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Serial learning: A multilevel access analysis*

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In Experiment I the lists were 36 and 48 unrelated words. Each was divided into successive groups of four words and learned to a perfect criterion. In Experiment II the lists were made up of six categorical groups of five exemplars each. Degree of learning was varied. In both experiments serial anticipation learning was followed by ordinary free recall and free recall under speed stress. Analyses of acquisition and of both recall tests indicate that group access is a marked function of serial position but that within-group retrieval given group access is constant over serial position. It is argued that serial learning proceeds simultaneously at different levels of representation.

The purpose of this paper is to report new information on how serial learning works. The rationale for the research is based on the following two points.

(1) When Ss are faced with learning a fixed and arbitrary sequence, they break up that sequence into idiosyncratic subsequences. Given access to a particular subsequence, they perform well until they come to the end of that subsequence. They then have to select or guess the next subsequence. Martin and Noreen (in press) have demonstrated the existence of such subjective subsequences and have detailed some of their properties.

(2) It seems clear that retrieval of information for purposes of overt responding proceeds via access routes. When information is grouped in some fashion, the access route to the members of a given group is through a representative code (Johnson, 1972) or control element (Estes, 1972). Mathews and Tulving (1973) present a thorough demonstration of this point.

These considerations introduce the possibility that a viable analysis of serial learning must proceed simultaneously at different levels. One level pertains to what happens within a subsequence. Another level pertains to what happens among the codes that we presume represent the subsequences. Martin and Noreen (in press) were intent on demonstrating the identifiability of subjective subsequences and hence had no control over their sizes and locations. In the present research, subsequences were under experimental control. This means that we can assess the likelihood of entering a subsequence of known size and location and separately estimate the likelihood of retrieving the members of that subsequence.

There is one further preliminary matter. In the Martin and Noreen (in press) study, we identified subjective subsequences by noting runs of errors and correct responses in serial learning taken to a subperfect criterion and then related those idiosyncratic patterns to anticipation errors and to output organization in free recall. There were, thus, numerous errors on the criterion trial in the learning task and considerable disorder in free recall, all sensibly analyzable. Three of the four conditions in the present two experiments, however, involve a criterion of one perfect pass through the list, and the lists all involve E-determined subsequences. Under such conditions there are, of course, no errors on the criterion trial, anticipation errors prior to criterion are of limited value, and output order in free recall is essentially serially perfect. Accordingly, in order to generate implicative data we introduce a speeded free recall test in which Ss receive a large bonus for very rapid output. Like other forms of stress, speed stress magnifies small differences, in our case differences in retrieval likelihood or strength. The result is that the seemingly perfectly known sequence falls apart into its original subsequences. This allows us to examine subsequence accessibility and items-within-subsequence accessibility separately after other indicators are showing perfect serial knowledge.

In Experiment I the serial task was a list of unrelated, arbitrarily grouped words. There were two list lengths. Experiment II differs in that the groups were based on conceptual categories. Only one list length was used, but we manipulated degree of learning prior to the recall tests. The two experiments also differ in that two variations on the speed stress scheme were used and the Es were different. Thus, there should be reasonable confidence about the generality of the results.

EXPERIMENT I

Method

A given S learned either a 36 or a 48-word list to a criterion of one perfect recitation. Learning was by the anticipation procedure, where what was to be anticipated was a group of four unrelated words. Thus, there were 9 and 12 4-word groups in the 36- and 48-word conditions. After criterion learning, the S was asked for free recall of all the words. After free recall, he was given a speeded recall test, wherein he was paid 10 cents a word for the first 7 sec of output and 1 cent a word thereafter.

The 48-word list consisted of high-frequency common unrelated four-letter words. These words were arbitrarily divided

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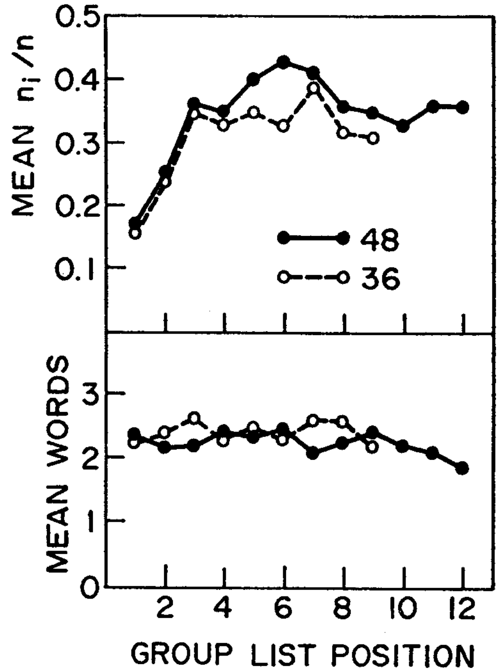

