*Journal of Experimental Psychology*
1971, Vol. 89, No. 1, 63–77

# ANALYSIS OF REHEARSAL PROCESSES IN FREE RECALL [1]†

DEWEY RUNDUS [2]

*Stanford University*

Following the procedure previously described by Rundus and Atkinson, overt rehearsal was required during the presentation of free recall lists. This rehearsal was tape-recorded and analyzed in conjunction with written recall data. Experiment I considered rehearsal and recall of lists of unrelated nouns. The serial position effect, the order of recall of items as a function of item strength, and the organization of list items by *S* were examined using rehearsal and recall protocols. The introduction of distinctive items into a free recall list affects recall of the distinctive item, items adjacent to distinctive items, and the list as a whole. Experiment II examined changes in rehearsal associated with these recall effects. In Exp. III, some items of a list were repeated. Recall of repeated items increased with spacing of the repetitions; an analysis of the rehearsal protocols suggested reasons for this increase. Lists containing both categorized and unrelated items were tested in Exp. IV. Category information was used extensively by *S* in structuring rehearsal. Clustering in recall was related to the observed rehearsal protocols.

The interpretation of memory phenomena found in free recall studies must be based on the understanding of *S* rehearsal processes. The concept of rehearsal has proved to be a most intricate and enigmatic proposition, the mechanisms of which have usually been inferred from complex analyses of test results. More specifically, input variables (presentation time, item order, interitem relations) are manipulated, changes in recall are noted, and the rehearsal process is posited as a logical extension of this empirical evidence. One problem with this inferential or "black box" approach is that until sufficient data are amassed from a variety of experiments, a number of cogent descriptions of rehearsal processes can be supported. For example, it may be that items are treated more or less independently, with rehearsal serving to increase item availability (Asch & Ebenholtz, 1962), or more generally, to strengthen their memory trace (Slamecka, 1968). Several items may be considered together, with rehearsal serving to form interitem associations or strengthen preexisting ones (Bousfield, 1953). It has also been suggested that an important part of rehearsal may be the formation of mnemonics or images (Bower, 1970).

Another approach to the understanding of rehearsal has been to instruct *S* to use some particular rehearsal strategy. One example of this approach is to require *S* to repeat each item aloud several times as it is being presented. This procedure produces a reduction in overall recall and a change in the shape of the serial position curve (Fischler, Rundus, & Atkinson, 1970; Glanzer & Meinzer, 1967). In these and other similar experiments which provide strict control of *S*'s rehearsal, it is possible to observe which rehearsal strategies are able to account for various free recall data. It would be highly desirable, however, to determine what *S* is doing in rehearsal while still allowing him flexibility in his choice of strategies.

The studies reported here employed an overt rehearsal technique described by Rundus and Atkinson (1970) allowing direct observation of *S*'s rehearsal. This procedure provides rehearsal data in a form that may be used in comparisons across *S*s while imposing a minimum of restrictions on *S*'s choice of rehearsal strategies. As a list is being presented, *S*

[1] This paper is based on a dissertation submitted to Stanford University. The author is grateful for the advice and encouragement of Richard C. Atkinson and the helpful comments of G. H. Bower and H. Clark. This research was supported by the National Science Foundation under Grant NSF-G3-443X and a graduate fellowship to the author.

[2] Requests for reprints should be sent to Dewey Rundus, now at the Rockfeller University, New York, New York 10021.

is instructed to study by rehearsing aloud any item or combination of items which he has seen in the list. The resulting rehearsal protocols are tape-recorded and later analyzed in conjunction with *S*'s free recall output.

Although, in the procedure described, the recorded rehearsal protocols for *S* consist only of repetitions of items, this does not imply that *S* is rehearsing by simple repetition. Higher order strategies used by *S* should be reflected in the rehearsal data. If items are being "associated," if words are being coded with mnemonics, or if images of word groups are formed, then items in these groups should appear together in the rehearsal protocols. Thus the exact coding strategy would be unknown, but any organization of the list by *S* should be observable.

The dual-storage model proposed by Atkinson and Shiffrin (1968) provides a framework for much of the discussion to follow. The model assumes that recall of an item is based upon the retrieval of information from both a temporary but highly available short-term store (STS) and a more permanent long-term store (LTS). Of special interest is a proposed rehearsal buffer consisting of a limited number of items in STS which *S* has chosen to rehearse actively. When a new item is presented for study, that item enters STS. This new item may then be chosen for inclusion in the rehearsal buffer. Due to the limited capacity of the rehearsal buffer, the entry of a new item into a full buffer necessitates the deletion of one of the items currently in the buffer. Rehearsal of an item is assumed to maintain that item in STS. This rehearsal serves a twofold purpose. First, if an item is still being rehearsed at the time of test, information about the item will be retrievable from the highly available STS. Second, the model postulates that transfer of information about an item to LTS occurs only while that item resides in STS. Since the probability of recalling an item from LTS is assumed to be a positive function of the amount of LTS information about the item, it follows that the longer an item is maintained in STS via rehearsal, the higher will be its recall probability.

The primacy and recency effects, usually observed in the U-shaped serial position curves of free recall studies, prove amenable to the dual-storage assumptions of a model such as the one described. The recency effect refers to the high recall probability of the last few items of a list. Since the time between presentation of these items and the recall test is short, information about them should still be retrievable from STS. Any activity between study and test which disrupts STS should minimize retrieval of useful information from STS and thus reduce the recency effect. Such a reduction was observed in studies by Postman and Phillips (1965) and Glanzer and Cunitz (1966). In both experiments, a mathematics task was interpolated between the study of a list and its test. The recency effect was virtually eliminated while little change was observed in the rest of the serial position curve.

The primacy effect, the high probability of recall observed for initial list items, is more difficult to explain. It is highly unlikely that *S* would maintain the initial list items in STS until the time of test; therefore, primacy must be a LTS phenomenon. At the beginning of list study there are few items competing for *S*'s attention and thus these items should receive a good deal of rehearsal. In addition, the initial list items may be maintained in rehearsal as later items are being shown, thus gaining rehearsal at the expense of items from the middle of the list. Since LTS information, and consequently recall probability, is assumed to increase with rehearsal, a major component of the primacy effect may be the extensive rehearsal accorded initial items. Fischler, Rundus, and Atkinson (1970) tested this interpretation by attempting to equate rehearsal of all list items. This was accomplished by instructing *S* to fill his study time by overtly repeating, at a steady rate, only the item being displayed. This procedure sharply reduced the primacy effect while only slightly lowering recall for middle list items and leaving the recency effect unchanged. The observed decrement in primacy supports the interpretation that additional rehearsal accorded initial list items is a main factor in the primacy effect. Even with rehearsal thus equated, a slight primacy effect persisted. This suggests that other factors such as the distinctiveness of the initial study positions or the importance of initial items in *S*'s organizational scheme contribute to primacy.

