Journal of Experimental Psychology
1970, Vol. 83, No. 3, 421–430

PAUSES AS RECODING POINTS IN LETTER SERIES[1]

GORDON H. BOWER[2] AND FRED SPRINGSTON

Stanford University

It was hypothesized that temporal pauses in letter series are the major places at which recoding occurs, either in terms of a pronunciation code (e.g., VAF) or a meaningful code (e.g., IBM). If pauses determine the units on which recoding is attempted, then there will be an optimal and several nonoptimal ways to locate pauses in a given series of codable trigrams. Three immediate recall experiments confirmed this expectation, comparing optimal pausing with several nonoptimal ways of presenting the sequences. Analyses of transition error probabilities supported the view that pauses determine *S*'s recall units, that recall is superior when a pause-bound group is recodable, and that subjectively coded groups are detectable even when no pauses occur in the series.

The present experiments concern the effect of recoding on short-term memory for letter series and are addressed specifically to the relation between perceptual units and recoding units. An efficient strategy for learning any arbitrary series of symbols is to segment it into smaller groups, units, or chunks. With temporal series, a powerful determinant of the subjective groups is the temporal proximity of adjacent elements. If pauses are located throughout a series of digits, the chunks adopted are those segments between long pauses. These chunks become *S*s' recall units in the sense that transition error probabilities are very high on transitions between groups, but are low on transitions within a group (cf. Bower & Winzenz, 1969). So, in this sense, temporal pauses determine the boundaries of the chunks in recall.

The pause may achieve this result by allowing *S* a moment for rehearsal of the preceding input segment, since it momentarily frees the central processing mechanisms from interruption by newly arriving information. With letter series, the pause may not only allow rehearsal, but also may provide an opportunity for *recoding* of the preceding segment of the input series of letters (e.g., three letters); the central processing mechanism presumably attempts to "look up" information about that trigram in long-term memory. The nature of the information available in long-term memory will vary with the trigram. One sort of information is articulatory, defined largely by an array of grapheme–phoneme correspondences learned by readers (speakers) of the language. Thus, if the acoustic stimuli in the prior segment have been "eff-aye-ess," then *S* will have the necessary correspondence rules to recode that triplet with the shorter pronunciation "fas." If this recoding is done during the pause, then it reduces the load on *S*'s short-term memory, since the articulatory parameters required for storage of the unit "fas" are much fewer than required for storage of the triplet "eff-aye-ess." The *S* would then use his grapheme–phoneme dictionary in reverse for decoding at the time of recall. In brief, this pronunciation encoding enables *S* to replace a long code by a short code, and *S*'s memory for it will be better as a consequence of this substitution.

Another kind of encoding with letter trigrams involves "meaningfulness" rather than a shortening of pronunciation. We are all familiar with acronyms and abbreviations like IBM, PHD, AMA, and FBI. They have meaning, are used like words, and are doubtless represented in the mental lexicon of every American college sophomore. Judging from the Underwood and Schulz (1960) norms, the third letter is also a

[1] This research was supported by Grant MH-13950 to the first author from the National Institute of Mental Health. The second author was supported by a National Science Foundation Graduate Fellowship.

[2] Requests for reprints should be sent to Gordon H. Bower, Department of Psychology, Stanford University, Stanford, California 94305.

very frequent associate when adults are given the first two letters. Thus, if a pause occurs after IBM in a series, *S* can "look it up" in his mental lexicon and perhaps substitute for it a meaningful code (of unknown nature). Retrieval of the meaningful code would then prompt recall of the pseudo-word unit, IBM.

The authors have supposed that pauses (explicit or implicit) are the most likely places at which this "dictionary look-up," or recoding, is done. If that were true, it would follow that for a given long string of letters, there would be an optimal and several nonoptimal placements of pauses. An example of optimal pauses for pronounceable recoding would be DAT BEC JAX PEL, whereas a nonoptimal phrasing would be DA TBE CJA XPE L. An example of optimal pauses for meaningful recoding would be FBI PHD TWA IBM, whereas a nonoptimal phrasing would be FB IPH DTW AIB M. The optimal pauses segment the series into letter groups about which *S* has relevant information, enabling either substitution of a shorter pronunciation or a meaningful surrogate.

Experiment I and II tested this conjecture about optimal and nonoptimal pause locations for sequences of four pronounceable or meaningful trigrams which *S* attempted to recall immediately. Considering the aforementioned examples in finer detail, the optimal-coding illustrations involve four triplets defined by three pauses, whereas the nonoptimal-coding illustrations involve a doublet, three triplets, and a single letter, defined by four pauses. If the optimal-coding sequences were recalled better than the nonoptimal ones, the outcome could not be assigned unequivocally to the recoding factors discussed earlier since other variables are confounded—the number of pauses and groups and the variable sizes of the groups for the non-optimal-coding strings.