Fig. 1. Upper panel: Mean stage of learning of first group entry. Lower panel: Mean words per group on first entry. List Lengths 36 and 48, Experiment I.

into 12 groups of four words each. The membership and word order for a given group remained intact through all experimental manipulations. Over Ss the serial order of the groups themselves was systematically varied so that word groups and serial position were not confounded. The 36-word lists were constructed by deleting three of the four-word groups according to a counterbalancing plan.

The Ss were 68 female students in the University of Michigan. The 36- and 48-word conditions were assigned to 36 and 32 Ss, respectively. They were paid volunteers and were tested individually. Each was instructed that her task was to learn either 36 or 48 words in their correct order. On the initial inspection trial, she was shown the list of words, four to a card, and required to read them aloud, each card in succession. On the first anticipation trial, she tried to recall serially the words on the first card. She was then shown that card and required to read the words aloud in correct order. That card was then turned face down and she attempted to recall serially the four words on the second card, and so on through the list. Learning continued until she could correctly anticipate the ordered words on every card. Guessing was encouraged, and the Ss were told that a good procedure was to mentally number each card and form an image relating the four words on that card.

After meeting the once-perfect criterion in this self-paced anticipation task, the S was asked for verbal free recall of all the words she could remember, in any order they came to mind. We designate this task as normal free recall (NFR). Following this, the S was again asked to free recall all the words, but with strong emphasis on speed. A bonus payoff scheme was explained: 10 cents for each word recalled in the first 7 sec and 1 cent for each word recalled after that. We designate this task as speeded free recall (SFR). Both recalls were taped. The 7-sec interval was timed from the tape after completion of SFR for bonus payment purposes.

Results

In passing, we note that the mean trials to criterion for the 36-word list is 6.83 (with a standard error of .29) and for the 48-word list is 7.56 (with a standard error of .37). The positive difference between these two means is .73 and the 95% confidence interval is −.78, 2.24, which clearly includes the zero-difference possibility.

Let n_i be the first trial in anticipation learning on which a given S first anticipated at least one of the four words belonging to the group at Serial Position i (1-9 for the 36-word list, 1-12 for the 48-word list), regardless of whether she was correct about the serial position of that group. Let n be the number of trials she took to reach the once-perfect criterion. Then n_i/n is the stage of learning at which this S first entered the group that belongs in Serial Position i. The upper panel in Fig. 1 shows a plot of the mean stage of learning (the average n_i/n over Ss) at which the group at Position i was first entered for both list lengths. The first group of four words was the earliest group entered, then the second group, and so on.

The lower panel in Fig. 1 shows a plot of the mean number of words out of four possible that were produced on the first entry to the group. These curves are flat over the list positions of the groups. Thus, for example, whereas the mean stage of learning for the first entry of the groups at Positions 1 and 5 for the 48-word list are .17 and .40 (upper panel), the mean number of words retrieved conditionalized on entry are 2.36 and 2.36 (lower panel).

What the two panels of Fig. 1 show is that recall of group members given group access is not a function of serial position, while group access is itself a clear function of serial position.

After serial anticipation learning, the Ss were asked for free recall (NFR) of as many words as they could remember, in any order. This was followed by a second free recall, but under speed stress (SFR). The top row in Table 1 gives the mean number of four-word groups entered during NFR and during SFR for both list lengths. The difference between 8.97 for NFR and 8.86 for SFR under List Length 36 is due to omission of one group in NFR and omission of five groups in SFR, each out of (36 Ss) × (9 groups per list) = 324 total groups that could have been recalled. Correspondingly, the difference between 11.75 for NFR and 11.47 for SFR under List Length 48 is due to omission of 8 and 17 categories, respectively, out of (32 Ss) × (12 groups per list) = 384 possible. These latter two frequencies translate into 2.1% and 4.4% group recall failures.