Structural features of rehearsal, the relationship between rehearsal and recall, output order as a function of item strength, and subjective organization in lists of unrelated words were examined in Exp. I. The next two experiments involved manipulations of items within a list of unrelated words. Experiment II considered changes in rehearsal and recall caused by introducing distinctive items into the study list. The effects of repeating items within a list and varying the spacing between the repetitions were explored in Exp. III. The final experiment examined the nature of *S*'s rehearsal, the relationship between rehearsal and recall, and features of output for lists containing categories.

## General Method and Analysis

The procedure involved in the collection and analysis of *S*'s rehearsal protocols was common to all studies. Methodology particular to each experiment will be described in the section dealing with that experiment.

*Subjects.*—Female undergraduate volunteers from the introductory psychology course at Stanford University served as *S*s. Class credit was given for participation. Each *S* served in one, 50-min. session.

*Procedure.*—During a session, *S* was shown 11 lists of nouns. The order of presentation of lists during a session and the order of words within a list were randomized for each *S*. Following presentation of a list, *S* was given a 2-min. written free recall test on that list. List items were printed on 4 × 6 in. index cards, one word per card. During study, cards bearing each list item were displayed one at a time, each card being shown for 5 sec. A timer-generated tone followed each 5-sec. interval and signaled the display of a new item. The *S*s were instructed to study by repeating aloud items from the current list during the 5-sec. study intervals. There were no restrictions placed upon the choice of items to be rehearsed or the rate of rehearsal as long as *S*'s rehearsal filled each interval. No *S* reported difficulty in following these instructions. A cassette tape recorder was used to record *S*'s rehearsal on all lists.

*Analysis.*—The recorded rehearsal protocols were coded numerically and analyzed on a computer. The tone pulses that had served to signal the display of a new item were used to partition the rehearsal from each trial into rehearsal sets (RS). An RS was associated with each item of the list and consisted of all rehearsals recorded during the 5 sec. while that item was being presented. If an item was repeated more than once in a given RS, each occurrence was counted in determining the total number of rehearsals accorded that item. Within each experiment, the first list presented to each *S* was the same and was used as a practice list. The data from this list were excluded from analysis.

### *Experiment I*

This study was designed to replicate and extend the findings of Rundus and Atkinson (1970) concerning free recall following a single presentation of a list of unrelated words.

*Method.*—Twenty-five *S*s were each presented 11 free recall lists. Each list consisted of 20 "unrelated" nouns with Thorndike and Lorge frequencies of occurrence from 10 to 40 per million. Recorded rehearsal protocols and written free recall data were collected. The order of presentation of the lists and item order within a list were random for each *S*. The first list was the same for all *S*s and was not included in analysis.

*Results and discussion.*—In Fig. 1, the recall probability of an item, $P(\mathrm{R})$, is shown as a function of its serial position in the study list. The U-shaped function exhibits both primacy and recency effects. Also shown in Fig. 1 is a plot of the mean number of rehearsals given an item as a function of its serial position. Number of rehearsals is seen to be quite high for the early list items and to decrease steadily as a function of serial position. Although not explicitly instructed to do so, *S* nearly always rehearsed an item at least once during the 5-sec. interval while it was being shown. The probability that an item was rehearsed while being presented was .996.

An item did not always appear in a continuous succession of RSs. An item might be entered into rehearsal, be absent from one or more RSs, and reappear in a later RS. Thus there are three types of items which may be included in RS: (*a*) the item being presented, (*b*) items from the immediately preceding RS, and (*c*) items not in the immediately preceding RS which have been returned to rehearsal after being absent from some number of intervening RSs. The mean proportions of the items in an RS from the middle of a list (Positions 4–18) which belong to these three classes were .31, .47, and .21, respectively. While it may be seen that the bulk of RS is made up of the new item and items from the immediately preceding RS, nearly one-fourth of the items in RS were returned to rehearsal following an absence. The proportions of these returned items which had been absent from rehearsal for 1, 2, 3, 4, 5, or 6 + intervening RSs were .57, .19, .10, .05, .05, and .05, respectively.

Figure 2 presents $P(\mathrm{R})$ for an item as a function of the last RS in which that item appeared. This function is fairly flat for the first two-thirds of the list and then rapidly increases to a high probability for items being rehearsed at the end of the study list. Recall probability was the same (.96) for all items present in the final RS. This $P(\mathrm{R})$ was the same as that observed for the final list item, suggesting that it is the presence of an item in rehearsal at the end of list study which gives rise to the recency effect.

Figure 3 presents $P(\mathrm{R})$ for an item as a function of the mean normalized number of rehearsals accorded the item during list study for items from serial positions 1–4, 5–10, 11–16, and 17–20. The measure of normalized number of rehearsals is found by dividing the number of rehearsals of an item by the total number of rehearsals for all items in that particular *S* list. Thus the normalized number of rehearsals is a measure of the proportion of the total rehearsals of a given *S* list which were accorded an item. This measure avoids a possible confounding due to different average rehearsal rates of different *S*s. For all curves in Fig. 3, $P(\mathrm{R})$ is seen to increase with amount of rehearsal. The curves for items from the first 16 serial positions are virtually identical. For a given amount of rehearsal, items from the initial serial positions have no better recall than items from the middle of the list. It thus appears

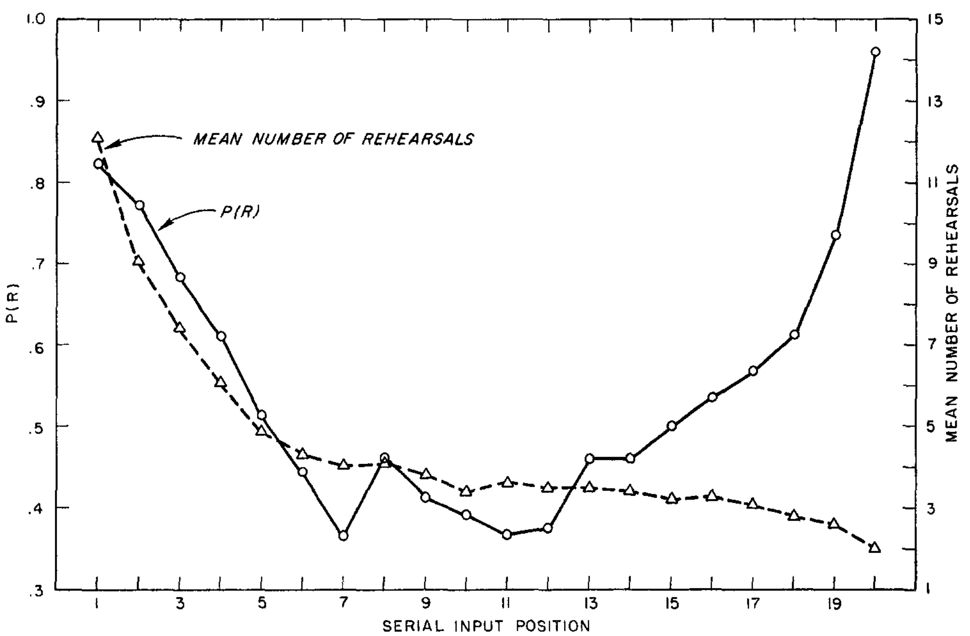


FIG. 1. The mean probability of recall, $P(\mathrm{R})$, and the mean number of rehearsals of an item as a function of its serial input position.

