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Memory units and the composition of recall

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The unitization hypothesis of organization predicts that different levels of free recall should be accounted for by the number of additional items recalled as part of higher order memory units. This prediction was tested by using various instructional procedures to obtain different levels of total recall from normal elderly subjects, identifying their memory units in order to analyze the composition of recall. The composition of recall shows that different levels of recall are accounted for by the number of additional items recalled as part of a constant number of multiitem units. These results directly confirm the unitization hypothesis.

There is considerable evidence for the importance of organization in human learning and memory (e.g., Tulving & Donaldson, 1972). In multitrial free recall, which has served as the most common means for studying this phenomenon, organization refers to the tendency of subjects to group, or recode, individual list items into higher order units, or chunks. Such groups consist of small clusters of items that tend to be recalled together consistently over trials. Free recall learning is believed to depend on organization, since the growth of recall during learning has been attributed to increasing organization of the list items.

The role of organization in free recall learning has usually been interpreted in terms of the unitization hypothesis (Miller, 1956). According to this hypothesis, subjects can process only a limited number of units, or chunks, of information. Organization provides a means for overcoming this limitation, since the grouping of individual list items into larger multiitem units allows subjects to recall more items without increasing the number of units that need to be retrieved. The unitization hypothesis therefore predicts that increasing recall during learning, as well as differences in recall obtained under different experimental conditions, should be accounted for mainly by the number of additional items recalled as part of such larger, multiitem units. However, this prediction has never been directly tested, since methods for identifying actual recall units have not been available. Most of the evidence in support of the unitization hypothesis has generally been derived from correlational analyses carried out between some quantitative estimate of organization and total recall. However, a direct test of the unitization hypothesis would seem to require analyses of the composition of recall, so that total recall can be examined directly in relation to the actual units of recall.

This experiment provides such a direct test of the unitization hypothesis. It was carried out under conditions designed to induce different levels of free recall performance in order to test the prediction that such differences can be accounted for by the number of additional items recalled as part of multiitem units. Free recall learning by normal, elderly persons was used to obtain different levels of recall. These subjects were used because their performance can be improved by various instructional techniques designed to encourage them to organize the to-be-learned items (Craik, 1977).

Grouping during recall was identified by two-dimensional (2D) recall, which requires the subject to write items in the actual groups in which they were remembered (Buschke, 1977). This method was used to analyze the different levels of total recall in terms of the number of single-item and multiitem units and, most important, in terms of the number of additional items recalled as part of such multiitem groups.

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METHOD

Subjects

Subjects were 48 normal community-dwelling adult volunteers aged 60 to 83 years (mean = 69, SD = 5.42), who were randomly assigned to one of four conditions (n = 12). They were members of the same senior citizens' center and gave informed written consent. They were tested in small groups.

Design

Sorting and 2D recall were used to obtain different levels of free recall learning. Each subject learned two lists of items: one

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by sorting the list items into groups and one by standard multitrial free recall (study-test learning). Sorting required the subject to sort the list items into groups on four consecutive trials and then to recall the sorted items on four consecutive trials without further presentation of the list. The interval between sorting and recall of the sorted items depended upon the condition to which the subject had been assigned. In free recall learning, the subject was given four alternating study-test trials and was also subsequently tested on four additional trials of recall without presentation. These additional trials were used to determine the total number of items learned during the preceding study-test trials. Two-dimensional recall was used only in some conditions of free recall learning. The experimental conditions were as follows:

Condition 1 (LL-LR-s-sr_{2D}): These subjects first learned (LL) and recalled (LR) the study-test list without 2D recall. They then sorted (s) the second list and recalled the sorted items with 2D recall (sr_{2D}). This condition provided a baseline measure of list learning without experimental manipulations.

Condition 2 (s-LL-LR_{2D}-sr-$_{2D}$): These subjects first sorted one list (s) for four trials and then learned and recalled the study-test list using 2D recall only during the four trials of recall without presentation (LL-LR_{2D}). This was followed by 2D recall of the previously sorted items (sr_{2D}). Sorting preceded the learning of the study-test list in this and in the next condition because some elderly subjects did not understand the instructions for 2D recall without previous grouping experience. In this condition, 2D recall was used only to identify grouping in recall without presentation.

Condition 3 (s-LL_{2D}-LR_{2D}-sr_{2D}): This condition was almost the same as Condition 2, except that 2D recall was also used in the study-test trials in order to increase learning and recall.