In the second row of Table 1 is posted the mean

Table 1
Mean Groups Entered and Mean Words Per Group Recalled in Normal and Speeded Free Recall for List Lengths 36 and 48

	36		48	
Statistic	NFR	SFR	NFR	SFR
Groups Entered	8.97	8.86	11.75	11.47
Words Per Group	3.90	3.08	3.89	2.96

number of words recalled per group entered, out of four possible. (These means are for initial entries only; additional words recalled on subsequent entries were not counted.) Whereas speed stress did not interestingly reduce the number of groups entered (top row of Table 1), speed stress clearly reduced the number of words retrieved from a group that was entered. In order to adduce statistical support for this conclusion, we consider only the groups that were entered in both NFR and SFR for each S. For each of these groups we count the number of words retrieved in NFR and in SFR and for each S determine the mean number of words dropped in SFR relative to NFR. For List Length 36, the number of such groups is 318. The mean number of words dropped over the 36 Ss is .80 (with standard error .11). The 95% confidence interval is .57, 1.02, which clearly does not include the null difference. Proceeding identically for the 359 groups entered in both NFR and SFR under List Length 48, the corresponding mean loss is .91 words (with standard error .09). Here the 95% confidence interval is .74, 1.09. Again the null-difference possibility is clearly excluded. Thus, as far as retrieval of groups per se is concerned, speed stress did not reduce retrievability; but when it comes to retrieval of elements within a group, speed stress caused a significant reduction in word production.

Given that a group was entered either in normal or in speeded free recall, we can determine the mean number of within-group words produced as a function of the list serial position of the group. These means are plotted in Fig. 2. The only appropriate comment is that retrievability of words within a group, conditionalized on group access, is not a function of the list position of that group.

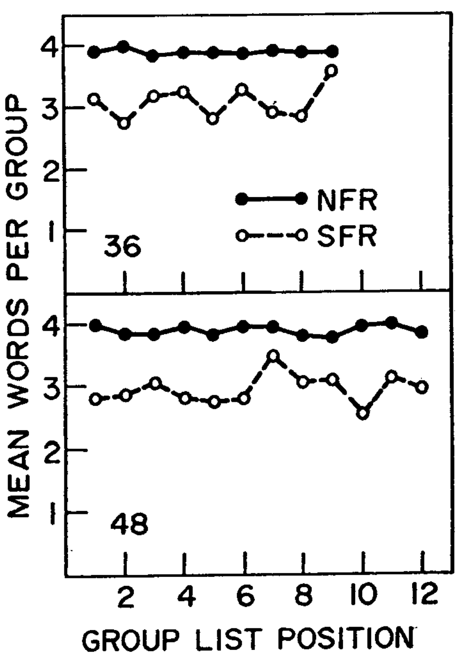

Fig. 2. Mean words per group in normal (NFR) and speeded (SFR) free recall. List Lengths 36 and 48, Experiment I.

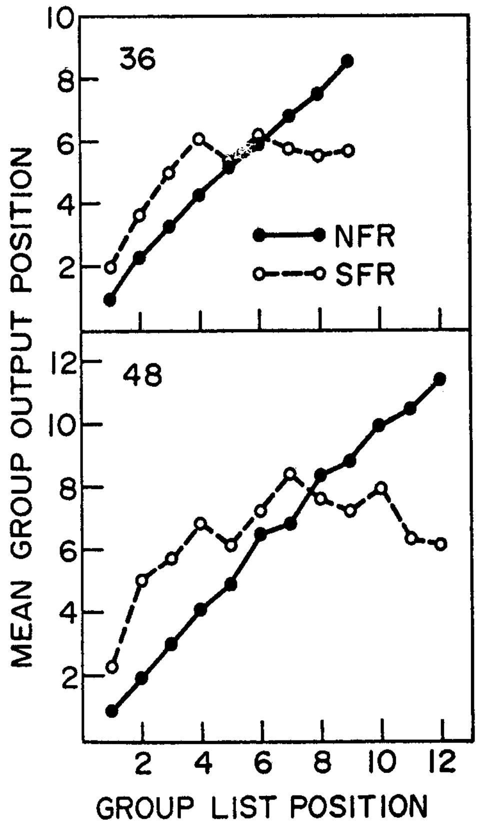

Fig. 3. Mean group output order in normal (NFR) and speeded (SFR) free recall. List Lengths 36 and 48, Experiment I.