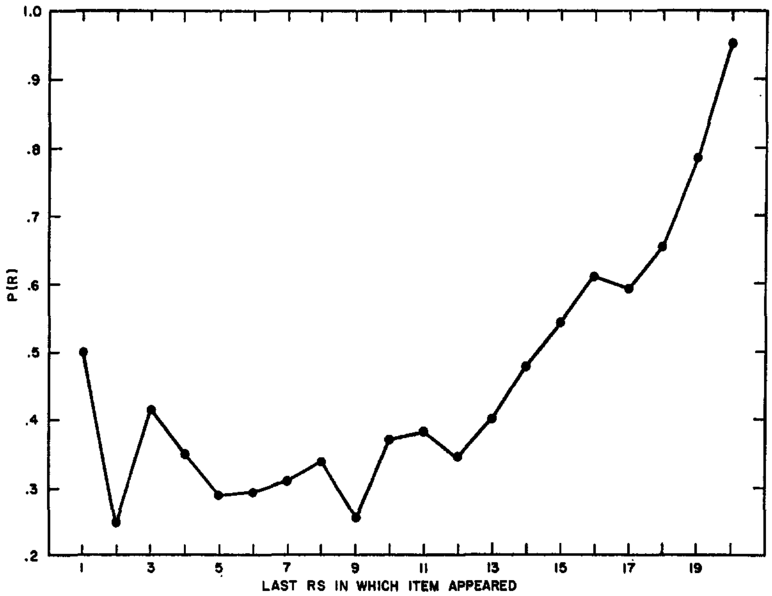


FIG. 2. The mean probability of recall, $P(R)$, of an item as a function of the last RS in which that item appeared.

that the primacy effect derives from the additional rehearsal accorded the initial list items. The curve for items from Serial Positions 17–20 is, at all points, above the other curves. This is not unexpected since items from the last list positions should have a high probability of being present in *S*'s rehearsal at the time of test and thus be retrievable on the basis of both STS and LTS information. Previous studies (Rundus & Atkinson, 1970; Rundus, Loftus, & Atkinson, 1970) have produced results similar to those shown in Fig. 3 and provide support for the conclusion that amount of rehearsal accorded an item is a good indicator of the memory strength of the item.

The relationship between the order in which items are recalled and their strength in memory has been the subject of some controversy. Data have been presented (Bousfield, Whitmarsh, & Esterson, 1958; Underwood & Schulz, 1960) which suggest that the strongest or best learned items are recalled first; while Battig, Allen, & Jensen (1965) present results supporting an opposite hypothesis. There is also evidence (Shuell & Keppel, 1968) that terminal list items appear early in recall. A dual-storage model might suggest that *S*s first recall items from the temporary STS and then attempt to recall on the basis of LTS strength those items which are no

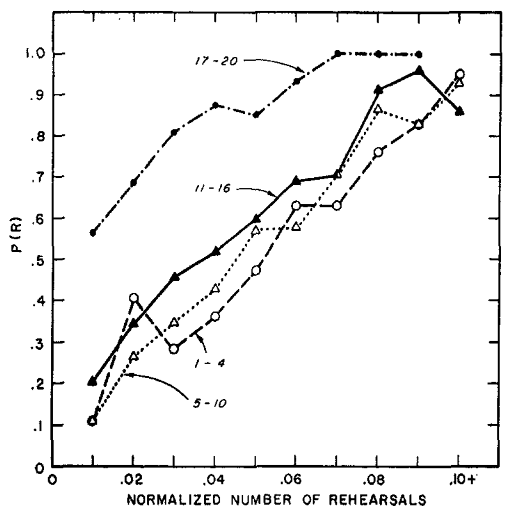


FIG. 3. The probability of recalling an item, $P(R)$, as a function of the mean normalized number of rehearsals accorded the item. (Shown for items here from Serial Positions 1–4, 5–10, 11–16, and 17–20. The circled numbers indicate the approximate mean number of rehearsals corresponding to a given mean normalized number of rehearsals.)

longer in STS. In the present study, it was observed that 93% of the time the first item recalled was present in the final RS. Figure 4 shows the proportion of those items present in the final RS which appear at various output positions. It is evident that items in the final RS appear early in output. The same function for items whose final rehearsal was in an earlier RS (the 15th RS was chosen as representative) is also shown in Fig. 4. A comparison of these two functions supports the hypothesis that items in STS at the time of test appear early in the output protocol.

The positive relationship between $P(\mathrm{R})$ and rehearsal (see Fig. 3) suggests that amount of rehearsal provides a good indicator of memory strength. It should be possible, therefore, to use the rehearsal data to relate the position of an item in the output protocol to its strength relative to other recalled items. In Fig. 5, the normalized number of rehearsals accorded an item is shown as a function of the Vincentized proportion of the output protocol in which the item appeared. In the Vincentizing procedure (Hilgard, 1938), the output protocol for each $S$ list is divided into equal parts, in this case sixths. The mean normalized number of rehearsals for items in each part is then computed. The average for each sixth of output is then calculated across all $S$ lists, yielding a single curve in which each $S$ contributes equally to each point.

When all list items are included in the analysis, the curve is seen to rise rapidly to a peak and then decline with output position. This function contains items recalled from both STS and LTS. The STS component may be minimized by deleting those items which appeared in final RSs. The function obtained when items present in the final two RSs are deleted is also shown in Fig. 5. With the STS component deleted, the order of recall is seen to be a function of item strength, with the items which received the most rehearsal appearing earliest in output.

