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GROUP STRUCTURE, CODING, AND MEMORY FOR DIGIT SERIES[1]

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Recognition and recall of digit series were studied as a function of segmental groupings imposed on the series either by the location of pauses or in the naming of successive numerical groups, e.g., *1735* was read to *S* as "seventeen, thirty-five." Experiments show that alteration of group structure of the same underlying digit string severely degraded memorial recognition of its repetition and that the normal improvement in immediate recall with repetition was annihilated by changing groupings at each presentation. Although a second presentation of a string with altered groupings is not recognized as a repetition of its earlier occurrence, this event is equivalent to an exact repetition when they are assessed by *S*'s later ability to recognize an ungrouped version of the underlying string. Repetition with the same groupings establishes one strong trace, whereas repetition with changed groupings establishes two weak traces either of which may mediate recognition of the uncoded version of the string. The "reallocation" hypothesis was proposed as a summary of these results, whereby group structure affects perceptual coding, which determines "where" the trace of the event is stored. This was contrasted to a "bin" hypothesis for serial recall. Experiments to differentiate these involved recall of strings in which only a subsequence or portion recurred. As predicted by the reallocation hypothesis, recall of the recurrent constant chunk improved only when it was located at the beginning of the string.

The following experiments concern the relationship between group structure, perceptual coding, and recall and recognition measures of memory for a digit series. A basic strategy that *S*s apparently employ in learning an arbitrary series of symbols is to segment or group successive items into subjective chunks, emphasized perhaps by implicit vocal stress or pausing. With digit series, this segmental parsing may even be reflected in the words *S* uses in representing the series, e.g., the series 37946 might be coded as "thirty-seven, nine hundred forty-six."

Although this segmental coding might be considered to reflect the transfer to digit series of *S*s' habits of performing syntactical parsings of sentences, the division of a digit series into subjective chunks may serve several purposes for the learner. First, the subjective chunks are small (2–4 digits) and are themselves easily learned, so *S*'s task is reduced in part to seriating a smaller number of units than was true before groupings were imposed. Second, the groupings might be imposed in a manner calculated to produce a rhythmic pattern. For example, a series of 10 digits might be so segmented as to produce a repetitive triplet–doublet pattern, such as (xxx́) (xx́), (xxx́) (xx́),

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where accent marks are placed over vocally stressed symbols and parentheses represent phrase-marking pauses.

Neisser (1967) has speculated on the functional significance of such rhythmic patterns. First, the accented beats and the phrase-marking pauses could serve as distinctive "anchor points" to which individual symbols are attached, thereby enabling *S* to keep track of their relative location in the series. Second, the overall rhythmic pattern might serve as a hierarchical plan for generating the serial list (cf. Johnson, 1965; Yngve, 1960). That is, the sequence conceivably could be generated by recursive decoding into, e.g., first vs. last constituents along the lines suggested by Yngve (1960) and Miller and Chomsky (1963) for sentence generation.

Regardless of the current credibility of these speculations, it is sensible that the basic units which are assembled by a serial recall mechanism are going to be subjective groups. This more limited view was tested in the following experiments. One obvious implication is that successive symbols within a subjective group will be more strongly associated than successive symbols that go across group boundaries. Available evidence suggests this is true. For example, Mueller and Schumann (1894) showed strong positive transfer when *S* learned a new series derived by piecing together functional groups previously learned in different series, but little transfer when the new series was derived by using adjacent elements from different groups of the previously learned series. Norman [3] found, with the probe-digit recall technique for series, that associations between Elements n and $n + 1$ were high if both elements occurred within a group (of stressed pairs), but were low if the adjacent pair occurred across group boundaries. McLean and Gregg (1967) reported on free emission of a grouped series, finding that interresponse times were short in recalling successive elements within a group, but were longer between group boundaries. Such results suggest that perceptual groupings imposed by *S* or *E* define the boundaries of functionally integrated response units. In addition, Garrett (1965) found that a pause in an auditory digit series determined "perceptual units" insofar as a superimposed click was perceived as having occurred closer to the pause than it in fact did (cf. Fodor & Bever, 1965).

If it is true that *S* learns a series by imposing stable functional groupings on it, it follows that learning could be seriously retarded by forcing *S* to adopt different groupings each time the same series recurs. It is this prediction which was tested in the first three experiments: For some series the same group structure recurred repeatedly, whereas for other series the group structure differed every time the series recurred. The prediction was simply that repetition of a series with the same group structure would lead to improvements in its immediate recall, whereas repetition with a changing group structure would produce relatively little improvement in recall.

These studies required that *E* largely control the groupings adopted by *S*. A variety of methods are available for achieving this end: For visual presentation, *E* could introduce spaces, dashes, or parentheses to mark the groups, as in 17-586; with auditory presentations, *E* could say the digit names with rhythmical stress and pausing, as in "one SEVEN . . . five eight SIX," or *E* could say the common names of the numerical groups with pauses, as in "seventeen . . . five hundred eighty-six." Intuitively, the latter method, saying the group names to *S*, appears to afford the strongest control over *S*'s groupings, so this method was adopted in all but one of the experiments. This direct phonemic coding of groups should produce the largest behavioral effects; the alternative methods may be expected to produce similar effects to the extent that they determine *S*'s grouping of the series.

Experiments I and II

The first two experiments investigated the benefit for recall of repeating a digit series either with the same or with a constantly changing group structure. Experiment I used 9-digit strings; Exp. II used 12-digit strings in order to produce a larger effect

[3] D. Norman, personal communication, 1967.

of the variable. The design was one introduced by Hebb (1961) and since studied by Melton (1963) and others, in which a particular digit string periodically recurs among a set of constantly changing items. Interest centers on improvement in immediate recall of the recurring string.

Method

Experiment I.—Ninety permutations of the digits 1–9 were taken from the tables of Moses and Oakford (1963) disallowing series with more than one adjacent pair in natural serial order. Each nine-digit string was subdivided haphazardly into successive digit groups of Sizes 1, 2, 3, or 4; the only restriction was that the number of groups in each string not exceed five, but within this restriction there was considerable variation in the number of groups, the number of groups of each size, and the sequence of group sizes in each nine-digit string. These 90 items were assigned to 10 blocks of 9 items; one of these items was designated to be the recurrent item and was presented on Trials 3, 6, 9, and 12 of the block, and the remaining 8 items were designated as noise items, presented once each. With letters representing distinct digit strings, each block followed the paradigm abCdeCfgChiC, where C is the recurring item in the block. For 5 of the 10 blocks, the recurrent item retained the same groupings over its four trials. For the remaining 5 blocks, the recurrent item had its group structure changed over its four trials. For example, the recurrent item coded as (17) (683) (945) (2) on its first occurrence might be coded as follows on its next three presentations: (176) (8) (394) (52), then (1) (768) (39) (452), and then (1768) (3) (94) (5) (2). These grouped digit strings were recorded on a Wollensak tape recorder by saying the numerical name of each group followed by a brief pause. Timing relations are difficult to specify exactly, but all strings were read in approximately $6 \pm .5$ sec.