As we noted earlier, nearly all groups of the serial list were entered in the recall tests. Thus, probability of group entry is not an implicative statistic. But order of group entry turns out to be implicative. In analyzing group output order, we have to contend with the several missing groups. Suppose a given S in the 48-word condition entered 10 of the 12 groups. The two missing groups were then assigned the mean rank output order of 11.5. If she omitted only one group, it was assigned an output order of 12.

In Fig. 3 the filled circles with solid connecting lines relate mean group output position to group list position in NFR. For both list lengths the groups were entered in essentially perfect serial order, from first to last. The corresponding results for speeded free recall (SFR) are given by the open circles connected by dashed lines. Although for both list lengths there is still a significant linear component [$F(1,280) = 50.25$ for Length 36 and $F(1,341) = 30.98$ for Length 48], the orthogonal quadratic component is now very evident [$F(1,280) = 32.11$ and $F(1,341) = 43.97$]. Thus, in contrast to NFR where group output order is left-to-right serial, in SFR the group output order tends toward early-late-middle.

Discussion

At this point we will do no more than summarize the results of Experiment I in an integrative way. Note first

Table 2
Mean Categories Entered and Mean Words Per Category Recalled in Normal and Speeded Free Recall for 1/6 and 6/6 Criteria

Statistic	1/6 NFR	1/6 SFR	6/6 NFR	6/6 SFR
Categories Entered	5.92	3.21	6.00	3.29
Words Per Category	4.62	3.63	4.98	4.00

the similarity of the curves in the upper panel of Fig. 1 and the SFR curves in Fig. 3. The stage of learning at which a particular group is entered (Fig. 1) is reflected nicely by the order of access in speeded free recall (Fig. 3). But neither this correspondence nor any implication of what these curves might mean can involve the S's knowledge of the internal contents of the groups. This is because the curves in the lower panel of Fig. 1 and the curves in Fig. 2, the curves reporting word retrievability given group access, are patently flat over serial position.

The effect of speed stress on free recall after serial learning comes in two parts. First, it markedly alters the output order of the subsequences that originally made up the serial task (see Fig. 3). Second, it reduces the number of elements produced from each group (see Table 1) and does so uniformly over group position (Fig. 2). Both of these effects of speed stress are to be taken in contrast to the situation where recall is leisurely, in which situation retrieval is serial and complete.

Finally, we found that list length had no interesting effect on any of the measures of performance we examined. Regretfully, we did not measure how fast our Ss proceeded through the lists, which of course leaves open the possibility that those Ss faced with the longer list gave themselves more time. In any event, the fact remains that list length did not affect any of our postlearning test statistics.

EXPERIMENT II

Method

In this experiment the serial list was 30 words long, partitioned into six groups of five related words each. Six categories were selected from the Battig and Montague (1969) norms and from each category the fourth through eighth most frequent exemplars were noted. The actual categories and words are: A METAL–gold, aluminum, silver, tin, zinc; A FOUR-FOOTED ANIMAL–cow, lion, tiger, elephant, pig; A PART OF A BUILDING–wall, floor, ceiling, room, basement; A MUSICAL INSTRUMENT–violin, clarinet, flute, guitar, saxophone; A SCIENCE–biology, zoology, botany, astronomy, mathematics; A VEGETABLE–bean, potato, tomato, lettuce, spinach. The five exemplars of a given category were arranged randomly on a single card. That arrangement remained fixed through all experimental manipulations. The cards themselves, however, were arranged in six different orders so that every category occurred at every serial position equally often over Ss.

The Ss were 48 female students in the University of Michigan. They were paid volunteers. Their task was exactly as in Experiment I, with the following exceptions: They were not told to mentally number the cards nor to form any images during acquisition. In speeded free recall (SFR), they were paid 10 cents a word for every word produced in 8 sec, knowing in advance that they would be stopped short at the end of 8 sec with no further chance at producing income.

All Ss received normal and speeded free recall tests. Prior to this, however, half of the Ss were taken to a 1/6 learning criterion, while the other half were taken to a 6/6 criterion. The 1/6 criterion is defined as perfect ordered anticipation of at least one of the six five-word groups, while the 6/6 criterion is a completely perfect recitation of the entire 30-word list.

Results

The 24 Ss taken to the 1/6 criterion met that criterion on the average in 1.67 trials (with a standard error of .16). The 24 Ss taken to the 6/6 perfect criterion required 4.71 trials (with a standard error of .27). Thus, the 6/6 Ss experienced, on the average, three more runs through the list than the 1/6 Ss.