A study of Rundus et al. (1970) provides further support for the observed relation

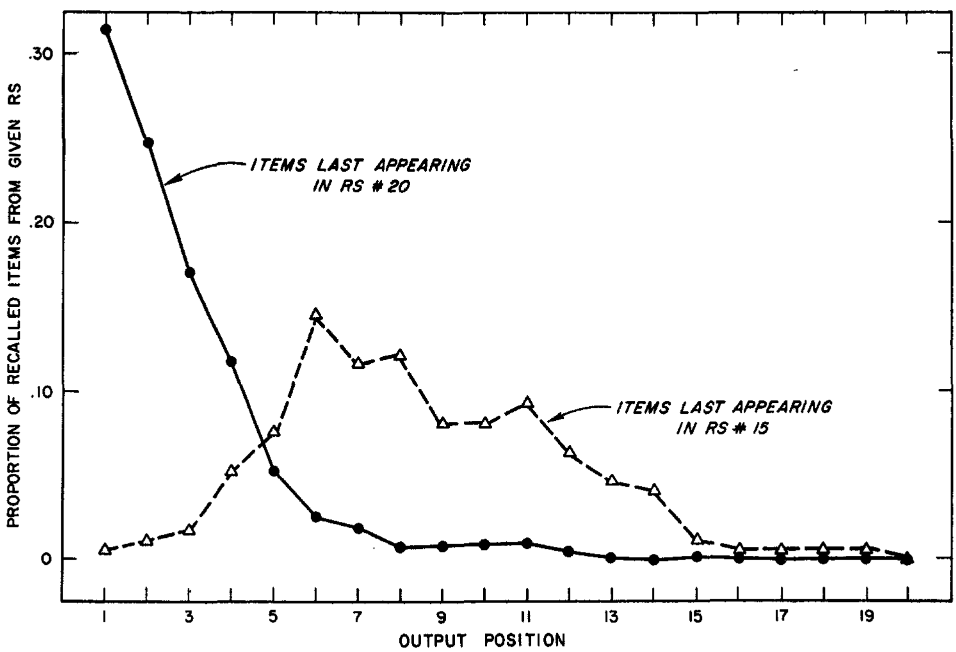


FIG. 4. For all recalled items whose last rehearsal occurred in RS #20, the proportion of those items recalled at various output positions is shown as a function of output position. (Also shown for items last rehearsed in RS #15.)

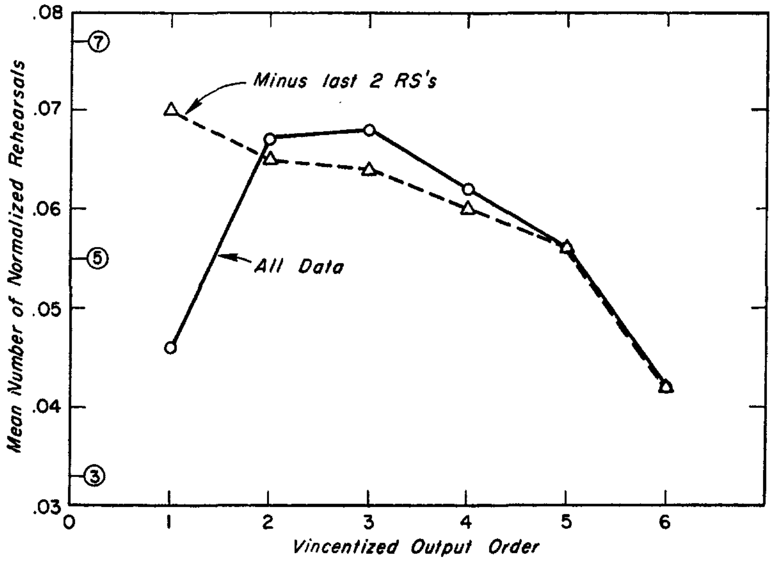


FIG. 5. The mean normalized number of rehearsals of recalled items is shown as a function of the sixth of the Vincentized output protocol in which the item was recalled. (Shown for all items and for all items not appearing in either of the final two RSs. The cricled numbers indicate the approximate number of rehearsals corresponding to a given mean normalized number of rehearsals.)

between item strength and output order. In their study, *S*s were given single free recall trials on 10 lists of words. Three weeks later, *S*s returned and were given a recognition test on all of the words previously presented. The probability of recognizing an item was then plotted as a function of the position of the item in the output protocol for the list in which it appeared. The result was an inverted U-shaped curve indicating a low recognition probability for the initial items recalled (STS items), a high recognition probability for the middle items output (the initial items recalled from LTS), and a low probability of recognizing the final items of the recall output protocol. It appears, then, that *S* initially recalls any items available from STS with subsequent items recalled as a negative function of their LTS strength.

There are indications, in both rehearsal and output protocols, of *S*'s attempt to organize the list presented. Evidence for the subjective organization of lists of unrelated words was first presented by Tulving (1962), and a summary of much of the work to date is provided by Shuell (1969). Measures of subjective organization such as the one suggested by Tulving (1962) are based on the similarity in the order of words on successive recall trials and are thus only suited for multitrial, free recall procedures. In the current study, *S* is left free to choose which words rehearse together. The organization reflected in this choice may be compared with the order of words in recall, making it possible to observe organization in a single, free recall trial. If the organization observed during rehearsal is related to that seen in recall, then it might be expected that the probability of adjacent recall of any two items would be a positive function of the number of times these two items appeared together in rehearsal. This was indeed observed to be the case. For any pair of items appearing in a given recall protocol (excluding any items which appeared in the final RS), the mean probability that the pair would appear adjacently in recall as a function of the number of adjacent rehearsals of the pair was .07, .20, .23, and .30 for 0, 1, 2, 3+ adjacent rehearsals. There are many

TABLE 1

Recall and Rehearsal for All Items, Red Items, and N Items

| Number of red items in list | All items P(R) | All items $\bar{X}$ number of rehearsals | Red items P(R) | Red items $\bar{X}$ number of rehearsals | N items P(R) | N items $\bar{X}$ number of rehearsals |
|---|---|---|---|---|---|---|
| 0 | .62 | 4.15 | — | — | .62 | 4.15 |
| 1 | .46 | 4.17 | .72 | 6.52 | .45 | 4.06 |
| 2 | .47 | 3.85 | .70 | 6.82 | .44 | 3.60 |
| 3 | .45 | 3.29 | .53 | 4.81 | .43 | 3.11 |

possible artifacts in a conditional analysis of this sort and several analyses (Rundus, 1970) were performed to examine these potential confoundings. All further analyses proved confirmatory to the hypothesis that adjacent rehearsal of two items was highly correlated with their subsequent adjacent recall.

*Experiment II*

Von Restorf (1933) demonstrated that when an item in a study list is distinctive, its recall probability is notably higher than that for other list items. In the present study some items of a list were printed in red, distinguishing them from the remainder of the items which were printed in black. Of particular interest were the changes in rehearsal and recall seen for (*a*) the emphasized items, (*b*) those items adjacent in list position to the emphasized items, and (*c*) the list as a whole.