Individual *S*s received instructions about immediate recall and the blocked nature of the experiment, but no mention was made of recurrent items. After the warning signal "Ready," they were to listen to each string, and when a terminal click occurred immediately after the last number, they were to begin writing the individual digits in left-to-right order in nine blank spaces provided on an answer sheet. The *S* was told that each series consisted of a permutation of the exhaustive set 1–9. He was further told that his recall score would be the number of digits written in their correct location and that he could either guess at or leave blank those positions he could not remember. He did not have to indicate the groupings heard, just the underlying digit sequence. The recall period was 7 sec. (usually more than ample time); there was no feedback, and *S* covered up his successive recall lines with a cardboard before he heard and recalled the next series.

The 10 blocks of items, 5 with repetition same and 5 with repetition different, were given to *S*s in different random orders. There was a 30-sec. pause between blocks while *E* advanced the tape recorder to the starting place for the next block.

The *S*s were 12 undergraduate students fulfilling a service requirement for their introductory psychology course.

Experiment II.—The design was similar in all respects to Exp. I with the following changes: (*a*) Each series was 12 digits long; and (*b*) the block size was eight strings long, symbolized aBcBdBeB where the recurrent string B appeared four times separated by a noise string. The 12 digits in a string were obtained from the first 12 entries in tables of random permutations of the numerals 1–20 (Moses & Oakford, 1963), deleting 10 and 20 and rewriting 11–19 as 1–9. Thus, each digit type from 1 to 9 could appear zero, one, or two times in the string, and the number of digit types with two tokens varied from three to five over the strings. Two consecutive tokens of the same digit were disallowed. Each string of 12 digits was divided into no more than seven groups of Sizes 1, 2, 3, or 4 in a completely haphazard fashion. The grouped digit series were tape-recorded at the approximate rate of one string in 7.5 sec. There were 10 blocks of trials conforming to the aBcBdBeB paradigm. In 5 of these blocks the recurrent string was repeated with the same group structure (RS), and in 5 it changed (RC). Recall time was 10 sec. and the interblock rest intervals were 30 sec. The *S*s were 12 undergraduate students from the same source as Exp. I.

Results

Experiment I.—Recall protocols were scored in terms of two indices: (*a*) whether or not the entire string of nine digits was recalled correctly and (*b*) the number of digits recalled in their correct absolute position. There was relatively little change over the 10 blocks of the experiment, so the blocks were pooled. Using the notation abCdeCfgChiC to denote each block, there are three item types: (*a*) the once-presented noise items (N), distinguished as the first two (ab), the second two (de), etc.; (*b*) Item C when it recurs with the same group structure over its four trials, abbreviated RS for "repeated same"; and (*c*) Item C when it recurs with a different group structure on each of its four trials, abbreviated RC for "repeated changed."

Figure 1 shows the results of the first recall measure, the proportion of strings that are recalled perfectly over the four trials

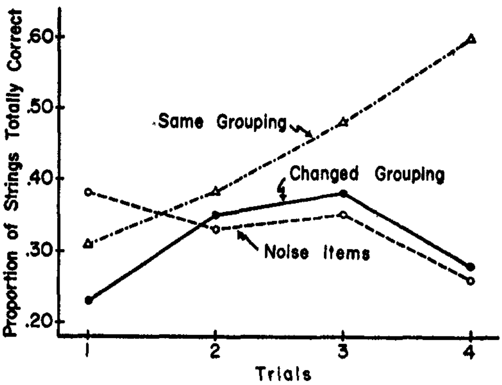

FIG. 1. Proportion of nine-digit strings totally correct in immediate recall over four presentations.

within each block. The points for the R curves are each based on 60 (12 *S*s × 5 blocks) observations, while the points for the N curves are each based on 240 observations. For the N items, there was a significant decline over the four portions of the block, F (3, 33) = 3.98, $p < .05$, possibly reflecting within-block proactive interference that dissipates with the rest interval between blocks. The feature of interest in Fig. 1 is a marked improvement over trials in recall of the recurrent item repeated with the same group structure and a nonmonotonic curve for the recurrent item repeated with different groupings. The Trials × RS vs. RC Items interaction is significant, F (3, 33) = 6.53, $p < .01$, indicating a greater learning effect for the RS items. Average proportions of totally correct recalls over the four trials are .44 for RS items, .31 for RC items, and .33 for N items. The RS items exceed the latter two, but the RC and N items do not differ significantly.

A similar picture emerges if recall is scored in terms of the number of errors per string. Error scores averaged around 1.95 out of 9 possible. Combining the first two vs. last two trials, the respective mean error scores were 2.09 vs. 1.13 for the RS items, 1.94 vs. 1.90 for the RC items, and 1.80 vs. 2.05 for the N items. The "learning effect," indexed by a reduction in error scores from the first to the second half of the trials, is .96, .04, and −.25 for the RS, RC, and N items, respectively. Pairwise t tests on these error reduction scores showed the RS items to be significantly different from the others, t (11) = 4.53 for RS vs. RC, but the RC and N items did not differ significantly, t (11) = 1.13, $p > .20$.

The results of Exp. I confirmed expectations. A series repeated with the same group structure was recalled progressively better despite the intervention of two noise items between presentations. A series repeated with differing group structures showed little improvement, being recalled no better than once-presented control items. This happened despite the fact that *S* was writing down exactly the same sequence of digits each time the recurrent item occurred (albeit with different input groupings).

Experiment II.—The principal results are shown in Fig. 2 in terms of the mean errors in recall per 12-digit string. As expected, the base level of errors on N items was quite high, around six per series. As in Exp. I, there was a significant within-block regression in recall of the N items, F (3, 33) = 4.20, $p < .05$. The RS and RC items display recall trends similar to those in Exp. I; there is a sharp reduction in errors over trials for the RS items, but virtually constant recall over trials for the RC items. The RS vs. RC × Trials interaction is highly significant, F (3, 33) = 8.00, $p < .01$, indicating the differential learning in the two cases. Figure 2 shows that Exp. II succeeded in its

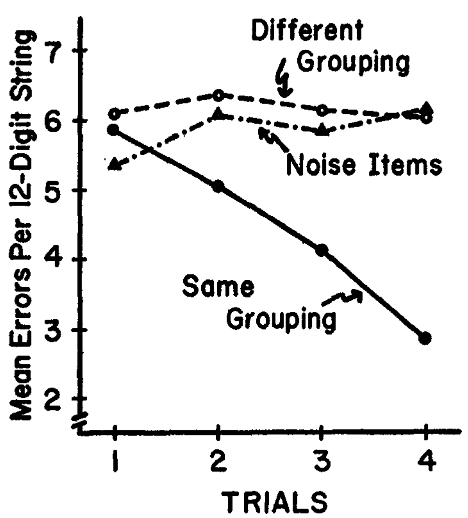

FIG. 2. Mean number of errors per 12-digit string in immediate recall over four presentations.

main purpose, viz., demonstrating a dramatic improvement for RS items and virtually none for RC items from a low-base-line performance.