An analysis of serial position effects in acquisition for this experiment is not particularly informative. For one thing, the 1/6 Ss did not get very far and, hence, the data necessary for a plot like Fig. 1 are mostly missing. For another, because of the number of categories (groups), the effective list length is too short for sizeable serial position effects to emerge in terms of the n_i/n measure for the 6/6 Ss.

In free recall a given S could enter six categories at most. The mean number of categories actually entered is shown in the top row of Table 2 for both degrees of learning (1/6, 6/6) and both free recall tests (NFR, SFR). A category was counted as having been entered even though in SFR her output was cut off while she was recalling from that category. In NFR nearly all Ss entered all six categories regardless of degree of learning (5.92 and 6.00). In SFR category entry was sharply reduced to a little over 3.2 categories, but again degree of learning was not a factor (3.21 vs 3.29). The mean number of categories precluded in SFR relative to NFR by the 8-sec cutoff was 2.71 for both degrees of learning, as can be computed from Table 2.

The second row in Table 2 reports the mean number of words recalled per category. (Again, only initial group entries contribute; subsequent reentries were excluded.) In the case of SFR, words recalled from categories interrupted by the 8-sec cutoff do not figure in the presented means. Proceeding as in Experiment I, those categories that were entered both in NFR and SFR were noted. For the 1/6 and 6/6 criteria, 56 and 58 such categories were identified. Then the mean number of words dropped per category was determined for each S. The NFR-to-SFR drop rate over Ss comes to .76 words per category for the 1/6 degree of learning. The 95% confidence interval is .46, 1.05. The corresponding mean for the 6/6 degree of learning is .81 words lost, with .47, 1.17 as the 95% confidence interval. Neither confidence interval comes close to including the null difference, and they cover approximately the same range of lost words per category.

Thus, what Table 2 shows is that the 8-sec deadline in speeded free recall reduced both category access and words-within-category access equally, regardless of degree of learning. The only effect of degree of learning apparent in Table 2 is that the 6/6 degree of learning leads to roughly .4 more words per category retrieved than the 1/6 degree of learning. In the case of NFR, the difference between 4.62 for 1/6 and 4.98 for 6/6 is not statistically assessible because of the ceiling of five words and the consequent limit on random error. In the case of SFR, the difference between 3.63 for 1/6 and 4.00 for 6/6 can be assessed as follows. Instead of averaging over all categories entered, we calculate for each S her mean words recalled per category (again ignoring categories cut off by the 8-sec limit) and use these means as the units of analysis, thus weighting each S equally. This increases the difference somewhat: 3.66 (with standard error .23) for 1/6 SFR and 4.15 (with standard error .16) for 6/6 SFR. The .49 difference has −.08, 1.05 as a 95% confidence interval, which includes the null difference.

Figure 4 shows the mean words recalled per category as a function of the list position of the category. The picture is entirely similar to the one shown in Fig. 2. Within-category production of words is not differential over list position at either degree of learning (1/6, 6/6) and either type of recall (NFR, SFR).

Figure 5 shows the relation between category output order in recall and category list order. (The procedure for handling missing categories was identical to that for Experiment I.) Again, filled circles with solid connecting lines are for NFR and open circles with dashed connecting lines are for SFR.

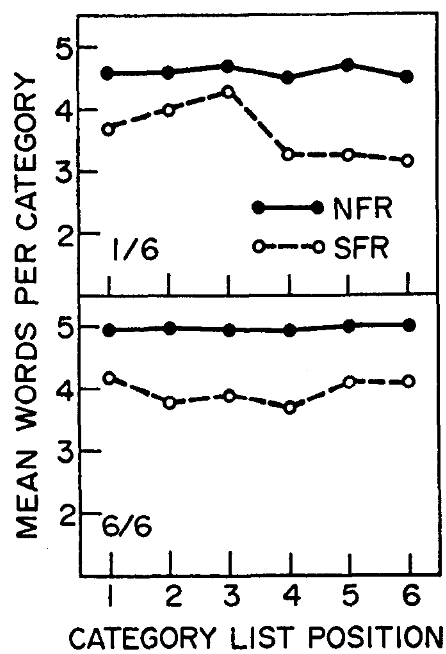

Fig. 4. Mean words per category in normal (NFR) and speeded (SFR) free recall. Learning criteria 1/6 and 6/6, Experiment II.

