Journal of Experimental Psychology
1970, Vol. 83, No. 1, 52–56

SUBJECT-IMPOSED CODING AND MEMORY FOR DIGIT SERIES[1]

DAVID WINZENZ[2] AND GORDON H. BOWER
Stanford University

The present experiment concerns the relation between accumulative learning over successive repetitions of a digit series and the identity of codings of successive recurrences of the series. Prior studies have shown no accumulative learning if the series is regrouped in new ways each time it recurs. The present experiment employed *S*s pretrained to recode each 12-digit series into a standard format, as four groups of 3. With this recoding strategy, *S*s showed accumulative learning in recall despite the series' being regrouped differently at each recurrence. Further evidence showed that *S*'s recall units were determined by the groupings he imposed on the series rather than by *E*'s pause-marked groupings. The results are consistent with the reallocation hypothesis, which assumes that the subjective code determines what is stored and how it is recalled.

In previous experiments (Bower & Winzenz, 1969), the effects of grouping on recognition and recall of a digit series were studied. The *S*s regularly employ some grouping strategy in learning long series of digits. Typical strategies may involve imposing rhythmical stresses and pauses on the string or grouping the digits and repeating their numerical names, such as recoding 7 5 2 6 8 as "seventy-five, two hundred sixty-eight." Neisser (1967) has suggested that this subjective organization provides "reference points" for attaching successive items in the series and that the organization may provide an execution scheme for serial reproduction.

If the organization or grouping of a digit string is an important aspect of what is stored, and if the same string of digits is grouped differently over successive presentations, then recall should not show the typical improvement in recall due to repetition (cf. Hebb, 1961). This effect was found by Bower and Winzenz (1969) when they presented *S*s with 12-digit strings for immediate serial recall. Within successive blocks of eight trials, a recurrent string was presented on Trials 2, 4, 6, and 8, while different "noise" strings were presented on the intervening Trials 1, 3, 5, and 7. One method of grouping was to locate pauses between groups; e.g., a digit string 17*683*945*2 was read at a 3 digits/sec rate, but with a distinct (1-sec.) pause occurring at the asterisks. The basic finding was that when the location of the pauses remained the same on each presentation of the recurrent string, recall improved, whereas there was no improvement in recall if the location of the pauses changed on each repetition.

To account for such data, the "reallocation hypothesis" was suggested. Each incoming grouped string is presumed to be analyzed by a perceptual coder to determine whether or not the string has been heard before. The presumed analysis is done primarily on the first group of the string, which is compared with the beginning segments of traces of previous strings in memory. If a match is found, the incoming string is shunted to that location in memory to strengthen the trace there. If no match is found, the incoming string is stored at a new location in memory, from which it is immediately recalled. Strings recurring with the same grouping can be matched (recognized), and hence strength will accumulate at the location mediating recall; however, if the grouping is changed from 17*683*945*2 to 1768*39*452, 17 and 1768 will not be matched, the strings will be stored

[1] This research was conducted while the first author held a National Defense Education Act Title IV Graduate Fellowship, and it was supported in part by National Institute of Mental Health Grant 13950 to the second author.

[2] Requests for reprints should be sent to David Winzenz, Department of Psychology, Stanford, University, Stanford, California 94305.

at different locations in memory, and hence no strengthening of traces due to repetition occurs.

One implication of the reallocation theory tested in the present experiment concerns the distinction between *E*-imposed grouping and *S*-imposed grouping. The perceptual coder is assumed to operate on and store the *S* groupings. In the previous experiments, however, the *E*-imposed groupings and the *S*-imposed groupings closely correspond since, in the absence of a counterstrategy, the path of least effort is for *S* to adopt the *E*-imposed groupings of successive digits in the string. But it is because of this adoption that a string recurring with changing *E*-imposed groupings shows no improvement in recall. However, it should be possible to train *S* to impose a standard group structure on each string (say, groups of three digits) irrespective of what *E* groupings are imposed on the string. An important consequence of *S*'s imposing a standard coding format is that different regroupings of a string by *E* nonetheless translate into the same sequence of *S* codes for storage in memory. That is, by recoding into a standard format, *S* undoes and nullifies different *E* groupings of the string. It therefore follows that standardized recoding by *S* should reduce the formerly devastating effect on recall of changing *E* groupings over successive presentations of a string. In particular, there should be improvement in immediate recall over successive recurrences of a string despite the changing *E* groupings imposed on it. The present experiment tests this implication.

METHOD

Thirty 12-digit strings were obtained from the first 12 entries in tables of random permutations of the numerals 1–20 (Moses & Oakford, 1963). The numerals 10 and 20 were deleted and 11–19 rewritten as 1–9; thus each digit type from 1 to 9 could appear zero, one, or two times in a string, and the number of double occurrences varied from three to five over the strings. The 30 strings were assigned to six blocks of 5 strings; one of the strings was designated to be the recurrent string to be presented on Trials 2, 4, 6, and 8 of the trial block, and the remaining 4 strings were designated as noise strings to be presented once each on Trials 1, 3, 5, and 7 of the trial block. Each string of 12 digits was divided into no more than seven groups of sizes one, two, three, or four. For two of the six blocks, the recurrent string was divided into four groups of 3s over trials (designated "constant 3333"). For another two of the six blocks, the recurrent string retained the same *group structure over trials, but the group structure* was not 3333 (designated "constant non-3333"). For the remaining two blocks, the recurrent string had its group structure changed over its four trials. These grouped digit strings were recorded on a Wollensak tape recorder at a rate of 1 digit/sec, and groups were indicated by a 2-sec. pause between digits.