Further analyses were done to locate the specific source of improvement over trials for the RS items. To this end, a measure of adjacent item association was used, viz., the conditional probability that Element $n + 1$ was not recalled correctly given that Element n of the series was recalled correctly. This transition error probability (TEP) was computed separately for all n to $n + 1$ transitions which fell within a group (called within-group TEP) and for all those n to $n + 1$ transitions which went across group boundaries (between-group TEP). The left panel of Fig. 3 shows these two measures for the four N items of each block. The within-group TEPs are uniformly lower than the between-group TEPs, indicating stronger adjacent associations within than between groups. Over the four N items of each block, the within-group TEPs remained approximately constant, whereas the between-group TEPs exhibited a steady rise, revealed in the increasing recall errors for N items in Fig. 2. The RC items yielded functions similar to the N items, but these were more irregular and are not presented. A graph of these statistics for the RS items appears in the right-hand panel of Fig. 3. Again, the within-group TEPs began low and remained relatively constant over the four trials; the between-group TEPs began higher, but progressively decreased to very near the level of the within-group TEP.

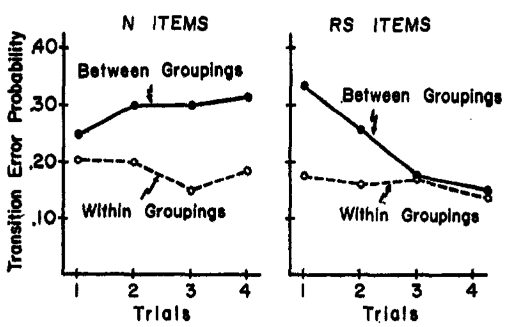

FIG. 3. Conditional probability of an error on Digit $n+1$ given correct on Digit n for 12-digit strings over four presentations.

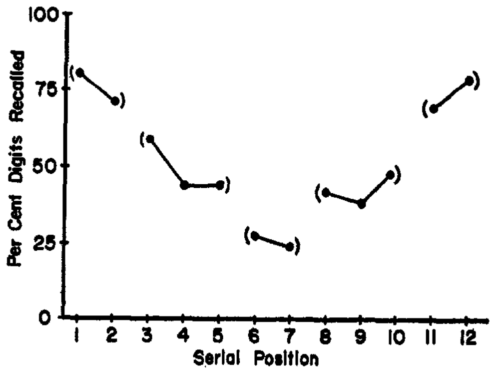

FIG. 4. Percentage of digits recalled at each serial position for noise items grouped in a 23232 pattern.

These data indicate that the main benefit of repetition for RS items was in improving the transitions between successive groups, but that repetition helped relatively little in integrating the elements within each group. By analogy to textual material, the digit groups appear to be acting much like words, and the effect of repetition is to build up compounds or higher order strings of words.

Serial position curves.—It is of interest to investigate how the serial position error curve is affected by the grouping of the series. The recall of those noise strings which had the same group structure was pooled. A serial position curve for one example is shown in Fig. 4, where the group sizes were 2, 3, 2, 3, 2. Other group structures displayed similar patterns. Although the general bowed shape of the classic serial position curve is apparent, there are also clear bumps and troughs in the curve corresponding to the location of the imposed groupings. A more revealing analysis of the serial recall is the TEP statistics shown in Fig. 5. The TEP plotted over Index i is the conditional probability of an error on Element i given a correct recall of Element $i - 1$ of the series. At $i = 1$ is plotted simply the error probability of the first digit in the series. The transitions moving into a new group in the series (the between-group TEPs) are crosshatched. It is clear that errors predominate in recalling across group boundaries and that transition error probabilities decline over successive elements

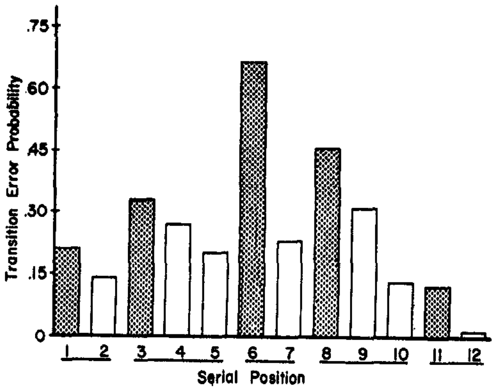

FIG. 5. Conditional probability of an error on Digit $n + 1$ given correct on Digit n for items in Fig. 4.

within the same group. The TEP profile is in fact very similar to those reported by Johnson (1965) for sentence recall, where his constituent phrase boundaries correspond to the present digit groupings. Even in this TEP analysis, however, there is still a decided serial position effect on between-group TEPs, i.e., the crosshatched bars increase, then decrease over serial position.

There were insufficient observations on particular group structures for RS items to analyze in detail which between-group TEPs showed the larger improvements with repetitions. A plot of serial position error curves, averaged over all RS items, showed marked improvement over repetitions in recall probability at all serial positions except the last two (which had very high recall probabilities every trial).

Summary

In summary, the first two experiments have shown devastating effects on recall of altering the phrase structure of digit strings. The normal improvement in recall with repetition was practically annihilated by changing the group structure at each repetition. The results suggest a critical relationship between perceptual coding of material and the learning effect normally induced by its repetition; viz., for multitrial learning to occur, the material must be coded in substantially similar ways over successive experiences with it. The results suggest a hypothesis which supposes that the perceptual coding of the input material determines a metaphorical "location in memory" at which it is stored. If two serial sequences are coded in substantially similar ways, the second input is shunted to the same storage location, there to make contact with and strengthen the trace of the first input of this series. The hypothesis requires the further assumption that immediate recall of a series in this type of experiment is mediated by the strength of the trace in the most recently activated storage location. Thus, a series that is coded and stored in a consistent manner can accumulate trace strength to improve recall, whereas a newly coded RC item is shunted to a new location, and its recall from that location is similar to that of a once-presented noise item.

For convenience in the following, this will be dubbed the "reallocation" hypothesis. It is primarily a heuristic and a clearly metaphorical model, envisioning separate storage locations to which input series are shunted by a coding process, which experiences leave behind traces at the storage location; and a recall mechanism that generates a response using the information in the trace at the most recently activated storage location. Moreover, earlier discussion and the TEP analysis suggest that the trace stored in a given location is in fact a complex bundle (hierarchy?) corresponding to the individual groups of the structured series. A less metaphorical formulation would suppose that the present method for imposing groupings in fact sets up a direct correspondence between a grouped series and a sequence of input phonemes. This view would then suppose that it is this phoneme sequence which is rehearsed and stored as a chain of associations. When an old digit series is regrouped, it now produces a new phoneme string; this fails to "contact" the trace of the phoneme string used previously, and hence no repetition effect is observed in its recall. This phoneme view of matters is attractive because other evidence (cf. Adams, 1967) suggests that immediate memory is affected by phonemic variables. However, Exp. III introduces some complications to this simple phoneme view of matters.

EXPERIMENT III

A relevant question is whether the null learning observed with RC items in Exp. I and II depends critically on the direct phonemic coding of the number groups in the repeated sequence. According to the phoneme view discussed above, the digit groupings were relevant only insofar as they determined the sequence of phonemes which

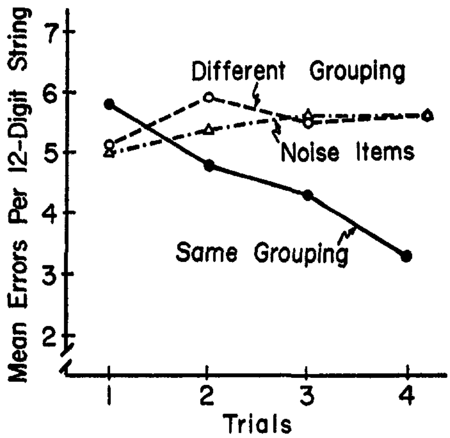

FIG. 6. Mean number of errors per 12-digit string in immediate recall over four presentations.