The nonoptimal, or control, conditions of the following experiments were designed to avoid these obvious confounded variables in one way or another. In Exp. I, the nonoptimal-coding sequences involved three pauses defining four triplets (as did the optimally coded sequences), but the sequences were altered slightly to render them uncodable in the ways envisaged. The alteration was simply to take the last letter of the series, put it first, and shift all letters one "space" to the right. This produces unpronounceable CCV strings like LDA TBE CJA XPE or meaningless strings like MFB IPH DTW AIB. The last-letter shift produces very little change in average letter-to-letter contingencies, so little change in recall would be expected if one believed that interletter associations guide recall of such sequences. In terms of encoding trigrams, however, the last-letter shift practically annihilates the former encodability of the optimally chunked sequences, and, for this reason, recall should suffer with such shifted sequences. Experiment II involved new control conditions in addition to the last-letter shift: one of these included reading the letter series with no pauses to see where recall in this condition would fall with respect to the optimal and nonoptimal codings; another distributed three pauses nonoptimally in the regular sequences, defining groups of sizes 4, 3, 3, and 2 (e.g., DATB ECJ AXP EL). Experiment III used strings composed of 2-, 3-, and 4-letter acronyms, and pauses were inserted to optimally segment or to break up the varying sized acronyms. The rationale of Exp. III is described later.

Experiment I

Method

Experiment I was a within-*S* comparison of immediate serial recall of four types of 12-letter strings. The four types were pronounceable vs. meaningful strings with the last letter shifted (nonoptimal coding) or not (optimal). Each *S* heard and immediately recalled 20 strings of each type in a randomly mixed order.

Materials and procedure.—The letters for the pronounceable strings were highly pronounceable CVCs (Underwood & Schulz, 1960). None were words. Ordered quartets of these were assigned to 20 12-letter strings. The meaningful acronyms and abbreviations were taken from slang dictionaries and various sources; many were suggested by the high-frequency letter associations in Table C of Underwood and Schulz. Ordered quartets of these were assigned to 20 12-letter strings.

The 12-letter strings were tape recorded at a rate of 10 sec. for the reading of the 12 letters. Each string was segmented by short pauses (approximately 1 sec.) and by vocal intonation into four trigrams. Each sequence of four meaningful or pronounceable trigrams was presented in two forms: the "optimal" form and the "shifted" form, where the last letter was shifted to the front of the string, as illustrated earlier. The two forms of a given sequence were separated by at least 8 intervening items (average of 24), so there should be little carry-over memory from the first to aid recall of the second form. Also, the two forms occurred first or second equally often over the various sequences. The four types of strings were meaningful-optimal, meaningful-shifted, pronounceable-optimal, and pronounceable-shifted, with 20 of each type. There were 20 blocks of four sequences, with one sequence of each type presented in each block of trials. After the reading of each string, a 15-sec. silent period ensued, during which *S* wrote his serial recall on an answer sheet which had 12 blank spaces marked off in a row. The *S* could record his recall in any order as long as the left-to-right spatial order corresponded to the temporal order of the letters; *S* was encouraged to guess if unsure of his recall. The *S* did not have to indicate the groupings heard.

The *S*s were 15 undergraduates fulfilling a service requirement for their introductory psychology course. They were run individually. The *S*s were not informed of the construction of the various types of letter series they would hear and were questioned at the conclusion of the experiment regarding anything they had noticed about the materials they were recalling.

Results

Recall was scored in terms of the number of letters recorded in the correct absolute position on the answer sheet. For sequences of meaningful acronyms, the mean number of letters correctly recalled was 9.7 when they were chunked optimally vs. 7.4 when the last letter was shifted. For sequences of pronounceable CVCs, recall was 9.2 when letters were chunked optimally vs. 7.6 when the last letter was shifted. Analysis of variance was carried out on the within-*S* 2×2 factorial, using *S*'s 20 recall scores in each cell of the design. The error term for assessment of the treatment effects was the replication variable pooled with its various interactions. For the meaningful material, recall of the optimal sequences exceeded recall of the shifted sequences, $F\ (1, 570) = 183$; for the pronounceable material, recall of the optimal sequence also exceeded recall of the shifted sequences, $F\ (1, 570) = 107$. There was also a significant ($p < .01$) interaction of the means, with the optimal-shifted difference being larger for the meaningful than for the pronounceable sequences.

The results confirm the earlier conjectures about optimal sequences. By shifting the location of the last letter, recall of optimal sequences deteriorates about 25%. This is a large effect in letter-span experiments because the base-line recall is fairly high and has relatively little variance. Analyses of serial position curves for the different types of items are presented later in conjunction with results from Exp. II.