Condition 4 (s-sr_{2D}-LL_{2D}-LR_{2D}): In this condition, both sorting (s) and 2D recall of the sorted items (sr_{2D}) preceded study-test learning and recall using 2D recall throughout (LL_{2D}-LR_{2D}). This condition was intended to obtain maximum recall because subjects learned the second list after experience with grouping and 2D recall, using recall during learning.

This experiment is concerned only with the composition of recall at increasing levels of learning in order to determine whether differences in recall are due to differences in the number of additional items recalled as part of multiitem groups. The causes of the increasing recall obtained by these experimental conditions are not analyzed, since these conditions were selected empirically to increase recall.

Materials

Each subject learned two lists of 16 unrelated four-letter nouns that were high in frequency, meaningfulness, concreteness, and imagery. These two lists were counterbalanced so that each was used for sorting and presented for study-test learning half of the time.

Each subject was provided a set of response forms for 2D recall. These forms contained a grid of spaces arranged in 10 columns and 20 rows, so that subjects could indicate items recalled as part of groups by writing each group in a separate column. When 2D was not used, the subjects wrote all of the recalled items sequentially in the left-hand column.

Procedure

In study-test learning, the items were read to the subject in a random order at a 3-sec rate for free recall in any order immediately following each presentation. In sorting, the subjects sorted items printed on cards into four groups of four items each. Each subject was allowed as much time as desired to sort the items, with the understanding that the items should be sorted the same way on the next trial. On each trial after the first, each subject tried to sort the items into the same group as on the previous trial. All of the items were visible throughout sorting, so that subjects could inspect all of the items before sorting and revise the groups freely. Subjects sorted the cards by arranging them into four columns of four items each. The experimenter recorded the groups made by each subject. The subjects were not told that they were expected to remember the sorted items later.

When 2D recall was to be used, the following instructions were read to the subject: "When you are recalling the words, some will come into your mind alone and some may come together, as groups. In order for me [the experimenter] to see which items you remember as groups and which you remember alone, write any items which come to mind together in the same column of your response sheet. Different groups get written in different columns. Items which you remember alone get written each in its own column. Remember, write as many items as you can, in the order in which they come to mind."

RESULTS AND DISCUSSION

In order to show that increasing levels of free recall are mainly due to the number of additional items recalled as part of multiitem units, unitization must necessarily be allowed to occur under relatively unconstrained conditions. Since learning by sorting experimentally controls unitization, the sorting recall data are not directly pertinent to the primary purpose of this experiment and, therefore, are not described here. The following analyses focus only on the list learning data.

The number of items recalled on each trial of study-test learning, as well as on subsequent recall without presentation, was computed in order to evaluate the effects of the instructional manipulations on the subjects' level of recall. In addition, the composition of each subjects' recall was analyzed in order to identify the subjects' actual recall units and the number of items recalled as part of such units.

Level of Recall

Figure 1 displays the mean number of items recalled on Trials 1-4 of study-test learning (LL) and the cumulative number of items retrieved (LR) subsequently by repeated recall without presentation on Trials 5-8. The latter provides an estimate of the number of items learned during the four trials of study-test learning.

Analysis of study-test learning showed that the effects of trials [$F(3,132) = 98.27$, $p < .001$], conditions [$F(3,44) = 23.26$, $p < .001$], and the interaction between these two factors [$F(9,132) = 2.07$, $p < .05$] all were significant. As Figure 1 shows, the mean number of items recalled during study-test learning was greater in Condition 4 than in Condition 3, and recall in both of these conditions (which used 2D recall during learning) was greater than recall in either Condition 1 or 2. Post hoc comparisons by Newman-Keuls tests confirmed these effects (all $ps < .05$). There was no significant difference in the number of items recalled in Conditions 1 and 2.

Analyses of the subsequent recall without additional presentation yielded similar findings. The number of items recalled without presentation differed significantly in the three instructional conditions [$F(3,44) = 21.68$,

