Perception and immediate recall of normal and "compressed" auditory sequences*

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For a fixed presentation rate, the ratio of speech-to-pause time was varied in three experiments. Ss recalled seven-digit sequences or monitored for item or order information in addition to recall. Removing 33% of the speech and substituting pause time improved recall accuracy and monitoring reaction times. The data suggest that loss of order information in recall may result from cumulative perceptual delays when adequate pause time is unavailable.

The relationship between presentation rate and accuracy of immediate recall is critical for any theory of short-term memory. However, published experiments on this issue are in conflict (Posner, 1963; Aaronson, 1967). One difficulty with those experiments using auditory material may be that the duration of the items has been confounded with the rate at which they are presented. For example, when presentation rate is increased naturally, by speaking faster, the durations of both the words and the intervals between them are decreased (Hutton, 1954). Also, when rate is increased by "speech compression," temporal segments are usually deleted in a uniform pattern from the stimulus material, from both the words and the intervals between words (Fairbanks, 1957a, b, c; Foulke, 1969). Variations in each of these temporal parameters may have different effects on the S's processing in an immediate recall task. Hence, it is of theoretical importance to obtain information on their separate effects.

Several lines of research suggest that (at least) two stages of perceptual processing are performed in series on the stimulus representation to increase its refinement, abstraction, or permanence. These stages may be differentially affected by the stimulus duration and the pause time between stimuli. At an early stage, which we will call "sensing," the stimulus duration (within limits) might determine the amount of stimulus information taken into a perceptual storage. However, the silent interval between stimuli might be critical for a higher level process, which we will call "identification." Past investigations are consistent with this approach. For example, Broadbent (1957, 1958) has postulated a large-capacity rapid

"decay" sensory storage, the S-system, followed by a limited-capacity perceptual storage, the P-system, which processes its input for later recall. Sternberg (1967) considered stages of perceptual processing ranging from a "raw image," or "direct copy," of the physical stimulus features to an identification based on a name or verbal label. Pollack (1959) provided evidence that auditory stimuli can be maintained as a "direct representation, much like that of a sound recording," but a more durable "categorized" representation can also be formed.

To study the effects of temporal parameters on immediate recall, Yntema et al (1964) and Aaronson (1967) varied presentation rate by varying *only* the silent intervals between words while holding word duration constant. Both studies found that increasing the silent intervals increased recall accuracy.¹ The present studies were conducted in order to assess further the effects of stimulus duration and pause time on perception and immediate recall of auditory sequences. In three serial recall experiments, the presentation rate of seven-digit sequences was held constant, while the ratio of stimulus duration to pause time was varied by "compressing" the speech and compensating with additional pause time between words.

Within the above theoretical framework, what general trends might one expect for the present experiments? For a low-level *sensory stage* of processing, the duration of the physical stimulus should be important. Within limits, the longer the physical stimulus is available for reference and the more information the stimulus contains, the more accurately and completely it can be represented. According to Brown (1958), coding of stimulus redundancy is important for later recall, when decay time and other items intervene. Hence, at an early stage of processing, representations of higher quality, which yield higher recall accuracy, may result from normal digit sequences, with their longer stimulus durations, than from compressed digit

sequences presented at the same rate.

On the other hand, for higher levels of processing, such as *identifying*² or *encoding* item and order information, the amount of processing time available between items may be critical. For example, the internal processing may not be carried out efficiently while the external auditory stimulus is present. Hence, a better identification or encoding, leading to higher recall accuracy, should result from the longer silent intervals between compressed digits than from the shorter intervals between normal digits.

EXPERIMENT 1: SERIAL RECALL

Method

Stimulus materials. The method used to record stimuli guarantees that a particular item is acoustically the same, regardless of its position in the sequence. (Natural speech often contains changes in stress and temporal grouping that depend systematically on serial position.) First, a master tape was recorded, containing one example of each digit from 0 (pronounced "oh") to 9, spoken by a male voice. This original master tape of 10 digits, equated for loudness, had a mean digit duration of 225 msec. A second master tape of 10 "compressed" digits was made by deleting several sections of about 17 msec (approximately uniformly) from each original digit and combining the remainder to form a continuous acoustic signal, using Garvey's (1953) chop-slice method. In this way about 33% of the speech was removed, resulting in a "compressed" master tape with a mean digit duration of 150 msec.

With the use of two Ampex tape recorders and electronic timing and control circuitry, seven-digit sequences of these numbers were rerecorded, one digit at a time, from the master tapes to form the stimulus tapes. For both normal (N) and compressed (C) seven-digit sequences, a 3-digit/sec presentation rate was used. For the fixed 3/sec rate, there was more speech time and less silent time for N than for C sequences.