Individual *S*s, after receiving instructions about immediate recall and the blocked nature of the experiment, were trained in a "shadow" technique for learning each digit string. The technique required *S* to group each 12-digit string into four groups of 3 digits each, repeating the numerical name of each group. For example, as the string 258379651938 was heard, *S* would segment successive groups of three and covertly say their numerical name, as "two hundred fifty-eight, three hundred seventy-nine, six hundred fifty-one, nine hundred thirty-eight." This grouping and shadowing was done by *S* as the digit string was read and *S* mouthed the numerical name of each group. Pilot work suggested that *S*s could do this without extensive practice at the slow (1/sec) rate used, but were much less successful at faster input rates. The *S* was also told that pauses would occur in each digit string and would not necessarily follow every third digit, but *S* was to carry out his grouping and shadowing irrespective of the pauses. After the warning signal "ready," *S* listened to and shadowed each string, and, when a terminal click occurred, began his recall by writing the individual digits in left-to-right order in 12 blank spaces provided on a recall sheet. He was told that his recall would be scored by the number of digits written in their correct location and he could either guess or leave blank those positions he could not remember. The recall period was 10 sec.; there was no feedback indicating the correctness of his recall, and *S* covered his successive lines of recall with a cardboard before the next digit string was presented.

The *S*s were 15 undergraduate students whose participation in the experiment fulfilled a service requirement for their introductory psychology course.

RESULTS AND DISCUSSION

The principal results are shown in Fig. 1, giving recall errors over four trials for strings recurring with a changing structure, for strings recurring with a constant structure, and for noise strings. The latter two types of strings are subdivided according to

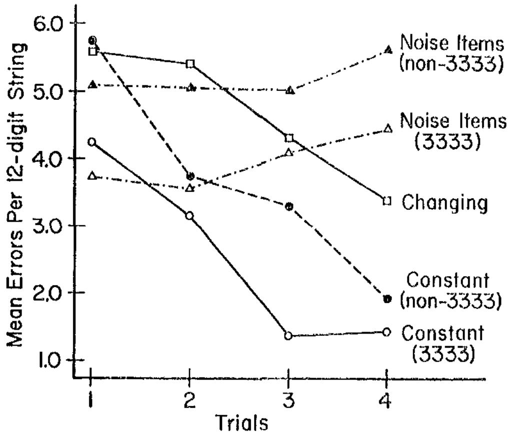

FIG. 1. Mean number of errors per 12-digit string in immediate recall over four presentations.

whether the *E*-imposed structure was 3333 or non-3333.

All three types of recurrent strings show an improvement in recall due to repetition, F (3, 42) = 41.10, $p < .01$, and are ordered as would be expected on the basis of congruence or conflict between the *E*-imposed grouping and the *S*-imposed grouping. Overall performance on recurrent items is best when the grouping codes of *E* and *S* agree; next best when the codes differ, but are both constant over trials; and poorest when *E*-imposed groupings change over trials, but *S*-groupings are constant; F (2, 28) = 19.85, $p < .01$. The difference in performance due to agreement or disagreement between the *E* grouping and the *S* grouping is also reflected in performance on the two types of noise items, where performance is superior when *E* and *S* groupings agree, F (1, 14) = 55.24, $p < .01$. Of particular interest is the learning effect shown by the recurrent string with changed grouping as compared with non-3333 noise items. A significant interaction, F (1, 14) = 6.88, $p < .05$, indicates *S*'s ability to recode the digit strings and display an improvement in recall due to repetition and the constancy of coding.

Further analysis was done to show *S*'s facility in recoding the digit strings. The recall of all noise strings having an *E*-imposed 23232 group structure was examined. (Each *S* recalled six such strings over the course of the experiment.) The serial position curve for recall of these noise strings (not shown) had the traditional bowed shape, but there were peaks and troughs in