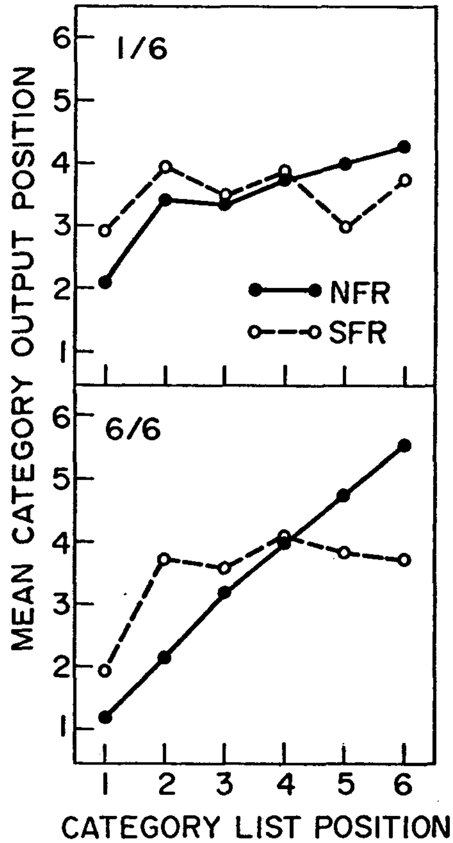

Fig. 5. Mean category output order in normal (NFR) and speeded (SFR) free recall. Learning criteria 1/6 and 6/6, Experiment II.

Consider first the results for NFR. The only orthogonal component of significance for either degree of learning is the linear component [$F(1,115) = 17.94$ for 1/6 and $F(1,115) = 376.39$ for 6/6]. The remaining components in combination yield $F \leqslant 1$ for both degrees of learning. The linear slopes for the 1/6 and 6/6 conditions are .36 and .87 (with standard errors of .078 and .041). The difference between the slopes is associated with $z = 5.80$. Thus, it is clear that degree of learning sharply affected order of category recall.

Consider now the results for SFR in Fig. 5. The curve relating output order to list position in the upper panel (1/6) has no significant trend components [$F(5,115) = 1.51$, $p = .20$ for all orthogonal components in combination]. The curve in the lower panel (6/6), however, has significant linear and quadratic components [$F(1,115) = 12.44$ and $F(1,115) = 10.60$]. Thus, even though the number of categories recalled prior to the 8-sec cutoff was the same for both degrees of learning (3.21 for 1/6 and 3.29 for 6/6, see Table 2), degree of learning nevertheless exerted a strong influence on recall order.

Discussion

A point worth noting is that the number of categories

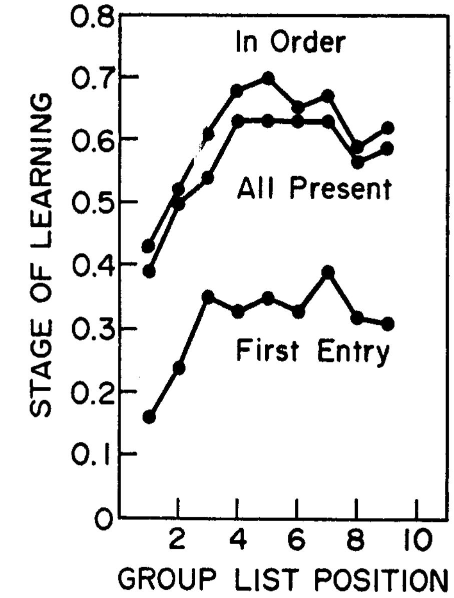

Fig. 6. Mean stage of learning of first group entry, all words present, and all words in correct order. List Length 36, Experiment I.

entered in normal free recall was the same regardless of degree of learning (5.92 vs 6.00 in Table 2). This is true also of speeded free recall (3.21 vs 3.29 in Table 2). Therefore, at least in a situation involving only six ordered categories, knowledge of the categories themselves must accrue in very short order. What is acquired over additional learning trials must be category order information. The change in linear slope from .36 to .87 for the 1/6 and 6/6 NFR curves in Fig. 5 documents this conclusion. The change from no trend of any kind to significant linear and quadratic trends for the 1/6 and 6/6 SFR curves in Fig. 5 is further documentation.

