Transformations on sets in short-term memory: Temporal and spatial factors influencing deletion*

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An individual's ability to perform a deletion operation on sets in short-term memory was explored in a reaction time (RT) experiment. Special attention was given to the importance, for deletion, of temporal and spatial variables. Ss did perform a deletion operation. The speed of correct recognition was influenced by both the delay between the deletion (D) set and a test item and the serial order correspondence between identical items in the to-be-remembered or positive (P) set and the D set.

The speculation that short-term memory (STM) may be used as a system in which mental operations are performed has gained increasing attention. Posner (1967) and Atkinson and Shiffrin (1968) have suggested that STM may have different uses. One use of an STM system described by Posner is that of operational memory where information from long-term memory (LTM) is activated and utilized in problem solving. This notion is similar to the "workspace" function described by Hilgard and Bower (1966) and Atkinson and Shiffrin (1968) and the "active" memory postulated by Sternberg (1969). These notions of STM have inspired researchers to begin looking at STM as more than a simple intermediate retention system of limited capacity.

DeRosa (1969), for example, investigated an individual's ability to perform a deletion operation on a set of recently perceived items. In his study, a positive set (P) of four different elements was followed by a second set, called the deletion (D) set. Items in the D set that were identical to P items were to be deleted from the P set and regarded as negative elements. Seven hundred and fifty milliseconds after the last D item was shown, a test or probe item appeared. If the probe was identical to one of the items in the P set but not in D (PD), a YES response was required; otherwise, a NO response was appropriate. The positive set was always constant at four and the D set varied from one to three. The RT data were consistent with the hypothesis that Ss performed a deletion transformation. Indicative of a deletion strategy was the observation that RT increased linearly as a function of the size of the set of items that remained positive; net P, $[n(P - D)]$.

One shortcoming of the DeRosa (1969) study was that it was difficult to specify how deletion might have been accomplished. It was noted that there was a

complete absence of a relationship between the order correspondence of P and D items and RT. It was believed that RT might be facilitated when the order of items in the two sets was identical. This was not the case. For example, rank-order correlations were computed to describe the consistency of the order in which identical items occurred in the two sets. If the P set was composed of the digits 4, 7, 9, 3 and the deletion set was 4, 9, 3, the value of the rank-order correlation between the two sets would be +1.00. The 7 which is present in the P set but not in D was disregarded in calculating the correlation coefficient. For P sets of four items always followed by three D items, four possible rank-order coefficients exist: +1.00, +.50, -.50, and -1.00. When RT was plotted as a function of the value of the correlation coefficient, there was a complete absence of any effect of correlation. If reactions had been fastest when the value of the correlation was +1.00, the conclusion might have been drawn that the positive set was serially organized in memory and that individuals delete items by comparing, in a fixed order, each D item to a memorial representation of the positive set, with the comparison process terminating after each match and beginning again with the next item. The delay between the last D item and the probe was always 750 msec. This delay may have been greater than the time necessary to complete all deletions. If this is true, the effects of the order correlation may not have been manifest due to the length of the delay.

The present study represents an attempt to replicate and extend the DeRosa (1969) study by examining the deletion operation in greater detail. In particular, the delay between the last D item and the probe was systematically manipulated. Furthermore, larger P and D sets were used in this study to allow for the possibility that the correlation effect, if existent, would only be manifest when larger sets were used. This seems feasible, since larger P and D sets would provide a somewhat greater tax on memory and also since these larger sets would allow for a greater number of values of the order correlation to be manipulated.

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Fig. 1. Mean RT to positive probes as a function of $n(P-D)$ for each delay condition.

METHOD

The Ss were 16 male undergraduates who each participated in four 1-h experimental sessions. Stimuli were the digits 1-9 presented on the viewing face of three I.E.E. display cells mounted 3 ft from S. Two cells were horizontally adjacent. The left cell provided the presentation of the P set. The D set was shown on the right cell. A probe cell was mounted above and centered between the two lower cells. A microphone monitored S's vocal responses and also activated a voice-operated relay. The Ss were instructed to say "yes" if the probe digit was identical to any item in the PD set and "no" otherwise. The voice key turned off the stimulus and terminated a Hunter Klockounter, which displayed RTs to the nearest .001 sec.

Each trial consisted of a serial presentation of five P items followed by two, three, or four D items that were all members of the P set. Each stimulus was on for 200 msec and off for 100 msec. The time between the termination of the last digit of D and the onset of the probe was 100, 200, 400, 700, or 1,000 msec.

Twelve program tapes were used to present 476 different trials. Each trial was presented once with each delay for a total of 2,380 trials. Within a series of trials, the delay between the last D item and the probe was held constant, as well as the number of items in D. The selection of D items and probes was balanced such that each serial position in P was selected as a D item and a probe with equal frequency. Over trials, the probability that the probe was a member of the PD set was .50.

RESULTS AND DISCUSSION

The analyses of the data were based on mean RTs for correct responses computed separately for each S. None of the Ss had error rates higher than a predefined cut-off of 25%, and the average error rate for the entire experiment was approximately 14%.

Figure 1 represents the data for positive responses. Reaction time is plotted as a function of the number (n) of items in the $P-D$ set for the five delay conditions. A noteworthy feature of the data in Fig. 1 is the fact that RT increases as a function of $n(P-D)$. The average increase in RT per unit increase in $n(P-D)$ for the five functions is 64 msec. The relationship is highly significant [$F(2,30) = 59.47$, $p < .001$]. Furthermore, RT increases as the delay between D and the probe decreases. The longest reactions are associated with the 100-msec delay. Delay is a significant variable [$F(4,60) = 26.07$, $p < .001$]. Finally, the five functions in Fig. 1, although differing in vertical displacement, do not differ significantly in slope. Indicative of this finding is the absence of a $n(P-D)$ by Delay interaction [$F(8,120) = .74$, $p > .05$].