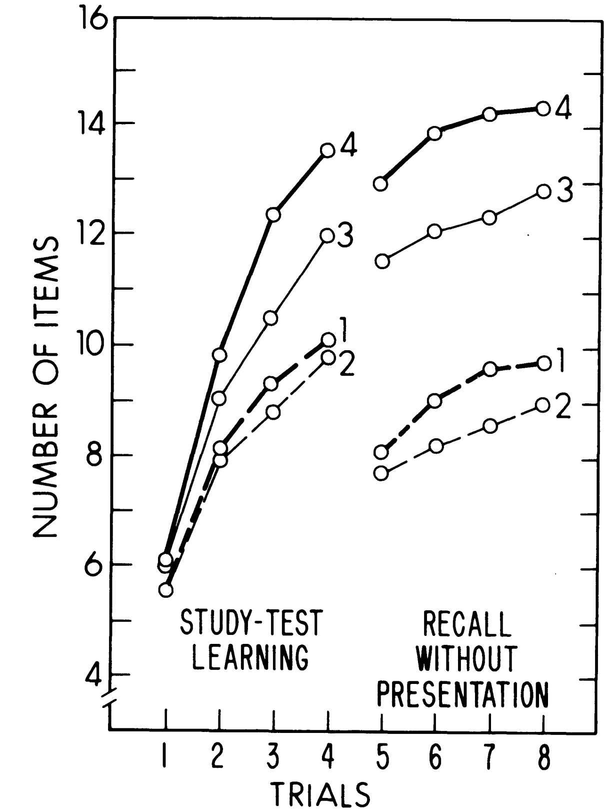

Figure 1. Mean number of items recalled on each trial of study-test learning and cumulative number of different items recalled without further presentation after learning in each of the four conditions: 1 = LL-LR-s-sr_{2D}, 2 = s-LL-LR_{2D}, 3 = $\text{s-LL}_{2D}\text{-LR}_{2D}\text{-sr}_{2D}$, and 4 = $\text{s-sr}_{2D}\text{-LL}_{2D}\text{-LR}_{2D}$, where LL = list learning, LR = recall after list learning, s = sorting, sr = recall after sorting, and 2D = two-dimension recall. Note that 2D recall was used during list learning in Conditions 3 and 4.

$p < .001$]. Newman-Keuls tests confirm that more items were recalled in Condition 4 than in Condition 3, and subjects in both of these conditions recalled significantly more items than those in Conditions 1 and 2 (all $ps < .05$). There were no significant differences between the latter two groups.

These results indicate that increasing levels of recall were obtained under the present conditions. In order to test the unitization hypothesis, the composition of recall in each condition was analyzed to determine whether the number of additional items recalled as part of multiitem units accounts for the increasing recall found here.

Composition of Recall

The 2D recall procedure was used to identify each subject's units in recall and to analyze the composition of recall. In this analysis, recall consists of two types of units: multiitem units, which are groups of two or more items recalled together, and single-item units, which are items recalled alone. The number of multiitem units is given by the number of items recalled as initial items of such units. The total number of units, therefore, is the number of initial items of the multiitems groups plus the number of single items. In recall of multiitem units, the initial item is retrieved along with one or more additional items recalled as part of that same unit. Such additional items are critical for analysis of the composition of recall in this experiment because they show the effects of unitization. Total recall is the sum of these three components: single items, initial items, and additional items.

Figure 2 shows the composition of recall for Conditions 2, 3, and 4 during repeated recall without presentation following study-test learning. Two trends are apparent in these data. First, despite differences in the level of recall between these three conditions, the number of units recalled in each remained constant (as shown by the heavy horizontal line) [$F(2,33) = 1.59$, $p < .05$]. What did change between these conditions, however, was the number of additional items recalled as part of multiitem units [$F(2,33) = 15.91$, $p < .001$]. Recall increased because the number of additional items recalled as part of multiitem units increased. Across Conditions 2, 3, and 4, fewer items were recalled as single-item units [$F(2,33) = 4.28$, $p < .05$], and more multiitem units were recalled [$F(2,33) = 5.92$, $p < .001$], and the total number of units recalled remained constant across all three conditions.

These results confirm the unitization hypothesis, since they show that the different levels of recall are largely accounted for by the number of additional items recalled as part of multiitem units. As predicted

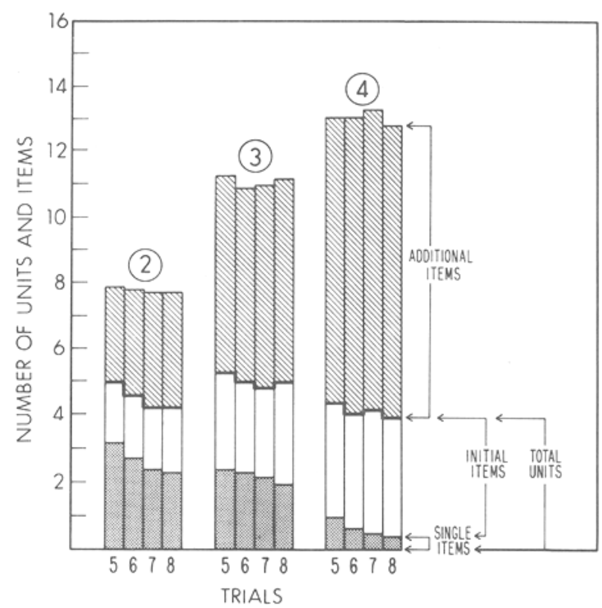

Figure 2. Mean number of items recalled on each trial of recall without presentation. The 2D recall allows identification of the components of recall: single items (those recalled alone), initial items of groups (the number of multiitem units), and additional items recalled as part of multiitem units. The total number of units recalled is indicated by the heavy horizontal line and is the sum of single items and initial items of groups (single-item units + multiitem units).