Sequences were determined by taking the first seven digits from random permutations of 0 to 9, excluding consecutive forward or backward runs of Length 3 or greater. Different sequences were used for N and C tapes. Intelligibility tests were performed on these digits by presenting them, one at a time (S-paced), at 35 dB SPL, the intensity used in the three experiments. Six Ss heard 10 practice, 88 normal, and 88 compressed digits in the order NC (three Ss) or CN (three Ss). Ss named the digits correctly on 99.5% of both N and C trials.

Procedure. The sequence of events on a single trial was as follows. At the start of

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Fig. 1. Experiment 1. Serial position curves of total, item, and order errors in recall.

each trial a yellow "ready" light signaled S that he could start by pressing a pedal when he was ready to attend. He then heard a 1,000-Hz tone in his earphones (Permoflux PDR-8), warning him that a seven-digit sequence would start in .67 sec. Four seconds after the last digit, a 500-Hz tone signaled S to recall aloud the digits in the presented order, making the best guess he could when uncertain. If S recalled correctly and in the correct order, a green light was flashed; otherwise a red light was flashed.

The experimental session was divided into four blocks of 32 trials each, a different seven-digit sequence on each trial. Half of the Ss received blocks in the order NCCN and half CNCC. At the beginning of the session, Ss had 10 practice trials of the same condition as their first block of experimental trials. Sixteen undergraduate Ss were paid for their services, and the top 25% received an extra monetary bonus as motivation for high accuracy.

Results

Even though 33% of each item was removed, immediate recall accuracy was significantly higher for C than for N. The ordinate of the serial curve in Fig. 1A is the percentage of stimuli recalled in error.³ For 13 of the 16 Ss, the percentage of errors was smaller for the sequences of shorter digits and longer pauses ($p < .02$, binomial test).

Recall errors were separated into item and order errors. An item error was scored for a given stimulus position when that item was not recalled anywhere in the response sequence. An order error was scored when a stimulus item was recalled, but not at its original stimulus position. No overall difference in item errors occurred between N and C (Fig. 1B). Rather, the difference in accuracy can be attributed to differences in order errors, as shown in Fig. 1C ($p < .01$, t test).

Although frequency of item errors did not differ between conditions, the shape of the serial curves did. As an index of shape, least-squares lines for Positions 1 to 6 (Fig. 1B) were determined for each S. The difference in slopes between N and C sequences was significant ($p < .05$, one-tailed t test). Relatively more of the errors occurred toward the end of the sequence for N than for C.

Discussion

Consider the data in relation to the two-stage processor discussed earlier. If stimulus duration for both normal and compressed digits is about adequate for "sensing" physical features of the items, then item errors should be few and there should be little overall difference in item errors between conditions. However, a higher level verbal "identification" may determine order information primarily during the silent intervals. If the necessary identification time exceeds the silent interval, a backlog of items may accumulate and be identified in the wrong order. Hence, more order errors would be

expected for sequences of normal digits with their shorter pause times.

Further, if two assumptions are made, such accumulations could yield a bow-shaped serial position curve of order errors (Fig. 1C) whose degree of asymmetry is determined by temporal parameters. (1) Perceptual processing is serial in nature; items are handled one at a time, and unprocessed items accumulate in a buffer storage while early items are processed. Broadbent (1957, 1958) and others provide evidence supporting this. (2) The order of identifying (and recalling) items is not determined strictly by the presentation order but, instead, by a probability distribution over the accumulated unidentified items in the buffer.

Figure 2 illustrates how a bow-shaped curve might be obtained. The top line represents stimulus items arriving at a constant rate. The second line indicates the time at which each of seven (possibly degraded) items are taken from the buffer (not necessarily in their presented order, i.e., Assumption 2). The third line indicates the number of unidentified items in the buffer at the time of each identification. As the stimulus sequence progresses, for a serial identifier that lags behind the presentation, the buffer accumulation builds up. However, when the stimulus sequence terminates, the buffer size begins decreasing. When items are selected for identification, the chances of selecting them in the wrong order would be higher with larger buffer accumulations, as in the middle of the series.⁴ If identification occurs primarily during the silent intervals, greater accumulations and more order errors should result for normal than for compressed digits.

The shape difference between the N and C curves of item errors (Fig. 1B) is consistent with the hypothesis of identification delays. The presence of more

Fig. 2. A model of the temporal course of perceptual processing.

Fig. 3. Experiment 2. Monitoring reaction times and recall accuracy. N = normal; C = compressed; SP = serial position.

stimulus features for normal digits produces better "sensing" and item recall early in the sequence. However, identification delays (and consequent degradation of "memory traces") would accumulate over the series more rapidly for normal sequences with their short pause times, reducing recall accuracy toward the end. For both normal and compressed digits, item errors increase over the series, except for the last position. Recall for the last digit may improve partly because no subsequent digits are available to delay its identification. Similarly shaped item error curves have been obtained in previous studies (Aaronson, 1968; Ryan, 1967; Glanzer, 1966).