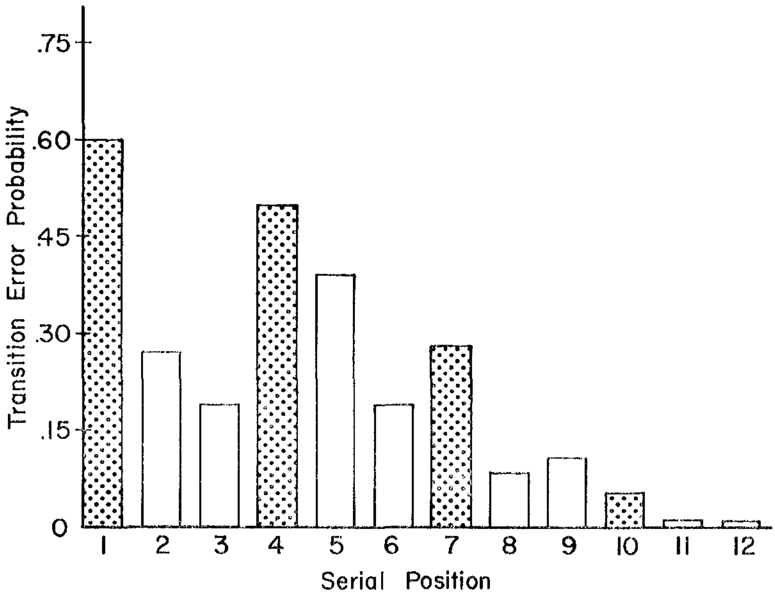

FIG. 2. Conditional probability of an error on Digit $n + 1$ given correctly on Digit n for noise items grouped in a 23232 pattern, but regrouped by *S* into a 3333 pattern.

the curve which corresponded, not to the E-imposed 23232 group pattern, but to the 3333 group pattern S imposed on the string. A more discriminating measure of recoding units in serial recall is the transition error probability (TEP) statistic shown in Fig. 2. The TEP plotted over Serial Position $n + 1$ is the conditional probability of an error on Digit $n + 1$ given correct recall of Digit n of the series. The unconditional probability of an error on the first digit of the series is plotted at $n = 1$. The crosshatched bars indicate transitions between groups in S's imposed 3333 grouping pattern. They reveal a high error probability in transitions between S-imposed groups, with a decline in TEP over successive elements within S's groupings.

The experiment succeeded in demonstrating S's ability to group serial material irrespective of how the material is grouped by E in presentation. That the S groupings are the recall units can be seen most easily by comparing Fig. 2 and 3. Figure 3 is reproduced from the former experiment by Bower and Winzenz (1969), which was similar to the present one, except the former Ss were not trained to impose a standard grouping format on each digit string; rather, those Ss appeared simply to use the groupings imposed by E. In Fig. 3, S's TEP pattern clearly follows E's groupings, with large TEP spikes at the group boundaries (Positions 1, 3, 6, 8, and 11). In contrast, in Fig. 2, the large TEP spikes appear at the grouping boundaries specified by S's recoding format (Positions 1, 4, 7, 10). Although Ss were hearing exactly the same strings in the two conditions, details of their serial reconstructions differ in accord with the recoding strategies employed in the two conditions.

If S can impose a standard grouping on each input string, the reallocation hypothesis predicts that he should show improvement in recall of a recurrent string despite changes in its E-imposed group structure. This result was obtained, as shown in Fig. 1. In the former experiment by Bower and Winzenz (1969), improvement in recall of a recurrent string occurred only when the E groupings remained the same over successive presentations; however, in the present experiment, the S groupings clearly predominated, and some accumulated learning was evident even with changing group structure of the recurrent string. These results can then be interpreted as supporting the reallocation hypothesis of memory for digit strings. The fact that recall was better when E and S codes agreed rather than

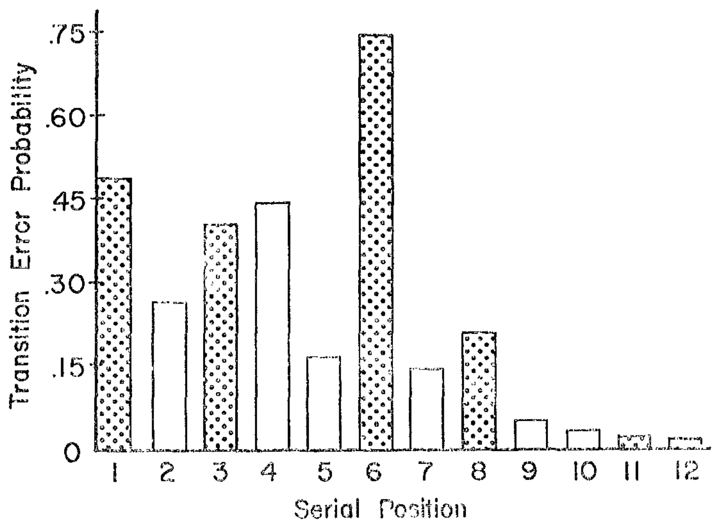

FIG. 3. Conditional probability of an error on Digit $n+1$ given correctly on Digit n for noise items grouped in a 23232 pattern (from Bower & Winzenz, 1969).

conflicted appears to show that subjective recoding into groups that cut across pause boundaries is difficult and prone to errors and failures.

REFERENCES

Bower, G. H., & Winzenz, D. Group structure, coding, and memory for digit series. *Journal of Experimental Psychology,* 1969, **80**(2, Pt. 2).

Hebb, D. O. Distinctive features of learning in the higher animal. In J. F. Delafresnoye (Ed.), *Brain mechanisms and learning.* Oxford: Blackwell, 1961.

Moses, L., & Oakford, R. *Tables of random permutations.* Stanford, Calif.: Stanford University Press, 1963.

Neisser, U. *Cognitive psychology.* New York: Appleton-Century-Crofts, 1967.

(Received May 10, 1969)