Experiment II

Method

The materials and procedure were similar to those in Exp. I, except that two new types of control items were added for both the pronounceable and meaningful strings. One addition was that of ungrouped strings, recorded with no pauses at all, but the input rate was still 10 sec. for reading the string. Another addition was that of normal strings, but with pauses segmenting groups of sizes 4, 3, 3, and 2, as in PHDX KEA MAI BM. There were thus eight types of strings in all, four pronounceable and four meaningful types, each with pauses or no pauses, with pauses distributed in a 4, 3, 3, 2, or in a 3, 3, 3, 3 fashion; the latter strings were in normal order or with the last letter shifted to the initial position. There were 10 blocks of eight trials, with each type of item being represented in each block. To achieve some control over the makeup of the sequences exemplifying particular conditions, all 80 sequences recalled in Exp. II were composed from 10 basic sequences of four meaningful trigrams, i.e., 40 acronyms. These are called the basic *m* sequences. Each basic *m* sequence was so chosen that by rearranging its letters, a pronounceable (*p*) sequence of CVCs resulted. The 10 basic *m* and *p* sequences were each presented in four different forms: (*a*) with optimal pauses marking groups of 3; (*b*) with misaligned pauses marking groups of sizes 4, 3, 3, and 2; (*c*) with no pauses; or (*d*) with the last letter shifted to the front of the string, with pauses marking groups of 3. Only one form of a given basic sequence occurred in any eight-trial block, and two different forms of the same *m* or *p* sequence never occurred with fewer than 16 intervening items on the recall tape. Conditions of presentation and immediate recall were identical to those in Exp. I.

The *S*s were 12 undergraduates from the previous source, in a different school quarter than those in Exp. I.

Results

The main results of Exp. II are displayed in Table 1, showing average letters recalled

TABLE 1

MEAN LETTERS CORRECTLY RECALLED FOR THE EIGHT TYPES OF SEQUENCES OF EXP. II

Presentation type	Sequence type	
	Meaningful acronyms	Pronounceable CVCs
Aligned pauses	10.1	9.4
No pauses	8.4	7.9
Misaligned pauses	8.2	7.6
Last-letter shifted	7.1	7.5

in the correct position for the eight types of items. Several statistical contrasts of the treatment means were examined by analyses of variance. First, meaningful sequences were recalled better overall than were pronounceable strings, F (1, 864) = 12.9, $p < .001$. Within the meaningful strings, the four presentation types differed, F (3, 432) = 43.0, $p < .001$; Newman-Keuls tests showed that the "aligned pause" items were best, last-letter-shifted items were worst (both p's $< .01$), but the two middle conditions did not differ from one another. Similarly, within the pronounceable strings, the presentation types differed, F (3, 432) = 18.6, $p < .001$; Newman-Keuls tests showed that the "aligned pause" items were best ($p < .01$), but the remaining three types of items did not differ reliably from one another.

An alternative, but standard, conception of serial recall is that it is mediated by adjacent letter-to-letter (digram) associations and that recall difficulty will correlate with the level of preexisting digram associations in the sequence. Such preexisting digram associations are presumed to be indexed by the relative frequencies of occurrence of the digrams in English text. Therefore, when last letters are shifted and pauses are introduced in different places, a critical question from this viewpoint is whether the altered digram frequencies introduced by such manipulations on the base sequences are of a nature that might produce the observed variations in recall level. This question can be answered for the present letter sequences by consulting a table presented by Baddeley, Conrad, and Thomson (1960) which tabulates digram frequencies in English text, with the space between words counted as a twenty-seventh character. Each character-to-character transition in one of the present sequences was scored according to the conditional probability (from the Baddeley et al. table) of the second character, given the first. These transition probabilities were then averaged over all the transitions in the sequence and then over all sequences within a given experimental condition. This provides an average index of preexisting digram associations for the various sequences, and the index does vary with the number and location of pauses. However, these variations in the digram index turn out to be completely uncorrelated with the level of recall in the present experiments. In Exp. I, the index for the shifted sequences was slightly higher than for the optimal sequences, though the latter were better recalled. In Exp. II, with its eight conditions, the rank order correlation between sequence recall (cf. Table 1) and the digram index was an insignificant −.10. Similarly, in Exp. III (to follow), the nonoptimal-pause sequences had a slightly higher digram index than did the optimal-pause sequences, which were better recalled. This analysis therefore indicates that manipulations of pause structure were not achieving their effect on recall by way of incidental changes in preexisting digram associations.

Integration of serial responses.—Serial position recall curves were examined and had the typical bowed shape except for bumps and troughs corresponding to the pause-defined chunks of the series (cf. Bower & Winzenz, 1969, for similar curves). Although such curves chart overall recall at each position, they provide only a very murky picture of the "interitem associations" operating within the series. The associative integration of the serial responses can be inferred more readily by examining the correlations between recall and nonrecall of successive letters in the string.