S heard. Experiment III therefore compared learning of RS and RC items with another grouping method that does not directly vary the phonemic structure of the input string. This alternate method was simply to read the digit names with pauses between groups. Thus the sequence 185-62, formerly read to *S* as "one hundred eighty-five, sixty-two" in Exp. I and II, was read to *S* as "one eight five . . . six two" in Exp. III. In this case, for RC items *S* heard exactly the same sequence of phonemes—only the locations of the pauses changed over repetitions of the same series.

Method

Procedure.—The design, procedure, and materials were identical to those in Exp. II, with only the grouping procedure changed. All 12-digit strings were rerecorded by saying the digit names (approximately 3/sec rate) with a distinct pause (approximately 1 sec.) between groups. Duration of the strings was 8–10 sec. depending on the number of groups (and pauses) in the string. The *S*s were 12 undergraduates from the same source as Exp. I. Their instructions were identical to those for Exp. I and II.

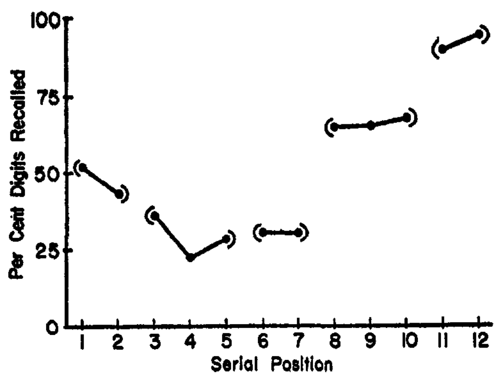

FIG. 7. Percentage of digits recalled at each serial position for noise items grouped in a 23232 pattern.

Results

The mean recall errors per string are shown in Fig. 6 for the three conditions, N, RC, and RS. The overall pattern is strikingly similar to that in Exp. II (cf. Fig. 2). Errors on RS items decrease, on N items increase slightly, and on RC items remain relatively constant over trials. The RC vs.

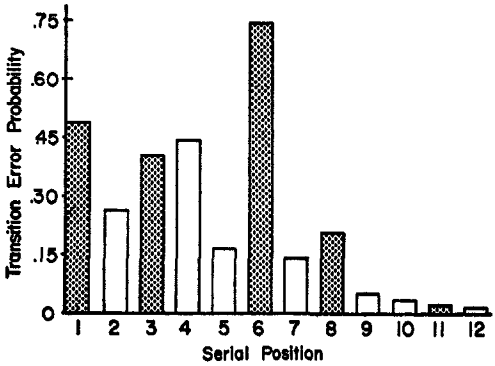

FIG. 8. Conditional probability of an error on Digit $n+1$ given correct on Digit n for items in Fig. 7.

RS Items × Trials interaction is significant, $F(3, 33) = 11.01$, $p < .01$, replicating the differential learning rates observed in Exp. II for these two cases. Further analyses of TEP statistics for N items showed serial position patterns remarkably similar to those in Exp. II. One example pattern, 23232, yielded the serial position curve and TEPs shown in Fig. 7 and 8. This pattern may be compared to Fig. 4 and 5 for the same group structure but with phonemic coding of the groups. The overall similarity of the two patterns suggests that simple pauses induce functional groupings just as strongly as does phonemic coding.

It may be concluded that the null learning of RC items is not a simple consequence of direct alteration of the phoneme sequence produced when different groupings dictate different numerical names for the groups because the same null effect is produced when RC items involve the same input sequence of phonemes, differing only in the location of pauses. Thus, the temporal segmentation of the sequence determines the recall units, and these units shift as the segmentation shifts.

A defensible view is that although the input string is digit names with pauses, the segmentation comes to be represented in terms of *S*'s implicit naming of numerical groups. Thus, "one seven . . . " is renamed "seventeen" by *S*. This is plausible; it would also salvage the phoneme theory since it would be claimed that *S*s in Exp. III were stimulating themselves in the manner that *E* was stimulating *S* in Exp. II where RC items showed no benefits from repetition. A minor problem with this account, however, is *S*s' introspective reports in Exp. III; most of the *S*s claimed that they were *not* doing this phonemic coding into names of numerical groups. But such introspections should probably be interpreted with caution.

In any event, with this hedge about implicit phonemization, it now becomes difficult to discriminate between the phoneme hypothesis and the reallocation hypothesis. In the following, they will be treated as roughly equivalent, but results will be discussed in terms of the reallocation concepts.

Experiment IV

Supposing the correctness of the reallocation hypothesis, what does it imply about recognition memory? The simplest view would be that recognition of identity depends on the new experience being shunted to a storage location where there is an old trace. If the old trace there is strong enough to effect a substantial match to the new input (e.g., the matching score exceeds a statistical decision criterion), then *S* will report that he recognizes the current input as a substantial repetition of a series he experienced earlier. If the group structure and coding of the input string determine the storage location to which it is shunted, it then follows that recognition memory for identity should be seriously degraded by altering the input coding between the first and the second presentation of the same series. This implication was tested in Exp. IV.

This account places recognition of identity in a pivotal role with regard to the beneficial effect on recall of multiple repetitions. A failure to recognize the current input as "old" provides a fairly clear indication that its recall will be divorced from the potential benefits of prior presentations. Some evidence is available with respect to this implication. First, and anecdotally, *S*s in Exp. I, II, and III never spontaneously reported recognition of identity for repetitions of RC items, but often did for RS items. Second, experiments by Martin (1967) and Bernbach (1967) have shown for paired-associate learning that when *S* fails to recognize the stimulus term as "old," his paired-associate response on that trial is a sheer guess. Moreover, the subsequent course of learning for such items is best characterized by saying that the occurrence of a recognition failure "resets" the item back to the beginning, where *S* started with total ignorance of that item. Third, experiments by Kintsch and Morris (1965) and Kintsch (1966) on multitrial recognition learning have shown that recognition failures act like recurrent "resetting" events over the trial series; once a recognition failure occurs, practically the entire preceding history of reinforcements with that item can be written off as virtually ineffective for later recognition responses.

Experiment IV used the continuous recognition paradigm introduced by Shepard and Teghtsoonian (1961), in which *S* gives recognition responses to a long series of items, half of which are repeats of earlier ones. Half of the items were RS and half RC repeats, and each type was tested at lags ranging from 1 to 24 intervening items to provide full information about the retention curve.