Fig. 2. Mean RT to negative probes $\overline{PD}$ (left panel) and PD (right panel) for each delay as a function of $n(P - D)$.

The data for positive responses are consistent with those obtained by DeRosa (1969). He concluded that increases in RT associated with increases in $n(P - D)$ were in keeping with a strategy in which Ss delete items from the P set, and then compare the probe serially to members of a reduced positive set. This conclusion is supported in the present study. The absence of a $n(P - D)$ by Delay interaction lends statistical support to the notion that Ss appear to wait until all deletions are completed before searching memory. Regardless of the size of D, varying delays between D and the probe did not produce changes in the mode of processing. More analytical inspection of the data in Fig. 1 leads one to conclude that the delay variable produced reliable effects in the expected direction, with the longest delays producing the fastest latencies. However, it appears that after 700 msec, all presearch processing (deletions, upgrading the positive set, etc.) has been completed. The 700-msec and 1,000-msec functions are nearly equal. Post hoc comparisons between means indicated that these two conditions did not differ, but that both were significantly faster than each of the other delays. This result is completely consistent with the speculation that the 750-msec delay used in DeRosa's (1969) study may have exceeded the time necessary to perform deletions and upgrade the net positive set.

The results for negative reactions are shown in Fig. 2. The left panel of the figure shows RT as a function of $n(P - D)$ when the probe was a member of the set that was not shown in either P or D ($\overline{PD}$). The right panel depicts responses to items that were deleted (PD) from the positive set. For the moment, attention will focus on the left panel. It is clear that the data for $\overline{PD}$ probes are very similar to those observed for positive probes. All five functions increase linearly as a function of $n(P - D)$. The slope of the average function of the five curves in

the figure is 55 msec per unit increase in $n(P - D)$. The size of $n(P - D)$ is highly significant [$F(2,30) = 41.80$, $p < .001$]. Delay is also a reliable variable [$F(4,60) = 17.67$, $p < .001$]. The $n(P - D)$ by Delay interaction is not significant [$F(8,120) = .46$, $p > .05$], indicating that the five functions in the left panel of the figure do not differ significantly in slope. The results for positive and negative ($\overline{PD}$) probes are therefore virtually identical. The only aspect of the negative set data that is not completely in keeping with the data observed for $\overline{PD}$ probes is the fact that the 400-msec delay does not differ significantly from the 700-msec delay condition, as was the case for positive probes. This single inconsistency with the results for positive probes is difficult to understand.

The data shown in the right panel of Fig. 2 present a very different picture. Although both $n(P - D)$ and delay are again significant variables ($p < .001$ for both), the five functions do not demonstrate the same overall patterns as those observed for the $\overline{PD}$ and $\overline{PD}$ data. The four functions associated with the shortest delays all initially increase as $n(P - D)$ increases from one to two. However, when the single D item is identical to the probe, RTs drop markedly. This finding is true for all but the 1,000-msec delay condition, which exhibits the typical relationship between RT and $n(P - D)$. Associated with these differences in the slopes of the PD functions is a statistically significant $n(P - D)$ by Delay interaction [$F(8,120) = 2.06$, $p < .05$]. The cause of the drop for the four shortest delays may be associated with the fact that the single to-be-deleted item is immediately available as a negative item and Ss can compare the probe to *only* the one D item. Between 700 and 1,000 msec, this direct access to the single PD item appears to no longer exist and Ss examine the reduced positive set.

Fig. 3. Mean RT to positive and negative probes as a function of the correlation between the ordinal positions of identical items in P and D.

The final aspect of the data to be examined is the relationship between order correspondence between P and D items and RT. Data are shown in Fig. 3 which depict the relationship between RT and the possible rank-order coefficients that existed for D sets of three items (left panel) and four items (right panel). It is clear that when only three D items precede the probe, the correlation variable has no influence on RT. The two functions are essentially flat, and the order variable is not significant [$F(3,45) = 1.67, p > .05$]. The results for D sets containing four items do show a tendency toward a relationship between RT and degree of rank-order correlation. In general, the closer the order of deletion items parallels their order of presentation in the P set, the more rapid the RTs to both positive and negative probes. Although the differences in RT are not of great magnitude, they are reliable [$F(7,105) = 4.80, p < .01$]. Also, both the linear and quadratic components of the variance associated with the correlation variable are significant ($p < .01$ for both). No other higher order component is significant. A final factor worthy of mention is the lack of a Delay by Correlation interaction [$F(28,420) = 1.14, p > .05$]. The data in Fig. 3 have been summarized over delay. It was thought that the short delays might be those associated with the largest differences in RTs when viewed as a function of correlation. This was not the case. The data for D sets of four items does lend some support to the notion that deletion is a process which is in part serial. The enhancement in retrieval associated with the correlation variable is most pronounced when the order

correspondence between P and D is identical. Poorest performance is associated with low and intermediate levels of the relationship.

In summary, the present study has replicated the earlier study by DeRosa (1969). It is evident that Ss do perform a deletion operation on information in recent memory. The operation is very rapid. Although both the delay between the D set and the probe and the order correspondence between the P and D items did influence RT, their importance appears to be limited by the rapid nature of the mental operation. The added time available with longer delays is apparently spent in activating, upgrading, and rehearsing the positive set in memory for subsequent search.

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