EXPERIMENT 2: MONITORING FOR AN ORDERED PAIR PLUS RECALL

To test the hypothesis of perceptual lag, it would be valuable to obtain further evidence about the time at which ordered identification occurs. One possibility is to ask the S to respond as soon as he perceives the order of a pair of items in the sequence. The greater the delay between the presentation of the pair and the S's perception of its order, the longer the response time (RT) should be. Therefore, we conducted Experiment 2, in which Ss were required to monitor the sequence for an ordered pair, as well as to recall in serial order.

Method

The same equipment and stimulus tapes were used as in Experiment 1. One second after S started each trial he was shown a "critical pair" of digits that would subsequently occur in the auditory sequence in adjacent positions. The pair appeared in one order on the left side of the visual display and in the reverse order on the right, for example "36" and "63." (An element of the pair could not occur alone in the sequence.) The display lasted 2 sec, and 1 sec elapsed before the 1,000-Hz tone signaled the auditory digits. Ss were told to press a response key as soon as they heard the critical pair in the auditory sequence: the left-hand key if the pair was spoken in the order on the left side of the visual display and the right-hand key otherwise. The RT from the onset⁵ of the first digit of the critical pair was recorded. Four seconds after the sequence terminated, Ss recalled aloud the items up to and including the critical pair, making their best guesses when uncertain. At the end of each trial, Ss saw two sets of feedback lights: green lights for correct recalls and correct keypresses, and red lights for errors.

The experimental session was divided into four blocks of 30 trials each, half the Ss receiving the order NCCN and half CNNC. In each block of 30 trials, the critical pair occurred equally often (five

times) at each of the six possible stimulus positions, and the left and right response keys were each designated to be correct on 50% of the trials. Conditional on these restrictions, the critical pairs were chosen randomly from the seven-digit sequences. Ss received 12 practice trials of the same condition as their first block of experimental trials. A new group of 24 undergraduate Ss was paid for their services, and the top 25% received a monetary bonus.

Results

Reaction times. Figure 3A shows that for correct monitoring responses, RTs to critical pairs were longer for N than for C ($p < .01$, F test). The graphed data are for the first half-session. During the second half, reaction times decreased by a greater amount for N than for C, reducing the differences (see section on practice effects below). Figure 3A shows that RT differences increased with position of the critical pair in the sequence. Least-square lines were determined for each S, and the slope of RT vs serial position was steeper for N than for C for 22 out of the 24 Ss (Serial Position by Item-duration interaction: $p < .01$, F test).

Recall performance. Figures 3C and 3D show the percentages of order and item errors. The sequence length was determined by the location of the critical digits. "Preserved pairs" (Fig. 3B) provides a second index of information about order: the percentage of recalled stimulus pairs (for positions up to and including the critical pair) that occurred in successive adjacent response positions. As expected, error rates increased with sequence length for both groups ($p < .01$, F tests). Also, the data show that there were more item and order errors, and fewer preserved pairs for N than for C. Although these duration effects did not quite reach statistical significance, the interaction between duration and sequence length did ($p < .01$, F tests): the greatest duration effects occurred at intermediate sequence lengths.

In Experiment 1, there were many more order than item errors (Figs. 1B and 1C) and the ratio of order-to-item errors was greater for N than for C (5.2:1 and 4.1:1, respectively). Similarly, in Experiment 2 there were more order than item errors (Figs. 3C and 3D) and, again, the ratio of order-to-item errors was greater for N than for C (5.3:1 and 4.6:1, respectively).

Discussion

The Ss in Experiment 2 were required to respond as soon as they perceived the order of the "critical pair" of items in each sequence. Hence, we have considered RT as an index of perceptual delay; the greater the delay between the presentation of the

critical pair in the auditory sequence and the S's perception of its order, the longer the response time should be. With this assumption, the data of Fig. 3A provide evidence that in a serial recall task Ss lag behind in their identification of order information to a greater extent for normal than for compressed digits. By the last position, the RT difference is 200 msec, even though the difference in duration between normal and compressed items is only 75 msec. Hence, the increased RT for normal items does *not* arise simply because Ss wait until the digit of longer duration is completed before responding. Rather, inadequate processing time between normal digits causes perceptual delays to accumulate over the series. These monitoring data support the hypothesis that differences in order errors for our first experiment were due in part to differences in identification delays between normal and compressed sequences.