Method

Design and procedure.—The *S* heard a series of 305 grouped five-place numbers, had to judge each as new or old, and assign one of three confidence ratings to his judgment (guess, moderate, certain). The five-place numbers used were the first five entries in tables of random permutations of the

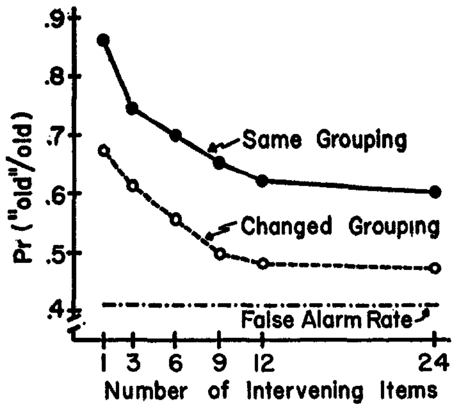

FIG. 9. Probability of a five-digit string being recognized as old on its second presentation.

digits 1–9. No 2 items were permitted to have more than the same three digits in identical serial order, e.g., the pair 71284 and 12853 would be disallowed. There were 155 items in all; 150 were presented twice, and 5 filler items were presented once, accounting for the 305 in the series. Each item was subdivided into two, three, or four groups at random, and the sequence of numerical names of these groups was recorded on tape; reading was at a rate of approximately 3 sec. for each five-digit string. For 75 of the repeated items, the second presentation of the item was read with the same group structure (RS); for another 75, the second presentation involved a marked change in group structure (RC). The two item types were distributed randomly throughout the input series. The trial sequence was so arranged that approximately one-sixth of each type of item had its second presentation at lags of 1, 3, 6, 9, 12, or 24 intervening items after its first presentation.

The 16 *S*s were undergraduates from the same source as Exp. I. They were assigned in random alternation to two groups of 8 *S*s. After standard information about the task, the 8 *S*s in the "naive" condition were told that the strings would be read grouped, but that they should make their recognition ratings with respect to the underlying digit series irrespective of its grouping. The 8 *S*s in the "informed" condition were further forewarned explicitly that for half of the items the second presentation would be grouped differently than the first presentation, and they should try to concentrate only on the underlying digit string in making their recognition judgments.

Results

The main results are shown in Fig. 9 giving proportion of recognition ("old") responses to RS and RC items at Lags 1–24, averaged over the two instructional conditions. The average false-alarm rate on new items was .42, so performance on RC items still exceeded chance even at Lag 24. Recognition of RS items obviously exceeded that of RC items, as predicted. The RS vs. RC difference appears to affect recognition in nearly a constant manner independent of lag; i.e., the probability curves are approximately parallel over lags. This parallelism holds as well when performance scores are transformed into the *d*'s of signal detection theory (cf. Wickelgren & Norman, 1966), which represents an alternative measure of recognition performance.

The overall results in Fig. 9 are in the direction predicted by the reallocation hypothesis. The declining curve for RS items presumably reflects the declining strength of the trace of the first presentation, whereas the RC curve reflects in addition a lowered probability that the second presentation would be shunted to the same storage location as the first presentation.

From the viewpoint of the reallocation hypothesis, the puzzle in these data is why recognition of the RC items is as good as it is. If the second presentation of an RC item is coded differently from its first presentation, why is it not treated as a new item, with a "recognition" probability at only the chance false-alarm rate? A hint as to a possible answer to this question is provided by analyzing the data for the informed vs. naive *S*s, who differed in degree of instructional preparedness for the RC items.

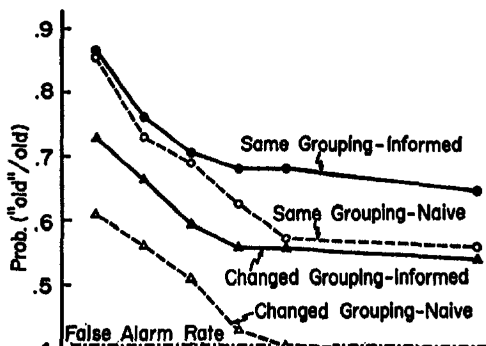

FIG. 10. Probability of five-digit string being recognized as old on its second presentation.

Recognition performance for these two subgroups on RS and RC items is displayed in Fig. 10. Within each group there is a large and nearly constant separation between RS and RC items, but the informed group is apparently performing at a somewhat higher level than the naive group, particularly on the RC items. The false-alarm rate was similar for the two groups: .43 for informed *S*s and .41 for naive *S*s. An overall analysis of variance on hit rate (arc-sine transforms) incorporating instructional set, RS/RC, and lag, however, yielded significant effects at the .05 level for only the RS/RC and lag variables. Instructional set had no significant main effect, nor did it enter into significant interactions with the other variables.

Recognition of RC items may perhaps be understood in terms of a recoding strategy which several *S*s reported using. This strategy was simply to recode *E*'s grouped five-digit string into a standard format naming the individual digits. Thus, the input string "eighty-nine, three hundred forty-one" would be implicitly recoded and rehearsed as "eight, nine, three, four, one." And, of course, the RC phrase "eight, nine hundred thirty-four, one" would be mapped into the same phonemic string under this standard recoding. To the extent that this decoding strategy is applied, it would tend to nullify the effects of the RS/RC variable and to produce recognition of RC items. If informed *S*s used this strategy more often than naive *S*s, then they would differ mainly on recognition of RC items. Although their results differed in this direction, it was not a significant effect statistically.

This suggested factor could be checked out in further experiments specifically designed to better control *S*'s coding strategy. The plausibility of such strategic complications, however, should not be permitted to obscure the main result of Exp. IV, viz., that altered grouping of the digit string had a drastically degrading effect on recognition of identity from memory. In reference to Exp. II, this recognition of repetition for RC items was probably much less than in Exp. IV due to the greater length of the strings (12 vs. 5 digits) and the instructional set of the earlier *S*s.

Experiment V

A further interesting implication of the reallocation hypothesis was tested in Exp. V. It concerns recognition of a ***visually uncoded*** test string after *S* has experienced two auditory inputs of the string, with the group structure of the two inputs being the same (RS) or different (RC). For example, after auditory input of (89) (341), and then (8) (934) (1), *S* would be tested for recognition of the visual string 89341. Suppose that *S* will recognize this visual string as an "old" series that he has heard if he can match it successfully to a trace he has in memory; assume further that his probability of obtaining a successful match for such a string is an increasing function of the number of different locations at which this series has been stored and the strength of the trace at the relevant locations. That is, *S* will recognize the RC item 89341 if he can match it either to the trace of (89) (341) or to the trace of (8) (934) (1). Presumably, he not only could recognize it then, but could also tell us something about the way the string had been grouped.

By this account, comparison of recognition on such uncoded tests for RS and RC items then amounts to comparing *S*'s ability to find one "strong" trace vs. one of two "weak" traces. In the absence of more detailed information about the processes, one cannot predict in advance which of these cases will yield better uncoded recognition, or indeed whether they will be equivalent. However, one determinant prediction is that recognition memory in both these cases should exceed that for an item presented only once. In the terms used above, this once-presented item will be represented by a weak trace in only one location, and it should be less likely to be found and matched than would be a strong trace in one location or a weak trace in one of two locations. Experiment V was undertaken to test this prediction.

Method

Design and procedure.—Each *S* received 10 blocks of input-test phases, the blocks separated by 30-sec. rest intervals. In the input phase of each block, *S* listened to 12 auditorily grouped strings (group names), each string five digits long. The test phase which immediately followed consisted of 12 slides, each visually presenting 1 five-digit string for recognition with reference to the immediately preceding phase of auditory inputs in the block.

