1·28**	0·39
R4	8	2·19	1·58	0·21	0·12
	9	1·99**	1·40	0·33**	0·20
	10	1·57*	1·11	0·33**	0·19
R5	8	2·99**	1·54	0·12*	0·03
	9	2·02*	1·74	0·19**	0·05
	10	2·96**	1·96	0·25*	0·15

Note. Error ratios in R2 to R5 that are significantly greater than the comparable error ratios in R1 are indicated by asterisks (Wilcoxon Matched-Pairs Signed-Ranks test).

* $p < 0{\cdot}05$.
** $p < 0{\cdot}01$.

DISCUSSION

If item-to-item associations were the only memory traces mediating performance in immediate memory tasks, one would expect performance to improve with increasing size of rehearsal group. This is because the ratio of the number of strengthened item-to-item associations to the number of rehearsed items becomes progressively more favourable with increasing size of rehearsal group. Furthermore, there is no reason to expect significant numbers of within-position errors, if item-to-item associations are the only associations mediating immediate memory performance. Thus, there is reason to believe that serial position-to-item associations are also contributing to correct memory performance in this situation. In addition, it is necessary to assume that these serial position cues can be hierarchically organized into a "beginning," "middle," and "end" group and a "beginning," "middle," and "end" position within a group. Such a theory gives a satisfactory intuitive explanation of why there is an optimum size of rehearsal group. The explanation is as follows: when either the number of positions within a group or the number of groups gets too high, the mapping from serial position cues to items becomes too ambiguous, assuming that humans possess only a finite number of serial position concepts.

Because the optimum rehearsal group size was three in the present experiments, the indicated number of different serial position concepts is in the neighbourhood of three. Because of the possibility of defining one serial position concept (e.g. "middle") by exclusion, the possibility of using remote serial position-to-item associations, and the availability of item-to-item associations, it is at least equally likely that there are only two serial position concepts used by humans in this situation ("beginning" and "end"), as that there are three serial position concepts. A more precise formulation of the theory is needed to settle such a question.

The present results should not be interpreted as indicating that serial position cues are the only cues mediating short-term serial list-learning. The "associative intrusions" found in other studies (Wickelgren, 1965, and 1966) argue strongly for the existence of item-to-item associations. Furthermore, the relatively negligible decline in item recall from 3's to 4's and 5's suggests the existence of a compensating factor which is improving with increasing group size, namely, item-to-item associations. Available evidence indicates that both serial position-to-item associations and item-to-item associations are strengthened by presentation of a list and that both are used in retrieval from short-term memory.

Finally, it is worth noting that the associative-memory conception of serial-position information is completely compatible with the simultaneous use of item-to-item information. Non-associative memories, in which serial position is easily represented by an ordered set of locations, are not very easily adapted to make simultaneous use of item-to-item information.

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