Since present interests focus on pause-defined recall chunks, the statistics computed subsequently are based on the idea that whole chunks (subsequences of letters) tend to be recalled in an all-or-none fashion. If

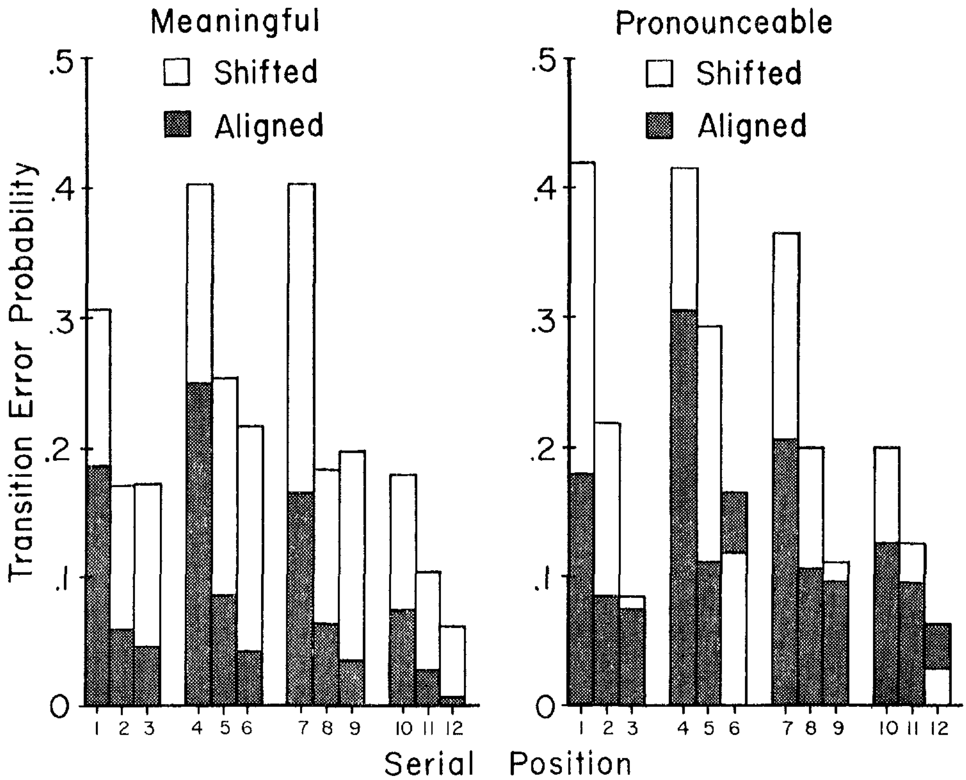

FIG. 1. Transition error probabilities for the four types of sequences in Exp. I.

the elements in Serial Positions n and $n + 1$ belong to the same recall chunk, then they should tend to be recalled or nonrecalled together (i.e., to be highly, positively correlated). Conversely, if these adjacent elements belong to different recall chunks, then one chunk may frequently be recalled without the other, so that recall of Elements n and $n + 1$ should be less correlated than in the former case.

Tabulations of the necessary 2×2 frequency tables and contingency correlations for recall of each pair of adjacent positions for each sequence type are very time consuming, so more convenient statistics are typically used since these provide practically the same information as the correlations. One of these measures is the transition error probability (TEP), defined as the conditional probability of an error on Element $n + 1$ given a correct recall of Element n. Another similar measure is the transition shift probability (TSP), defined as the joint probability of either a correct-error or an error-correct recall pattern for Positions n and $n + 1$. The TEP and TSP are highly correlated and are negatively correlated with the contingency coefficient for recall of Elements n and $n + 1$. With a chunked series, the TEP and TSP are large on the transition into the first element of a chunk, but are appreciably smaller for transitions within a chunk (cf. Bower & Winzenz, 1969; Johnson, 1968). Conversely, this means that *S*'s chunk boundaries can be identified operationally by large spikes in the TEP and TSP profiles.

A caution in interpreting adjacent-item correlations (or TEP or TSP values) is that positive correlations can be expected due to pooling over idiosyncratic differences in series difficulty or *S*s' recall levels, even though adjacent items are, in fact, recalled independently. For example, if the letters in half of the series were recalled independently with $p = 1$ and the letters in the