The five-digit strings and their groupings were similar to those used in Exp. IV. Tape recording of the 12 strings for the input phase consisted of saying the grouped string (3 sec.), pausing for 3 sec., and then saying the next grouped string. The 12 auditory inputs consisted of the following: (*a*) the first and last buffer items which were presented once, but were never tested; (*b*) two items presented once and tested; (*c*) two items each presented twice with the same groupings (RS) and tested; and (*d*) two items presented twice but with different groupings on the repetition (RC) and tested. The number of items intervening between repetitions of the same string was three, four, or five, averaging out to four. The aforementioned items account for 6 of the 12 recognition test slides. The remaining 6 test slides were new five-digit distractors that had not been previously presented in the experiment. The order of input and test items was so arranged that the number of intervening events (inputs or tests) between the last input of an item type and its test averaged out to 9, with a triangular distribution over lags of 9, ±1, ±2, and ±3. The specific digit series instancing the RS and RC conditions were completely counterbalanced over *S*s, i.e., a given string was an RS item for 8 *S*s and an RC item for the other 8 *S*s. The 10 blocks of items were presented in the same order to all *S*s.

The *S*s were 16 students from the same source as Exp. I and were run individually. They were instructed to decide whether or not each visually presented five-place number represented the same underlying digit string as some one of the auditorily presented strings in the preceding input phase. The *S* responded "Old" or "New" and added one of three confidence ratings (guess, moderate, positive), but received no feedback regarding the accuracy of his judgments.

Results

Over the 10 blocks of the experiment, recognition performance improved significantly; there was about a 9% decline in false-alarm rate and a 13% rise in correct hits. Despite these trends, however, the rank ordering of the item types remained the same over the course of the experiment. The average proportion of old responses to the four item types are shown in Table 1, pooled over the 10 blocks of the experiment.

Pairwise *t* tests on the proportions in Table 1 reveal the following pattern: (*a*) Items presented once were recognized more often than were distractor items, $p < .01$; (*b*) items presented twice were recognized more often than items presented once, both p's $< .01$; but (*c*) recognition of the RS and RC items did not differ significantly, $t\ (15) = 1.42, p > .15$.

TABLE 1

RECOGNITION PROPORTIONS FOR UNCODED ITEMS

Item type	Proportion
Noise items (false alarms)	.40
One-presented items	.57
Twice-presented items	
Repeated same	.70
Repeated changed	.74

The results confirm the prediction that uncoded recognition of RS and of RC items would exceed the once-presented items. Also, in this instance, presentation of the same grouping twice was approximately equivalent to presentation of two different groupings once each. Indexing the learning effect by the improvement in hit rate over the false-alarm rate, the results fall into a simple quantitative pattern: one presentation of a string produced an increment of .17 over the false-alarm rate, while two presentations of the string produced an average of about twice the increment, or .32.

Exp. IV and V together represent a curious reversal of effects. In Exp. IV, changing the coding of a series markedly degraded its recognition, whereas in Exp. V, repetition of a series with altered coding produced just as good recognition memory as did repetition with the same coding. The difference, of course, is in the nature of the recognition test, whether the test string is coded differently than the memorial string which it must contact or whether the test string is uncoded.

Although generally consistent with these results, the reallocation hypothesis does not particularly clarify the processing components engaged when *S* recognizes an uncoded visual series as identical to a coded auditory series he heard earlier. One possibility is that *S* tries out several (random) articulatory codings or parsings of the uncoded test string, attempting to match these trial codes to some phoneme sequence he has stored in memory. There are several speculative elaborations possible on this theme. An alternative possibility is that *S* tries to recode everything during input and test into the same standard format, viz., the series of names of the individual digits. Then the auditory string "eighty-nine, three hundred forty-one" would map onto the same phoneme sequence as does the visual string 89341. Moreover, if *S*s were to note increasingly the utility of this strategy as the experiment progressed, one could explain the observed improvement in recognition performance over the session. A problem with this account, however, is that unless the decoding strategy is consistently applied, it would predict poorer recognition for RC than for RS items. In the data, however, RC items were recognized slightly better than RS items, and this rank ordering was consistent over the 10 blocks of the experiment. A further implication of a "decoding strategy" explanation is that when *S* recognizes a visually uncoded string, he should be unable to recall anything about the phonemic grouping of the auditory input to which that string refers. The alternate explanation, i.e., generating trial articulatory codings for matching tests, would imply that *S* would have this grouping information available when he recognizes an uncoded string. (Obvious "corrections" for guessing or false alarms would have to be considered.) Thus, future experiments might yield more differentiating evidence if *S* were required also to indicate the grouping that the test string had had during input.

Experiments VI and VII

Experiments VI and VII return to the immediate recall paradigm of Exp. II in an attempt to better elucidate the mechanism underlying the repetition effect in serial recall. Experiments I, II, and III indicated a practice effect for RS items but not for RC items. The reallocation hypothesis explained the RC results by supposing that a differently coded series is assigned to a different location than earlier traces of the series, thus precluding contact with and strengthening of those earlier traces to mediate better recall. According to this view, a correlative behavior that partially indexes where *S* shunts the current input is whether or not he recognizes the first few groups of the string as a recurrence of one experienced earlier. If *S* does not recognize the first few groups of the altered recurrent string, that means he has shunted it to a new location and thus has effectively divorced his immediate recall of that string from the benefits of a prior history of experience with it.

An alternative view of matters would suppose that in the context of such serial tasks, *S* uses only a small number of storage slots or bins that are tied together in serial order and that all input sequences are referred to these same bins. Suppose in particular that the central processing mechanism switches the first group (coded unit) of the input string into the first bin, the second group into the second bin, and so on, allocating the sequence of groups or coded units in a string to a sequence of storage bins (cf. Conrad, 1965; Neisser, 1967). The successive bins may be conceived as implicit positional "stimuli" to which coded response units become associated. According to this view, repetition of an identically structured string assures reassignment of the same coded response to the same bin, so the strengthening effect on that unit is much like two trials of A-B, A-B in associative learning. On the other hand, when the group structure is altered between repetitions, entirely different coded response units are being assigned to the successive bins, and the effect at each bin is much like the A-B, A-C paradigm of negative transfer.

Either of these views implies the aforementioned results of a repetition effect for RS but not for RC items. Is there a differential prediction of the two views? There are doubtless many. One which has appealed to the authors and which is tested below is the following implication of the bin theory: If the third (e.g.) group of a string is repeated exactly, then according to the bin hypothesis this constant third group would be associated repeatedly with the third bin and thus its recall should improve with practice, irrespective of what is happening in the preceding and following bins. The constituent elements and size (but not the number) of the preceding and following groups may vary widely, but the bin hypothesis implies that these variations should not affect the normal improvement in recall of the constant third group. This implication was tested in Exp. VI.

The reallocation hypothesis leads to a more differentiating set of predictions for such "constant chunk" experiments. Recall that it was assumed that since the string is processed sequentially, the central processor decides where to shunt the incoming string on the basis of recognizing the first informative group or two in the string. To be very specific, suppose that if the central processor recognizes the first group, it shunts the input string to that prior storage location which caused the recognition; if it fails to recognize the first group, then the input string is shunted to a new storage location. From this view of matters, one would predict that a constant first chunk (in an otherwise variable string) would improve in its recall over repetitions since the input string is repeatedly shunted to the same storage location, there to accumulate trace strength for the constant portion of the various strings, i.e., for the constant first chunk. On the other hand, a constant middle or last chunk would not show improvements in recall because a variable first group would cause each new string to be shunted to a new location, so there would be no accumulation of trace strength for these constant portions at the most recently activated storage location. In contrast to these differential predictions, the bin hypothesis expects repetition to improve recall of any constant portion of the series, whether it be a first, middle, or last chunk. Experiment VII was undertaken to test these differential predictions.