*Method.*—Fifteen *S*s were each shown 11 free recall lists. The lists each consisted of 20 unrelated nouns with Thorndike and Lorge frequencies of occurrence of 10 to 40 per million. Either 0, 1, 2, or 3 of the words in a list were printed in red; the remaining words were printed in black. The words selected to be printed in red were chosen randomly for each *S*. The list conditions (number of red words in the list) were assigned randomly across all lists for all *S*s. One-third of all the experimental lists contained 1 red word, one-third contained 2 words, one-sixth contained no red words, and one-sixth contained 3 red words. The serial position of the red words was randomly chosen with the restriction that red words could appear only in Positions 5–16 with no more than 2 red words in any block of five serial positions. The *S*s were told that red words might appear, and if so, to be sure to remember them. Recorded rehearsal protocols and written recall were collected. The order of presentation of the lists and the order of items within a list were random for each *S*. The first list presented was always the same and contained 2 red words. This list was not included in analysis.

*Results and discussion.*—Table 1 presents the mean probability of recall and the mean number of rehearsals per item for (*a*) all items, (*b*) the red (R) items, and (*c*) the nonred (N) items in lists containing 0, 1, 2, or 3 R items. Both probability of recall and mean number of rehearsals were higher for R items than for N items. The additional rehearsal accorded the R items was not massed, but derived from a longer maintenance of these items in *S*'s rehearsal. This fact is best illustrated in those lists containing a single R item, where it was observed that the mean number of RSs in which the R item appeared was 4.5, while for N items the mean was 2.3. For these same lists, it was also noted that when the R item was presented, *S* did not drop all other items being rehearsed and concentrate solely on the R item. The mean number of different items in RS was 2.9 when an R item was being shown and 3.1 when an N item was displayed.

From the first two rows of Table 1, it may be seen that the introduction of a single R item sharply reduces overall probability of recall (Column 2), while rehearsal of the list remains about the same (Column 3). As more R items are included in a list, both recall and mean number of rehearsals tend to decrease for both R and N items. In general, then, the introduction of distinctive items into a list impairs performance on the list. When comparing lists with zero and one R item (Rows 1 and 2 of Table 1), overall mean recall probability is seen to fall from .62 to .46; however, there is no apparent change in *S*'s overall rehearsal. It is possible that the reduction in *S*'s performance may be due to a disruption of *S*'s organization of the study list as the result of the introduction of a distinctive item.

Figure 6 shows both the probability of recall and the mean number of rehearsals for the R item and the N items in serial positions adjacent to the R item in lists

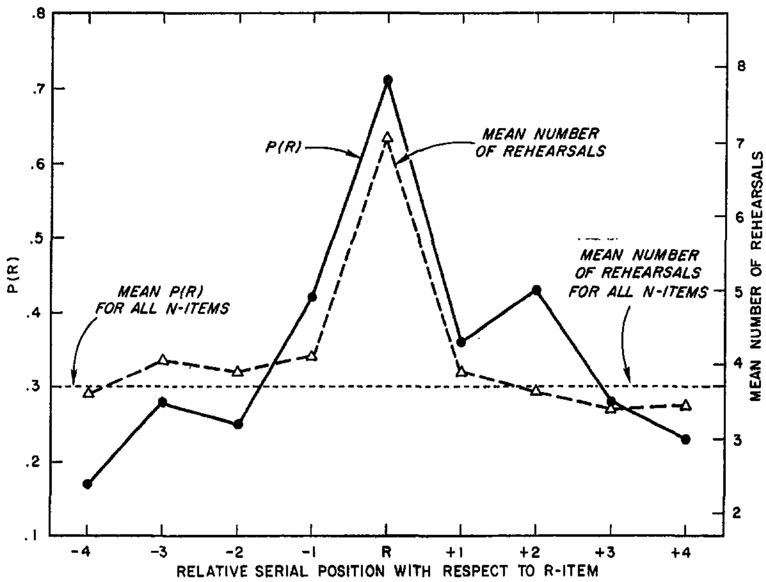


FIG. 6. The probability of recall, $P$(R), and mean number of rehearsals for R items and N items in serial positions adjacent to the R item. (Shown for lists containing one R item.)

containing one R item. A line indicating the mean probability of recall and mean number of rehearsals for all N items in Positions 4–17 in single R-item lists is also shown for reference. Recall appears to be best for those N items immediately adjacent to the R item and declines with distance from the R item. Mean number of rehearsals declines slightly for items appearing after the R item.

The main effects of introducing a distinctive item into a free recall list thus appear to be: (*a*) an increase in both rehearsal and recall probability for the distinctive item, (*b*) a decrease in overall performance on the list, and (*c*) some enhancement of items presented adjacent to the distinctive item.

*Experiment III*

Melton (1967) found that when an item is presented twice in a free recall list, its recall probability increases as a function of the number of items intervening between the two presentations. This spacing effect has been observed in several other studies (e.g., Glanzer, 1969; Tulving, 1969), while others employing somewhat different procedures fail to find the effect (Underwood, 1969; Waugh, 1967). The present study, using lists containing repeated items, incorporated an observable rehearsal procedure with the expectation that analysis of *S*'s rehearsal would provide evidence as to the nature of the spacing effect.

*Method.*—Eleven *S*s were each presented 11 free recall lists. Each list consisted of 25 presentations: 20 different words, 5 of which were repeated once. The words used were unrelated nouns having Thorndike and Lorge frequencies of occurrence from 10 to 40 per million. A list contained 1 of the 5 repeated words in each of five lag conditions of zero, one, two, four, or seven intervening items between presentations. The order of lists and of items within a list were random for each *S*. The serial positions of the repeated items were balanced within each *S* using a Latin-square design. An *S* received each lag condition in every serial position once during the session. When threre were insufficient items remaining at the end of a list to satisfy one of the lag conditions (e.g., when the item in Serial Position 22 was to be repeated at Lag 7), the second presentation of the repeated item was given at the end of the study list and data from that item was not included in analysis. The *S*s were told that some items might be repeated. Recorded rehearsal protocols and written free recall data were collected for each *S*. The first list presented to all *S*s was the same and was not included in the analysis.

*Results and discussion.*—In Fig. 7, the probability of recalling an item is shown as a function of the lag between presentations of the item. N items refer to those items which appeared only once in the list. To minimize recency and primacy effects, the items included in this analysis were restricted to those receiving their first presentation in Serial Position 6 or greater, and their last presentation before Serial Position 22. Recall probability generally increased with lag providing a confirmation of the spacing effect described by Melton (1967). Also shown in Fig. 7 is the mean number of rehearsals accorded an item as a function of its lag condition. This function is seen to be highly correlated with the recall probability function.