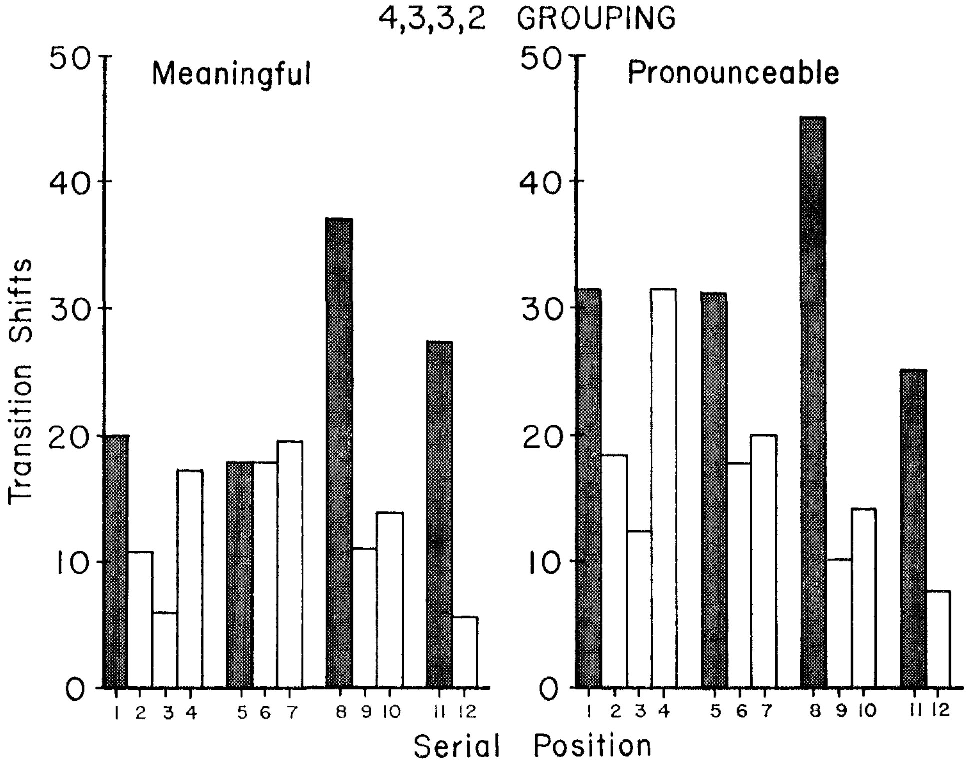

FIG. 2. Transition shift proportions for the misaligned sequences with group sizes of 4, 3, 3, and 2. (The initial transition into each pause group is shaded.)

remaining series with $p = 0$, then adjacent-item correlations would be unity despite the assumed independence of the basic recall process. This potential artifact can vitiate strong comparisons of absolute values of TEPs across different sequence types having widely different marginal recall probabilities. However, the problem is considerably less serious if one only compares relative TEP or TSP values across serial positions within a given sequence type. The latter strategy is adopted later, since the TEP or TSP profiles are used only to compare relative integration of different segments in the pause-parsed sequences.

The TEP profiles for the four types of sequences in Exp. I are displayed in Fig. 1, for meaningful acronyms on the left and pronounceable CVCs on the right. The TEPs for the optimally aligned and shifted sequences are superimposed to permit direct visual comparison. The pauses between triplets are reflected by spacing the triplets along the abscissa in Fig. 1. The TEP over Position 1 is simply the unconditional probability of an error in recalling the first element of the series.

Several observations can be made about the four TEP profiles in Fig. 1. First, the pauses induced large TEPs for the first element after the pause, with smaller TEPs for the second and third elements after the pause. This pattern characterizes all 16 (4×4) of the pause-determined triplets in Fig. 1. In 14 of the 16 triplets, the TEP declines monotonically over Elements 1, 2, and 3 of the triplet. Since the shifted sequences strongly follow this pause pattern, *S*s were obviously not chunking by meaningful or pronounceable trigrams that go across pause boundaries; if *S*s had done that with shifted sequences, then the TEPs at Positions 5, 8, and 11 should have exceeded those at Positions 4, 7, and 10, respectively.