Method

Experiment VI.—The procedure was similar to that of Exp. II, except that what recurred was only the third group of a five-group string, rather than the entire string as in Exp. II. The recurrent third group was always of Size 4. Other digits and groupings were arranged around this constant third group, so that it was preceded and followed by two groups comprised of four total digits, either (2)(2), (3)(1), or (1)(3). These surrounding digits as well as their groupings were changed between Trials 2, 4, 6, and 8 of each block and only the third group was recurrent on these trials. On Interspersed Trials 1, 3, 5, 7 of each block, a new noise item was read, usually one that did not have five groups or a third group of four digits. The *S* listened to a tape recording of the phonetically grouped series, then had 10 sec. to write his recall in 12 spaces on a recall sheet. He was urged to report out digits from first to last. The experiment contained 10 blocks of eight trials, the blocks separated by 30-sec. rest pauses. A different four-digit number was used as the recurrent third chunk in each of the 10 blocks. The *S*s were 12 undergraduate students from the same source as Exp. I.

Experiment VII.—This was similar to Exp. VI except that the constant chunk was three digits long and more conditions were compared. There were 12 blocks of eight trials, and on Trials 2, 4, 6, and 8 of the block some portion of these strings was recurrent. In different blocks, the recurrent portion in a five-group string was either (*a*) the first group, (*b*) the fifth group, or (*c*) the first and the third group jointly. In the latter case, the second group varied in size (1, 2, or 3) and constituency over successive presentations of the constant first and third chunks on the even-numbered trials of the block. On the odd-numbered trials of each block, a new noise string was presented and recalled; these usually had more or less than five groups. With 12 experimental blocks and three conditions, each *S* experienced each condition in four randomly selected blocks, in a scrambled order counterbalanced over *S*s. Also, there was some attempt to counterbalance over *S*s the condition to which a particular three-digit number was assigned as the constant chunk. For example, "851" was a constant fifth chunk for half of the *S*s and a constant first chunk for half of the *S*s. This required several tapes to be made.

The *S*s were 18 undergraduates taking the summer session course in introductory psychology. They were urged to record the digits in a first-to-last order, although they were not penalized for doing otherwise.

Results

Experiment VI.—Analyses of mean correct recall over the 10 experimental blocks revealed no significant performance change as the experiment progressed, so the 10 blocks were pooled for the following analyses.

The bin hypothesis predicts that *S*'s recall of the recurrent third group should improve over its four trials. The focal implication is with respect to recall of the third group as a unit, although the exact location of it in *S*'s serial output may vary somewhat due to forgetting or misrecalling the changing groups that precede and follow the constant third group. With this in mind, a very liberal scheme was adopted for scoring recall of the four ordered digits of the third group: if the third group as a unit was re-

TABLE 2

PROBABILITY (p) OF CHUNK RECALL AND MEAN (M) DIGITS RECALLED OF THE THREE-DIGIT CONSTANT CHUNKS

Condition	Statistic	Trials 1	2	3	4	Linear F
First	p	.47	.54	.56	.65	5.35*
	M	1.85	1.97	2.02	2.22	3.51
First and Middle	p	.46	.53	.63	.61	5.10*
	M	1.76	2.11	2.30	2.25	9.29*
	p	.11	.14	.15	.10	*ns*
	M	.61	.68	.72	.67	*ns*
Last	p	.51	.51	.44	.51	*ns*
	M	2.29	2.32	2.08	2.22	*ns*

* $p < .05$, $df = 1, 51$.

called with the first digit starting at any location from 3 through 7 (true position was 5), it was counted as a correct recall of the unit. With this lenient location scoring, the average probability of completely recalling the recurrent unit was .146 on Trial 2, .125 on Trial 4, .166 on Trial 6, and .156 on Trial 8. Based on 12 × 10 observations each, the standard deviations of these proportions (assuming independent binomial observations) range around .033, so even the most extreme two proportions do not differ significantly from each other. With this scoring in terms of complete recall of the entire unit, there was no evidence of repetition affecting recall of the constant third group.

A second analysis inquired how many items were recalled of the four in the recurrent chunk. Using a lenient scoring procedure too complicated to describe briefly, the net result is still the same as above: mean items correctly recalled of the four in the recurrent chunk were 1.77 on Trial 2, 1.67 on Trial 4, 1.72 on Trial 6, and 1.79 on Trial 8. Clearly, even with this more sensitive measure, there was no evidence for an improvement in recall over repetitions of the constant third chunk. Despite the statistical power available in this experiment, it failed to yield a repetition effect for the constant third chunk. This failure disconfirms the bin hypothesis since it predicted a strong effect here, while in fact none was found.

Experiment VII.—The main results of Exp. VII are displayed in Table 2 showing probability of complete recall of the constant chunk and the mean digits recalled in the constant chunk. There is no apparent improvement in recall of the constant last chunk nor in recall of the constant middle chunk. The linear F test for trials in both these cases is insignificant for both the probability measure and the amount recalled measure. On the other hand, there is a small but consistent improvement in recall of the constant first chunk in terms of the probability and amount recalled measures. The F test for linear trend is significant in three of the first four rows of Table 2, and in the fourth case the trend is clearly in the right direction.

Although recall of the constant first chunk improved significantly over its repetitions, there was very little change in recall of the variable nine digits which followed occurrences of the constant first chunk. Mean correct recalls of these variable last nine digits over the four occurrences of the constant first chunk were 4.69, 5.11, 4.54, and 5.06. These means do not differ reliably from one another.

Summary

In summary, these two "constant chunk" experiments tend to infirm a bin hypothesis which supposes that successive groups of the input string are assigned to successive storage bins from which the series is read out. That hypothesis predicts improvement in recall of a fixed group repeatedly reassigned to the same bin independently of whether this group was located at the beginning, middle, or end of the series. The results provide mild support for the allocation hypothesis since it predicted learning for a constant first chunk but not for a constant middle or last chunk, and this was found. After this experiment was completed, it was learned that Schwartz and Bryden (1966) had performed an experiment with an even more radical manipulation but tending to a similar conclusion. Using the Hebb-type design with digit names read to Ss without groupings, these investigators found no improvement in recall when the last seven of nine digits were recurrent, but with the first two digits changed at each recurrence of the last seven. These and the present results suggest that the first few digits or first functional group is acting as an "address" in memory for the digit string; and when a recurrent portion follows a new address in the input, that string is shunted to a different storage location, so one gets no accumulative benefits in recall for the recurrent portion of the string.