In Table 2, the rehearsals accorded an item in each lag condition are broken down into first and second presentation components. Column 2 shows the mean number of rehearsals of an item during its initial 5-sec. presentation period. As expected, no differences in rehearsal as a function of condition appear in this interval. Column 3 displays the mean number of rehearsals accorded an item following the initial 5-sec. presentation and prior to the second presentation. The increase observed over lag is expected since the length of this interpresentation period (and hence the opportunity for rehearsal) increases with lag. Column 4 shows the mean number of rehearsals of an item during the 5-sec. interval while it was being presented for the second time. In an attempt to explain the inferior recall of Lag 0 items, as compared with items at greater lags, it may be hypothesized that *S* pays less attention to a Lag 0 item during its second presentation period. The results shown in Column 4 would not support this interpretation: Lag 0 items receive no fewer rehearsals during their second pre-

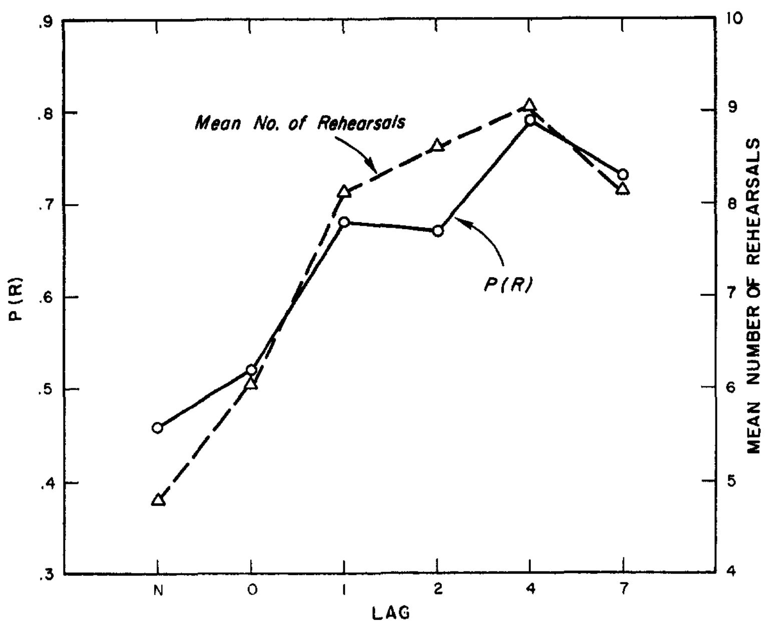


FIG. 7. The probability of recall, $P$(R), and mean number of rehearsals of list items as a function of the lag between repetitions. (N refers to items which were not repeated.)

sentation than do items with longer lags. The final column of the table displays the mean number of rehearsals accorded an item following its second 5-sec. presentation interval. With the exception of Lag 7, rehearsals are seen to increase with lag.

For this study, then, the probability of recalling a repeated item and the amount of rehearsal of the item both increase with spacing of the repetitions. From Table 2, at least two loci of the spacing effect may be noted. First, items repeated at zero lag receive far fewer rehearsals following their second presentation than do items repeated at longer lags. Second, the increased opportunity for rehearsal between presentations (Column 3) provided by the longer lags contributes to the additional rehearsal and better recall for items repeated at these spacings.

*Experiment IV*

The free recall paradigm in which the lists employed contain words related either associatively or categorically has proven useful in the study of organization in memory. The related words in such lists are usually clustered in *S*'s recall with both structural features of the study list and cues during recall having important effects on *S*'s performance (see Shuell, 1969, for a review of both methods and results). The present study was designed to examine the effects of categorically related words on *S*'s rehearsal. Additionally, by including both related and unrelated items in each list, comparisons can be made between *S*'s treatment of the two types of items during study and recall.

*Method.*—Twenty *S*s each received 11 free recall lists. Each list consisted of two, 6-item categories (C1 and C2) and 12 "unrelated" words (NC). The labels C1 and C2 were solely notational and were not related to any characteristics of the categories or their presentation order. The category words were the 6 most frequently given members of 22 noun categories from the norms of Battig and Montague (1969), and the 132 "unrelated" items were nouns with Thorndike and Lorge frequencies of occurrence "A" and "AA." Recorded rehearsal protocols and written free recall data were collected for each *S*. The first list was the same for each *S* and was not included in the analysis; the order of all other lists and the order of items within a list were randomized for each *S*.

TABLE 2

REHEARSAL DURING AND AFTER FIRST AND SECOND PRESENTATIONS OF AN ITEM

| Lag | $\bar{X}$ number of rehearsals during initial presentation of item | $\bar{X}$ number of rehearsals following initial presentation and prior to 2nd | $\bar{X}$ number of rehearsals during 2nd presentation | $\bar{X}$ number of rehearsals following 2nd presentation |
|---|---|---|---|---|
| N | 2.14 | 2.66 | — | — |
| 0 | 2.24 | — | 1.95 | 1.86 |
| 1 | 2.12 | .83 | 1.95 | 3.25 |
| 2 | 2.16 | 1.35 | 1.73 | 3.40 |
| 4 | 2.00 | 1.77 | 1.65 | 3.58 |
| 7 | 2.14 | 1.62 | 1.98 | 2.44 |

*Results and discussion.*—Clustering of the three types of list items (C1, C2, and NC) was observed in the output protocols. A repetitions measure of clustering (Bousfield & Bousfield, 1966) was calculated for each *S* list. This measure computes the difference between the observed number of adjacent recalls of items in each category and an expected value based upon the total number of items recalled in each category. Any difference value greater than zero indicates some clustering. In the present study, each of the three item types was considered as a category. A difference measure was found for each *S* list and the mean computed. There was a mean of 5.7 more repetitions observed than expected. The observed clustering may also be expressed as the ratio of the observed difference in repetitions to the maximum possible difference given perfect clustering (Gerjouy & Spitz, 1966). A value of 1.0 for this ratio would indicate maximal clustering. The observed mean value of this ratio in the present study was .70.

The organization of items by category was observed in rehearsal as well as recall. For RSs in Serial Positions 5–20 the proportion of the items in RS (excluding the item being shown) which belonged to C1, C2, or NC were calculated conditional upon the type of item being presented. The observed proportions of RS items which were from C1, C2, and NC, respectively, were .64, .12, and .25 when a C1 item was shown; .11, .72, and .22 when a C2 item appeared; and .20, .19, and .61

TABLE 3

PROBABILITY OF INCLUSION IN THE RS FOR POSSIBILE TYPES OF ITEMS

| Item presented | Probability that the RS will contain the item being presented | Probability that a C1 item will be included in the RS | | Probability that a C2 item will be included in the RS | | Probability that an NC item will be included in the RS | |
|---|---|---|---|---|---|---|---|
| | | C1 items from the immediately prior RS | C1 items not in the immediately prior RS | C2 items from the immediately prior RS | C2 items not in the immediately prior RS | NC items from the immediately prior RS | NC items not in the immediately prior RS |
| C1 | .94 | .73 | .59 | .17 | .06 | .22 | .07 |
| C2 | .96 | .14 | .06 | .75 | .61 | .20 | .06 |
| NC | .95 | .22 | .10 | .21 | .07 | .42 | .15 |

when an NC item was presented. Thus about three-fourths of the items in a given RS were from the same class. There are at least two possible explanations for the similarity in treatment of NC and category items. First, the NC items may be treated as a third "category" defined by *S* as all items not belonging to C1 or C2. Alternatively, *S* may tend to rehearse a category item only when a member of the same category is presented and not when an NC item or an item from the other category is shown. The result of such a rehearsal strategy would be the rehearsal of NC items when an NC item is presented.