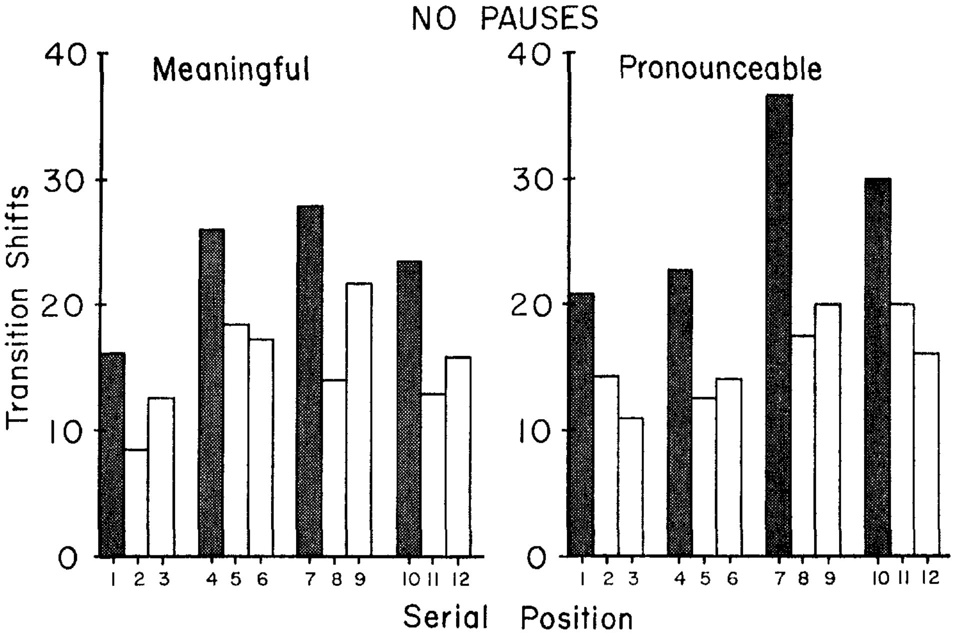

FIG. 3. Transition shift proportions for sequences presented without pauses. (The transition into each trigram group is shaded.)

In other words, the meaningfulness of a letter sequence was used for coding into response units if the pauses were properly placed, but not if they were not. A second observation from Fig. 1 is that the shifted sequences had higher TEPs than did the aligned sequences in 22 of the 24 position comparisons. (Positions 6 and 12 of the pronounceable sequences are the exceptions.) This simply reflects the overall better recall of the properly aligned sequences.

Observations on Fig. 1 were replicated in the TEP profiles for the aligned and shifted sequences in Exp. II. New patterns are available for the sequences with misaligned pauses or with no pauses. Clearer profiles for recall units emerged from a TSP measure rather than a simple TEP measure.

Figure 2 displays the TSPs for sequences grouped by pauses into chunks of sizes 4, 3, 3, and 2. The TSP after each pause is indicated by shading. As in Fig. 1, in nearly all the pause-bound groups (7/8), the TSP measure is largest on the first element of the group. The TSPs at Positions 4 and 5 which end one pause group and begin another are equal and are in striking contrast to the transition measures for analogous Positions 3 and 4 in Fig. 1. The initial group of 4 in size contained a meaningful or pronounceable trigram followed by an "odd" letter, and *S*s apparently chunked the 4 letters in just that way; the trigram showed the characteristic, decreasing TSP pattern, but a large TSP spike appeared on the fourth letter in the group which was as large as the TSP spike going across the pause-boundary to Position 5. In this instance, *S*'s coding was not being totally controlled by the pause structure of the presentation sequence.

The same phenomenon, of subjective determination of chunks, appeared most clearly in recall of sequences with no pauses. The TSPs for such sequences are shown in Fig. 3, where the trigram groups are spaced along the abscissa. Although pauses were absent, in every triplet the largest TSP occurs on the first element in each triplet. Thus, by this definition, *S*s were often recoding the letter sequences into meaningful or pronounceable trigrams. The TSP profiles for sequences without pauses are somewhat "noisier" and less exaggerated than

TABLE 2

Mean Letters Correctly Recalled for the Four Types of Sequences of Exp. III

Pause structure	String type		*M*
	Digram first	Quadrigram first	
4-3-3-2	6.34	9.64	7.99
2-3-3-4	9.30	7.13	8.21
M	7.82	8.39	

are those for the properly aligned pauses (cf. Fig. 1), but this is likely a result of a lower probability that no-pause sequences were chunked into successive triplets. That is, recoding is a "cognitive act" which simply may not be performed if there is not sufficient time or if *S* is not set to try it. Presumably, the trigram TSP profiles would be more exaggerated (i.e., larger differential in first vs. later within-group TSPs) for no-pause items if *S*s were informed of their pronounceable or meaningful character.

Experiment III

The theoretical hypothesis is that recall is facilitated when perceptual units correspond to familiar codable units in the sequence. At the empirical level, it has been shown that recall varies with the way a letter sequence is segmented by pauses. But some logical loopholes still remain for the hypothesis. For example, although the 3-3-3-3 structure was better recalled than the 4-3-3-2 structure in Exp. II, this could have been because the former structure was "easier" than the latter for reasons having nothing whatever to do with recoding of letter sequences from long-term memory. So long as codable trigrams are used (as in Exp. II), the triplet pause structure will always be superior to any nontriplet pause structure. But what has to be demonstrated is not that any particular pause structure is easier than another, but rather that the best pause structure is that which corresponds to the codable units in the series. That is, the hypothesis requires an interaction between the sequence of codable units and the sequence of pauses. Experiment III was designed to observe such an interaction.[8]

Each sequence in Exp. III consisted of four acronyms—one quadrigram, two trigrams, and one digram. The two trigrams always appeared in the middle, with the quadrigram and digram at the beginning and end. Examples are YMCA-DMZ-FBI-TV, with the quadrigram at the beginning (called Q strings), and TA-UPI-LSD-ROTC, with the digram at the beginning (called D strings). The other variable was the location of the pauses in the auditory series; these were such as to induce chunks of sizes 4-3-3-2 in that order or in the order 2-3-3-4. The expected interaction is that Q strings will be best recalled when read according to the 4-3-3-2 pause structure, whereas D strings will be best recalled when read with the 2-3-3-4 pause structure.