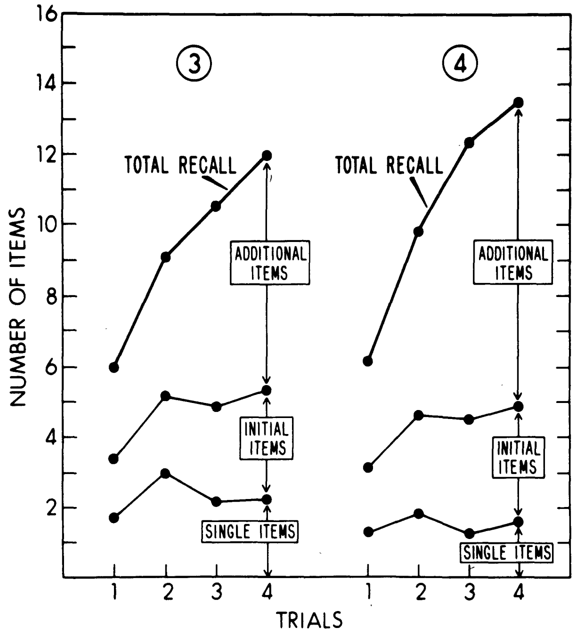

Figure 3. Composition of total recall on each trial of list learning in Conditions 3 (s-LL_{2D}-LR_{2D}-sr_{2D}) and 4 (s-sr_{2D}-LL_{2D}-LR_{2D}), in which components of recall are identified by 2D recall.

by this hypothesis, the increase in recall obtained across Conditions 2, 3, and 4 was due to the increasing number of such additional items recalled as part of multiitem units.

Unitization during learning is shown by analysis of the composition of recall during study-test learning (Conditions 3 and 4). Figure 3 shows the same pattern of recall as was found in recall without presentation.

The increase of total recall over trials is accounted for by the increasing number of additional items recalled as part of multiitem groups in both Condition 3 [$F(2,11) = 5.03$, $p < .05$] and Condition 4 [$F(2,11) = 6.26$, $p < .05$]. The number of such units (i.e., single items and initial items) recalled, however, remained constant from Trial 2 on in both conditions ($F < 1$). As in recall without presentation, the difference in total recall between Conditions 3 and 4 is due to recall of more additional items in the latter condition. These results also confirm the unitization hypothesis. These results indicate that the composition of recall after learning reflects the unitization that occurred during learning (see Figures 2 and 3).

This analysis of the composition of recall directly confirms the unitization hypothesis. As predicted, differences in total recall are accounted for largely by differences in the number of additional items recalled as part of multiitem units, and increasing recall during learning is accounted for largely by the increasing number of additional items recalled as part of multiitem units.

It is apparent that recall of additional items as part of multiitem units could be due to recall of more multiitem units, recall of larger units, or both. However, most of the increasing recall should be due to recall of larger units, if total recall is to increase in spite of limitations on the number of units that can be retrieved. Tulving (1964, p. 219) predicted that "the increase in intertrial retention as a function of practice reflects the growth in the size, but not the number, of subjective units of material that the subject can retrieve from the memory storage. . . ."

The present findings are consistent with this prediction (Figures 2 and 3), since they show that the number of items increases while the number of units remains constant. Most of the increasing recall in learning must therefore be accounted for by recall of larger units.

In addition to accounting for differences in total recall, the number of additional items recalled as part of multiitem units also provides a simple and direct measure of organization. This measure takes into account both the size and number of units without requiring detailed analysis of these two components of recall. Since each additional item indicates that an act of unitization has occurred, the total number of additional items reflects the amount of organization in recall.

While this experiment is limited to analysis of free recall learning of unrelated items, the present results suggest that identification of memory units and analysis of the composition of recall have the potential to increase our understanding of other kinds of learning and memory, including text-based memory and retrieval of permanent knowledge.

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