It was said that the allocation hypothesis is "mildly" supported by these data because there are a few interpretive difficulties. First, since *S* was urged to write his recall from first to last, there is differential output interference operating on the constant first vs. later chunks. Conceivably, *S* might improve his recall of a last constant chunk if he were permitted to write his recall in any order, i.e., if he wrote first those portions he might recognize as recurrent. Second, in this interpretation of the allocation hypothesis, the constant middle chunk was expected to improve when it was preceded by a constant first chunk. That is, if the constant first chunk causes the input string to be reallocated to the same storage location, then it was thought that the constant third chunk of the string could accumulate trace strength in that location. But Lines 5 and 6 of Table 2 show no improvement in recall of the constant third chunk in this case. This null learning here could arise for several reasons. One possibility relates it to the variable size (1, 2, or 3) of the second group inserted between repetitions of the constant first and third chunks, and this is checked out in Exp. VIII.

The pattern of our constant chunk results needs to be explored with other presentation procedures, lags between recurrence, recall strategies, and especially with different types of materials. Intuitively, it appears unlikely that serial recall of lists of unrelated words or sentences would be as disrupted as are digit strings by altering the first few elements of the string. If this intuition proves correct, it would imply that the outcome pattern obtained here will be restricted to only those cases in which serial lists are constructed by recombining and permuting elements from a very small vocabulary (e.g., nine digits).

Experiment VIII

This final experiment inquires whether the third chunk will improve in recall when the first and third chunk are constant *and* when the second chunk is of constant size. In Exp. VII there was no improvement in recall of the constant third group (cf. Table 2) when the second group varied in size (1, 2, or 3 digits). But this might result from the exact manner in which the input string is "overlaid" on the trace of the former string. If the input string (762) (318)(952)(361) is directly overlaid, element by element from the beginning, on the trace of (762)(1)(952)(85)(263), one would find coincidence of the first three digits (the first constant chunk), but mismatching for all the remaining digits. Although 952 is the third group in both strings, the variable size of the second group causes mismatching of the 952 elements when the two strings are overlaid. If this kind of exact "overlay" process is partly responsible for the accumulation of trace strength for particular digits, then one would expect the constant third chunk (following a constant first chunk) to be learned only when the second (variable) chunk is of a fixed size. This single condition was studied in Exp. VIII.

Method

The procedure was similar to Exp. VI, with eight blocks of trials in each of which the item recurring on Trials 2, 4, 6, and 8 had a constant first chunk (Size 3) and a constant third chunk (Size 3). The second group was always of Size 2, but the digits in it varied over the four occurrences of the other constant portions. The four digits following the constant third group varied in constituency and groupings over the four trials. On Trials 1, 3, 5, and 7, new noise items occurred, with the group size pattern 323. . . avoided. Grouping was by reading the sequence of numerical names. Strings were presented by a tape recorder. There were 10 *S*s from the same source as Exp. I, instructed to write their recall from first to last digits.

Results

The results are shown in Table 3 giving probability of unit recall and mean digits recalled (out of three) of the constant first and constant third chunks. The *F* test for trials is significant at $p < .01$ for both measures for both first and third recurrent chunks in the string.

The learning demonstrated here for the constant third chunk (following a constant first chunk), along with the failure in Exp. VII with a variable-sized second group, lends some credence to the "element-by-element overlay" hypothesis stated above.

TABLE 3

Probability (p) of Unit Recall and Mean (M) Digits Recalled for the First and Third Constant Chunks

Constant chunk	Trials				F (3, 27)
	1	2	3	4	
First					
p	.50	.70	.70	.75	6.35*
M	1.95	2.37	2.50	2.57	8.65*
Third					
p	.07	.20	.25	.28	7.28*
M	.64	1.14	1.25	1.30	5.39*

* $p < .01$.

There are several differences between the procedures in Exp. VII vs. VIII that might be relevant; in particular, three different types of recurrent items occurred in Exp. VII, whereas only this one type of recurrent item occurred in all eight blocks of Exp. VIII. The learning effect on the third chunk, indexed by the change from its first to the last occurrence in each block, was examined for the eight successive blocks over the experiment. There appeared to be no particular trend over blocks to these learning scores. That is, it did not appear that *S*s were coming increasingly to notice and learn the constant third group as the experiment progressed. However, such comparisons may be complicated by various nonspecific factors that vary over the course of the experiment—practice effects, cumulative proactive interference, etc. The conservative conclusion is that the learning of a constant third chunk, following a constant first chunk and a fixed-sized second chunk, is consistent with the allocation hypothesis, with the element-by-element overlay as the mechanism for accumulation of trace strength.

Discussion

To quickly summarize the results, it has been found that alteration of the group structure of a digit series severely degrades recognition of underlying identity, and it prevents the improvement in recall that normally accompanies repetition. This was true whether digit group coding was directly phonemic or whether it was produced merely by the location of pauses in the input series. Although recognition of an altered grouping is impaired, recognition of an uncoded series was about the same whether *S* experienced the same grouping twice or two logically equivalent groupings once each. When only a portion of the digit string constantly recurs, its recall improves with repetition if it is located at the beginning of the string, but not when it is located at the middle or end of an otherwise variable string.

These results have been discussed in terms of the hypotheses that grouping influences perceptual coding, that similarity of coding determines recognition of identity, and that recognition of repetition is normally a concomitant of a practice effect in recall performance. These various assumptions are summarized in the reallocation hypothesis, which also led to the further experiments on uncoded recognition and the location of a constant chunk in an otherwise variable string.

One may ask whether alternative hypotheses of serial learning could account for these results. The simple bin hypothesis appears to be eliminated by the differential results in the constant chunk experiment. Another alternative is that of simple serial chaining, which supposes that serial recall is mediated by forward associations between adjacent pairs of elements. The chaining hypothesis has two representations depending on whether the basic elements associated in pairs are assumed to be individual digits or phoneme clusters corresponding to numerical names of digit groups. The former identification is discredited by the null learning for RC items in Exp. I and II since the same pairwise digit adjacencies recurred in the RC items. Even if it be granted that the pairwise association grows less when the pair spans group boundaries, repetition in RC items should nevertheless produce automatic increases in pairwise associations and serial recall. But this did not happen. The alternative identification of the basic elements as phoneme clusters converts the chaining hypothesis to a more viable theory for these data, despite the fact that it denies the conventional operational identification between what *S* is learning and what he is writing down in his observable recall.

As stated earlier, the phoneme chaining hypothesis is very similar to the reallocation hypothesis and they both imply the RS vs. RC results of Exp. I, II, IV, and V. However, the results of Exp. III, VI, and VII raise a few problems for a simple phoneme chaining theory. In Exp. III, the input phonemes of RC strings were identical except for the location of pauses; the phoneme chaining hypothesis can handle the results of Exp. III only by assuming implicit recoding and rehearsal of the names of numerical groups suggested by the location of pauses. In Exp. VI and VII, and in the more drastic condition studied by Schwartz and Bryden (1966), the constant chunk or chunks should be reflected in a constant phoneme portion of a variable string within which the pairwise (phonemic) associations become stronger with repetition. If recall of the constant chunk is in some degree related to the strength of its pairwise interassociations (as well as the association leading into the constant chunk), then recall of it should have improved somewhat even when it was located in the middle and end portions in the variable string. But repetition effects on recall were found only for a constant first chunk.

The authors do not consider these to be major objections to the phoneme chaining hypothesis, especially since the generality of the pattern of results in the constant chunk experiments is not yet established. Thus, the phoneme chaining hypothesis should remain as a viable alternative to the metaphorical reallocation hypothesis until more discriminating evidence becomes available.

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