Method

Each *S* heard and recalled 32 12-letter sequences composed of 16 Q strings and 16 D strings, half of each grouped in sizes 4-3-3-2 and half grouped in sizes 2-3-3-4 by pauses in the tape recording. The Q strings had a quadrigram, two trigrams, and a digram in that order, whereas the order of digram and quadrigram was interchanged in the D strings. Two different tapes were prepared so that a given string appeared with the 4-3-3-2 pauses on one tape and with the 2-3-3-4 pauses on the other. One string of each of the four types appeared in each block of four trials. Each string required 10 sec. to read, at an approximate 2 letters/sec rate with 1-sec. pauses. Recall time was lengthened to 20 sec/string. Sixteen university students from summer school classes served as *S*s, assigned in alternation to the two counterbalancing tapes.

Results

The average number of letters correctly recalled in the four experimental conditions are shown in Table 2. The most obvious result in Table 2 is the interaction in the pattern of numbers: D strings were best recalled when the pauses were 2-3-3-4, whereas Q strings were best recalled when the pauses were 4-3-3-2. An analysis of variance on the means in Table 2 used the

[8] The general nature of this interaction design was suggested by a consulting editor who reviewed an earlier draft of the manuscript. The authors express appreciation for his suggestion.

replications variable and its interactions as the error term. This yielded a significant F (1, 448) = 183, $p < .001$, for the interaction term. There was also a small main effect for the string type, F (1, 448) = 7.85, $p < .05$, with Q strings being recalled somewhat better than D strings. The latter result was not expected and has no obvious interpretation. However, the point of the experiment was strikingly demonstrated in the large String Type × Pause Structure interaction. The strongest determinant of recall in this situation is neither the pause structure nor the sequencing of codable units, but rather the correspondence between these two variables. Recall is best when the perceptual (pause) units correspond to the recodable linguistic segments.

Finer analyses of the serial recall support the earlier results—that pauses are the main determinants of recall chunks as indexed by large TSPs across pause boundaries. To illustrate, Fig. 4 shows TSPs for the strings beginning with digrams and ending with quadrigrams, displayed for both the 2-3-3-4 and 4-3-3-2 pause structures. The TSP measure is largest at the beginning of the pause-marked segments in all eight chunks. Despite the series being meaningfully codable in segments of sizes 2, 3, 3, and 4, the TSP measure shows that the 4-3-3-2 pause structure overrode codability and determined the recall units. A similar TSP graph, only with reversed pattern, occurred for Q strings presented with the 4-3-3-2 vs. the 2-3-3-4 pause structure.

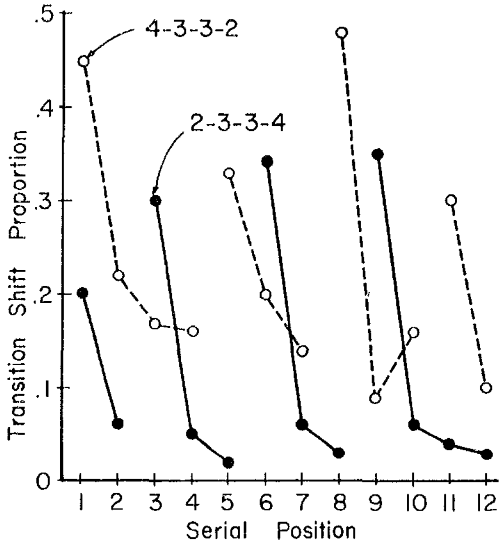

FIG. 4. Transition shift proportions for sequences beginning with a digram, with the imposed pause structure being either 4-3-3-2 or 2-3-3-4. (Unconnected adjacent points indicate an intervening pause boundary.)

DISCUSSION

First, to relate the present results to prior research, Laughery and Pinkus (1968) investigated immediate letter span for no-pause sequences of pronounceable CVCs, familiar initials, or the same letters in a scrambled, meaningless, unpronounceable order. Recall varied from best to worst in the order stated, and this held over a range of presentation rates from three letters/sec to one/3 sec. Laughery and Pinkus used a between-*S* design and instructed *S*s appropriately about the trigram chunkability of their sequences, whereas the present authors used a within-*S* design with many more conditions and did not instruct *S*s of the possibility of trigram chunking. Table 1 shows that in the no-pause condition, the present *S*s recalled the meaningful, unpronounceable sequences slightly better than the meaningless, pronounceable sequences. The discrepancy in ordering of these two conditions between the present study and that of Laughery and Pinkus could be due to multiple factors, including the specific samples of items used; it is fruitless to speculate on the cause of the matter.