Table 3 presents a more detailed analysis of the types of items included in RS. Data included in this analysis were from RSs in Serial Pcsitions 5–20. The rows of the table correspond to the type of item which was being shown during the 5-sec. RS, whereas the columns indicate the types of items which may be included in RS. Table 3 entries represent the probability of inclusion of the various types of items in RS. From Row 1 of Table 3 it may be seen, in Column 3, that when a C1 word is presented, there is a high probability (.73) that any C1 items which appeared in the immediately previous RS will be maintained in *S*'s rehearsal. In fact, their likelihood of remaining in rehearsal is about 4 times as great as that for other types of items. The entry in Column 4 indicates that when a C1 word is shown, C1 items presented earlier but dropped from rehearsal (i.e., not present in the previous RS) are nearly 10 times more likely to be reentered into rehearsal than are other items which had been dropped from rehearsal. Similar but weaker effects were again observed for the NC items.

Examination of the rehearsal protocols indicate that *S* is definitely using information about the category membership of an item. In fact, *S* appears to structure the contents of each RS to match the item being shown rather than simply including the new item in some ongoing rehearsal pattern.

Overall probability of recall was observed to be higher for category words (.67) than for noncategory words (.40). Category words also received a higher mean normalized number of rehearsals (.035) than did noncategory words (.028). This latter result, in conjunction with previous observations that the structure of *S*'s rehearsal is highly dependent upon categorical features of the list, suggests that the higher recall probability for category words is based, at least in part, upon superior storage of information about these items. The curves shown in Fig. 8 plot the probability of recalling an item as a function of the normalized number of rehearsals accorded that item. For both category and noncategory items, recall probability is seen to increase with amount of rehearsal. For a given amount of rehearsal, however, recall is better for the category words, suggesting that categorical information may be of value in retrieval. For this study, then, the superior recall of category items appears to be due to both storage and retrieval factors.

In Exp. I, it was observed that following recall of items from STS, the order of recall for the remaining items was a function of their LTS strength: the more rehearsal accorded an item the earlier that item appeared in output. If output order is indeed correlated with item strength, then, in the present study, recall of items within a category should proceed in order from most to least rehearsed. To look at data relevant to this question, three separate output protocols, one for each type of item (C1, C2, NC), were formed from the recall data of each *S* list. These subprotocols contained the output order of items within each item type relative to all recalled items of the same class (i.e., first C1 item recalled, second C1 item, etc.). To minimize the STS component, all items appearing in the last two RSs were excluded from the analysis. The subprotocols for each item type were then combined across *S*s using a Vincentizing procedure. The mean normalized number of rehearsals accorded items in the first, second, third, and fourth Vincentized quarters of the output protocols were .062, .052, .037, and .029 for C1 items; .062, .047, .038, and .033 for C2 items; and .062, .049, .040, and .032 for NC items. For all item classes, output order is a negative function of amount of rehearsal. This result provides striking support to the hypothesis that recall of items from LTS proceeds from strongest to weakest.

In the present study, item strength was not the only observed determinant of output order. As was previously mentioned, *S*s tended to recall category items in clusters. If recall of a cluster of items from one category was followed by recall of items from the second category, then the results described above would suggest that the final item of the first cluster might have a lower strength than that of the initial item recalled from the second category. To examine this possibility, a subprotocol for each *S* list was formed by deleting all NC items from the recall protocol of the list. All items appearing in the last two RSs were also deleted to minimize STS effects. The resulting subprotocol consisted of all C1 and C2 items not rehearsed in the final two RSs, in the order in which they were recalled. As an example, this subprotocol would be: $C2_1$, $C2_2$, $C2_3$, $C1_1$, $C1_2$, $C1_3$, $C1_4$, $C2_4$. The first item of the subprotocol could be from either C1 or C2. This item would then be followed by from zero to five other items of the same category prior to the appearance of the first item from the other category. This initial series of items from one of the categories was designated as the first cluster (FC) of the subprotocol. In the example given above, FC was of size three and consisted of the three C2 items which appeared prior to the first C1 item. The comparison of interest in this analysis is between the amount of rehearsal accorded the last item of FC ($C2_3$ in the example) and that given the first item of the other list category ($C1_1$ in the example). The mean normalized number of rehearsals accorded both the final item of FC and the initial item recalled from the other category were calculated conditional upon the number of items in FC and were observed to be, respectively, .051 and .069 for FC of one or two items, .043 and .067 for FC of three or four items, and .031 and .061 for FC of five or six items. For all sizes of FC, the final item of FC received less rehearsal than the initial item recalled from the second category. In addition, as the size of FC increases this difference

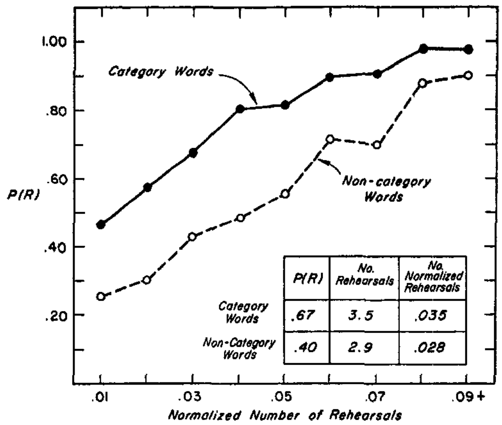


FIG. 8. The probability of recall, *P*(R), of an item as a function of the mean normalized number of rehearsals accorded the item. (Shown for category and noncategory items. The inserted table shows mean *P*(R), mean number of rehearsals, and mean normalized number of rehearsals for category and noncategory words.)

is observed to increase. Thus, while it was shown in Fig. 5 that the order of recall within a category proceeds as a function of item strength, *S* will recall an item of low strength within a category cluster prior to the recall of a higher strength item of a different category. This provides another indication of *S*'s use of category information during recall.

## Conclusion

At least two points should be kept in mind when considering the results of the studies just described. First, the recorded rehearsal procedure was designed to be an unobtrusive monitor allowing *S* freedom to rehearse any list items he chose as often as he chose. Thus at no time were the number of rehearsals of an item directly manipulated. Any relationship involving number of rehearsals is therefore correlational and should be regarded with care. Second, it was not intended that *S*'s overt rehearsals of an item should be thought of as the sole *causes* for memory of that item. Indeed, *S*s were instructed to feel free to study the lists in any manner they chose. Their instructions were that whenever they were "thinking about" one of the list items they should overtly rehearse that item. Thus the role of the overt rehearsals was to serve as *indicators* of what *S* was doing during list study. It was hoped that the number of overt rehearsals accorded an item might be a good measure of the number of times *S* "attended to" or "thought about" that item during list presentation.