The effect of degree of learning on retrieval of words within categories was only marginal in this experiment. We have no doubt, however, that the effect is real and can be magnified. In fact, we have no doubt about not having any doubt because of what learning must necessarily entail.

GENERAL DISCUSSION

The principal empirical generalization from these two experiments is that accessibility of a given subsequence in a serial learning task is closely related to the serial position of that subsequence, while, in contrast, the retrievability of elements within a subsequence is not related to the serial position of that subsequence. The stage of learning at which a subsequence is first entered (Fig. 1) and the order of output in speeded free recall (Figs. 3 and 5) are similar quadratic functions of serial location. On the other hand, neither list length, degree of learning, nor speed stress induced differential recallability of words within a subsequence as a function of the serial location of the subsequence (Figs. 1, 2, and 4).

The principal theoretical inference suggested by these empirical facts is that serial learning is a multilevel process. Two levels are readily identifiable. One is learning about the elements and their arrangement within a subsequence. Another is learning about the subsequences as subsequences and how they are arranged. While it is true that in these experiments we imposed a priori subsequences, it is equally true that when left to their own devices Ss will generate their own idiosyncratic subsequences (Martin & Noreen, in press). Thus, our inference of multilevel organization we take as cogent irrespective of the source of subsequencing.

Granting at least two levels of organization, we are inclined to argue that retrieval is hierarchically ordered from top to bottom. The general experimental situation prompts search for a code or control element that represents a subsequence (group, category). Elements within a subsequence are not retrieved until the code for that subsequence is retrieved. On this view, the bowed serial position curves for speeded free recall in Figs. 3 and 5 indicate the relative accessibility of the codes that represent the several subsequences. What the flat serial position curves in Figs. 2 and 4 indicate is that the effectiveness of a subsequence code for prompting the elements subsumed under that code is the same, regardless of the list position of the subsequence, that is, regardless of the accessibility of the code.

Nothing inherent in this position requires that element retrieval given code retrieval be a flat function of the serial position of the subsequence. Accordingly, the fact that such functions are flat (Figs. 1, 2, and 4) can be used to make a further inference about the serial learning process. The inference we have in mind is that subsequence learning, and hence subsequence code formation, precedes development of code accessibility and code order information.

It is possible to make an empirical case for this inference by examining the time course of acquisition during serial learning. Recall that the upper panel in Fig. 1 shows the mean stage of learning, n_i/n, at which a group was first entered. In that analysis, n_i was the trial on which a given S first accessed the group at Position i, and n was the total number of trials to criterion. We can repeat this type of analysis letting n_i be the first trial on which all four words of the group at Position i were produced, without regard for correctness of order. And we can do it all over again letting n_i be the first trial on which all four words were not only produced but also produced in their correct serial order. The resulting three functions are shown in Fig. 6 for the 36-word list from Experiment I. The bottom curve is repeated from Fig. 1. The 48-word list shows an identical pattern.

From bottom to top in Fig. 6, the three curves show the stage of learning when the group was first entered, when all four words were first produced, and when all four words were first produced in correct order. The salient feature of these curves is that they all have the same shape: A McCrary-Hunter (1953) normalization yields essentially coincidental functions. If we consider the height of a given point on the bottom curve as an index of when Ss got started on the group at that position, then the homologous curves for all present and all present in order mean that within-group acquisition proceeded at the same pace regardless of the list position of the group.

Groups at some serial positions, like Positions 1 and 2, were entered earlier and completed earlier than groups at other serial positions, like Positions 4 and 5. There is, however, no evidence of further consolidation or strengthening of the earlier groups relative to the later groups. This is evident from the flat functions in Figures 2 and 4. The trials subsequent to mastery of the groups, then, must have been addressed to developing accessibility of the group codes. The shape of the curves in Fig. 6 argues that less of this could have taken place for groups in the middle of the list. Enough of such access and order learning took place to meet the learning criterion and to support nearly perfect serial recall in the leisurely test condition (NFR in Figs. 3 and 5) but not enough to survive recall under stressed test conditions (SFR in Figs. 3 and 5).

The foregoing argument that within-subsequence learning precedes development of subsequence access and order information is more a matter of plausibility than proof. But we can bolster the plausibility further by pointing out that, for subjective subsequences, Martin and Noreen (in press) found that within-subsequence word order correlated with list order much more strongly than did the subsequences themselves in a free recall test following serial learning to a subperfect criterion.

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