It is probably more fruitful to speculate on the mechanisms of recoding and how these might be represented in an information-processing theory. The most explicit suggestions on this matter have been given by Laughery (1969) in terms of his computer-stimulation model for immediate serial recall. The basic idea is that during the interitem interval, the executive program first examines successive triplets of prior elements to see whether they can be recoded either in terms of pronunciation (for CVCs) or in terms of their meaningfulness. The process of determining whether a given letter triplet is recodable must involve something like a "dictionary look-up" in long-term memory or, failing that, a search through a set of grapheme–phoneme correspondence rules for a usable pronunciation naming the trigram. These correspondence rules could be indexed in terms of context-sensitive allophones (cf. Wickelgren, 1969), in which the pronunciation of a given letter depends on its preceding and succeeding neighbors. If the recoding search routine fails, then it would be presumed that *S* simply rehearses the individual letters (or their phoneme representatives), establishing links between them. If the recoding routine succeeds, then the trigram is replaced in short-term memory by a shorter code which permits faster, more efficient rehearsal. For pronounceable trigrams, this shorter code would be the phonemic parameters naming the trigram. This can lead to acoustic confusions in letter recall between trigrams with similar pronunciations (e.g., KAV and CAV), although the distinguishing letters (K and C) are not themselves acoustically confusable (cf. Pinkus & Laughery, 1967). For meaningful but unpronounceable trigrams, such as FBI and TWA, the shorter code is some "meaning surrogate." This could be the first letter plus the address of that "word" in long-term memory, or it could be an associated, pronounceable word, such as "feds" or "airline."

The contribution of temporal pauses to the recoding process is twofold: First, it appears likely from other work (e.g., Bower & Winzenz, 1969) that pauses determine perceptual groupings in accordance with gestalt principles of proximity of events (in time); second, pauses determine the most likely times within an input series at which the recoding search routine will be activated, since the executive program is momentarily relieved of monitoring for newly arriving material with which it would have to deal. The segment of recent material inserted into the recoding routine is most likely that segment which followed the preceding pause in the series. So, whether the recoding search routine succeeds or fails will be strongly dependent on where the pauses are located in the letter sequence.

Although this process has been described for auditory events with temporal pauses, the same principles would apply and the same results would be expected with visual presentations with spatial separation of elements. Segmentation of units in reading is heavily dependent on spacing, as il-lu-st-ra-te-db-yt-hi-se-xa-mp-le, and reading is very disrupted by unusual spacing. These recoding experiments could be done using other grouping principles besides those of temporal or spatial proximity. For example, in dichotic or dichoptic experiments, the channel (broadly defined) on which material arrives appears to serve as a grouping principle (cf. Yntema & Trask, 1963). Thus, if two meaningful trigrams are presented simultaneously to the two channels (a letter pair at a time), recall should be best if all letters of a given trigram came in over the same channel rather than being switched between channels. Thus, (T,F) (W,B) (A,I) should be reproduced more easily than (T,F) (B,W) (A,I), which requires channel switching for continuity of the meaningful trigrams. Experiments of this type are currently in progress.

REFERENCES

Baddeley, A. D., Conrad, R., & Thomson, W. E. Letter structure of the English language. *Nature,* 1960, **186**, 414–416.

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

Johnson, N. Sequential verbal behavior. In T. R. Dixon & D. L. Horton (Eds.), *Verbal behavior and general behavior theory.* Englewood Cliffs, N. J.: Prentice-Hall, 1968.

Laughery, K. R. Computer simulation of short-term memory: A component-decay model. In G. H. Bower & J. T. Spence (Eds.), *The psychology of learning and motivation.* Vol. III. New York: Academic Press, 1969.

Laughery, K. R., & Pinkus, A. L. Recoding presentation rate in short-term memory. *Journal of Experimental Psychology,* 1968, **76**, 636–641.

Pinkus, A. L., & Laughery, K. R. Short-term memory: Effects of pronounceability and phonemic uniqueness of chunks. In, *Proceedings of the 75th Annual Convention of the American Psychological Association,* 1967, **2**, 65–66.

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

Wickelgren, W. A. Context-sensitive coding, associative memory, and serial order in (speech) behavior. *Psychological Review,* 1969, **76**, 1–15.

Yntema, D. B., & Trask, F. P. Recall as a search process. *Journal of Verbal Learning and Verbal Behavior,* 1963, **2**, 65–74.

(Received July 22, 1969)