A number of writers (e.g., Mandler, 1967; Tulving, 1968) have proposed that recall depends upon organization. In addition to providing a monitor of the accumulation of "strength" for individual items of a free recall list, the recorded rehearsal photocols also provided an indicator of *S*'s attempts at list organization. In the study involving categorized lists, there was a pronounced tendency for *S* to rehearse together items from the same category. Presentation of a word from one of the categories not only increased the probability of other words from the category remaining in rehearsal, but perhaps more importantly, triggered the return to active rehearsal of words from that category which had been dropped from rehearsal. This latter result may help to explain the observation that in lists of "unrelated" words, items would often be dropped from rehearsal and later reappear. It is possible that these words were returned to rehearsal because *S* saw them as in some way related to a newly presented item and chose to include the old words with the new one in an organizational scheme.

The organization observed in rehearsal was also reflected in *S*'s recall. In Exp. IV, *S*'s tendency to rehearse together items of the same category was mirrored by the clustering of these items in recall. It was noted that once *S* had begun to recall a cluster of items from one of the categories, she would continue recalling those items even though the last item recalled in that cluster was, on the average, weaker than the first item recalled in the next cluster. Organization was also noted in lists of unrelated words in Exp. I. From the recorded rehearsal protocols, it was observed that the more often two items appeared adjacently in rehearsal, the higher was their probability of adjacent recall. Examination of *S*'s rehearsal thus made it possible to note the emergence of organization during study and its manifestation in recall.

In conclusion, it was obvious, both qualitatively to the listening *E* and quantitatively in the data analysis, that *S* was not treating a list in a simple, mechanical fashion. To adequately understand performance in a free recall task, it is therefore imperative to gain some knowledge of *S*'s strategies of rehearsal organization. To this end the procedure for the observation of rehearsal described here has proven, and should prove eminently useful in providing, access to *S*'s rehearsal processes.

## REFERENCES

Asch, S. E., & Ebenholtz, S. M. The principle of associative symmetry. *Proceedings of the American Philosophical Society*, 1962, **106**, 135–163.

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory.* Vol. II. New York: Academic Press, 1968.

Battig, W. F., Allen, M., & Jensen, A. R. Priority of free recall of newly learned items. *Journal of Verbal Learning and Verbal Behavior*, 1965, **4**, 175–179.

Battig, W. F., & Montague, W. E. Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology*, 1969, **80** (3, Pt. 2).

Bousfield, A. K., & Bousfiled, W. A. Measurement of clustering and of sequential constancies in repeated free recall. *Psychological Reports*, 1966, **19**, 935–942.

Bousfield, W. A. The occurrence of clustering in the recall of randomly arranged associates. *Journal of General Psychology*, 1953, **49**, 229–240.

Bousfield, W. A., Whitmarsh, G. A., & Esterson, J. Serial position effects and the Marbe effect in the free recall of meaningful words. *Journal of General Psychology*, 1958, **59**, 255–262.

Bower, G. H. Organizational factors in memory. *Cognitive Psychology*, 1970, **1**, 18–46.

Fischler, I., Rundus, D., & Atkinson, R. C. Effects of overt rehearsal processes on free recall. *Psychonomic Science*, 1970, **19**, 249–250.

Gerjouy, I. R., & Spitz, H. H. Associative clustering in free recall: Intellectual and developmental variables. *American Journal of Mental Deficiency*, 1966, **70**, 918–927.

Glanzer, M. Distance between related words in free recall: Trace of the STS. *Journal of Verbal Learning and Verbal Behavior*, 1969, **8**, 105–111.

Glanzer, M., & Cunitz, A. R. Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behavior*, 1966, **5**, 351–360.

Glanzer, M., & Meinzer, A. The effects of intralist activity on free recall. *Journal of Verbal Learning and Verbal Behavior*, 1967, **6**, 928–935.

Hilgard, E. R. A summary and evaluation of alternative procedures for the construction of Vincent curves. *Psychological Bulletin*, 1938, **35**, 282–297.

Mandler, G. Organization and memory. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation.* Vol. I. New York: Academic Press, 1967.

Melton, A. W. Repetition and retrieval from memory. *Science*, 1967, **158**, 532.

Postman, L., & Phillips, L. W. Short term temporal changes in free recall. *Quarterly Journal of Experimental Psychology*, 1965, **17**, 132–138.

Rundus, D. *An analysis of rehearsal processes in free recall.* (Tech. Rep. No. 159) Palo Alto, Calif.: Stanford University, Institute for Mathematical Studies in the Social Sciences, 1970.

Rundus, D. & Atkinson, R. C. Rehearsal processes in free recall: A procedure for direct observation. *Journal of Verbal Learning and Verbal Behavior*, 1970, **9**, 99–105.

Rundus, D., Loftus, G. L., & Atkinson, R. C. Immediate free recall and three-week delayed recognition. *Journal of Verbal Learning and Verbal Behavior*, 1970, **9**, 684–688.

Slamecka, N. An examination of trace storage in free recall. *Journal of Experimental Psychology*, 1968, **76**, 504–513.

Shuell, T. J. Clustering and organization in free recall. *Psychological Bulletin*, 1969, **72**, 353–374.

Shuell, T. J., & Keppel, G. Item priority in free recall. *Journal of Verbal Learning and Verbal Behavior*, 1968, **7**, 969–971.

Tulving, E. Subjective organization in recall of "unrelated" words. *Psychological Review*, 1962, **69**, 344–354.

Tulving, E. Theoretical issues in free recall. In T. R. Dixon & D. L. Horton (Eds.), *Verbal behavior and general behavior theory.* Englewood Cliffs, N. J.: Prentice-Hall, 1968.

Tulving, E. Distribution and repetition effects in memory for discrete events. Paper presented at the meeting of the Midwestern Psychological Association, Chicago, May 1969.

Underwood, B. J. Some correlates of item repetition in free recall learning. *Journal of Verbal Learning and Verbal Behavior*, 1969, **8**, 83–95.

Underwood, B. J., & Schulz, R. W. *Meaningfulness and verbal learning.* Philadelphia: J. B. Lippincott Co., 1960.

Von Restorf, H. Uber die Wirkung von Bereichsbildungen im Spurenfeld. *Psychologische Forschung*, 1933, **18**, 299–342.

Waugh, N. C. Presentation time and free recall. *Journal of Experimental Psychology*, 1967, **73**, 39–44.

(Received October 9, 1970)