The data for order errors and preserved pairs are also consistent with those of Experiment 1. The available time between items to identify them in proper order is less for N than for C; consequently more order information is lost. Also, as in Experiment 1, there is more difficulty maintaining order than item information, and this difference is greatest for the normal sequences. In Experiment 2, the difference in shape for serial curves of item errors was again maintained. Averaged over all sequence lengths, the mean position of item errors was later in the series for N than it was in the series for C, Serial Positions 2.82 and 2.61, respectively. For Experiment 1, it was hypothesized that this shape difference between N and C curves resulted from a trade-off between digit redundancy (improving normal digits early in the series) and identification delays (degrading normal digits late in the series). In Experiment 2, even though the shape difference was maintained, slightly more item errors occurred for normal digits regardless of serial position. Perhaps the additional requirement to monitor for a critical pair increased identification delays (even at early positions) enough to offset the advantages of the longer stimulus duration.

EXPERIMENT 3: MONITORING FOR A SINGLE DIGIT PLUS RECALL

We hypothesized that the difficulties of order perception in the above experiments were *not* due to any special processing of order information per se. Rather, *order errors result from delays in the identification of the items themselves*.⁶ Our perception of speech lags slightly behind the presentation. The greater the lag, and the greater the number of

Fig. 4. Experiment 3. Monitoring reaction times and recall accuracy.

unidentified items accumulated in perceptual storage, the greater the opportunity to select them in the wrong order for identification. To test this hypothesis, an experiment was conducted on the perception of item information during a recall task using the same experimental paradigm and stimulus sequences used in the above order-perception experiment.

Method

This experiment was identical to Experiment 2, with the following exceptions. On each trial, Ss first saw a single "critical digit" that would occur in the auditory sequence with a probability of .70 (30% of the trials were "catch trials" on which the critical digit was not spoken). Ss were told to press a YES key as soon as they heard the critical digit in the auditory sequence. When they did not hear the critical digit, Ss pressed a NO key immediately after the sequence ended. Four seconds after the last digit, a 500-Hz tone signaled S to recall aloud the items up to and including the critical digit, or the entire sequence on catch trials.

The session was divided into 12 practice trials and four blocks of 30 experimental trials, half of the Ss receiving the order NCCN and half CCCC. In each block of 30 trials the critical digit occurred equally often (three times) at each of the seven

possible stimulus positions (i.e., 21 critical trials), and 9 trials were "catch trials." Conditional on these restrictions, the critical digits were chosen randomly from the seven-digit sequences. A new group of 26 undergraduate Ss was paid for their services, and the top 6 received a monetary bonus.

Results

Reaction times. As shown in Fig. 4A, RTs for correct monitoring responses were longer for N than for C ($p < .01$, F test), and this RT difference increased with serial position (Duration by Position interaction: $p < .05$, F test). For both N and C, RTs generally increased over the series. However, for both groups, RTs are relatively long at the first serial position. This has been found in earlier studies (Aarons, 1968) and seems to indicate that Ss are less prepared to respond at the start of the series than at subsequent positions.

Recall performance. Figures 4D, 4C, and 4B show that item and order errors increase and preserved pairs decrease with sequence length for both N and C ($p < .01$, F tests). There were slightly more order errors and fewer preserved pairs for N than for C. However, slightly more item errors occurred for C than for N. As previously found, order errors exceeded item errors, and the ratio of order-to-item errors was greater for N than for C (5.1:1 and 3.9:1,

respectively). Also, as in Experiments 1 and 2, a greater percentage of the item errors occurred toward the end of the series for N than for C. Averaged over all sequence lengths, the mean serial position of item errors was 3.4 for N and 3.2 for C.

Catch trials. For catch trials (when the critical digit did not occur during the auditory sequence) recall trends were similar to those of Experiment 1 and to the recall data for "critical" trials of Experiments 2 and 3. There were more item errors and order errors ($p < .05$, F test) and fewer preserved pairs for N than for C. Also, the ratio of order-to-item errors was greater for N than for C, 4.4:1 and 4.0:1, respectively.

Practice effects. As in Experiment 2, RTs decreased with practice to a greater extent for N than for C. RT differences between the first and second half-sessions were 173 msec for N and 30 msec for C. Perhaps Ss decreased their identification time by decreasing the amount of information they extracted, especially for normal digits. Indeed, with practice, item errors and monitoring errors increased slightly for N but decreased slightly for C. Also, the percent of preserved pairs increased less with practice for N than for C.

Discussion

Ss in Experiment 3 were required to respond as soon as they perceived the "critical" digit in the auditory sequence. Their RT was taken as an index of perceptual delay; the greater the delay between the occurrence of the critical digit in the sequence and its perception, the longer the response time should be. With this assumption, the data of Fig. 4A are consistent with the notion of a limited-capacity processor whose identification rate cannot keep up with the stimulus rate. The positive slopes of RT vs serial position suggest perceptual lags for both N and C. The steeper slope across serial positions for normal digits would result from greater accumulations of unidentified items. Again, as we found earlier, such accumulations in a temporary buffer should increase order errors and decrease preserved pairs for normal digits on "critical" and "catch" trials.

In Experiments 2 and 3, we aimed to study the temporal course of perception of order and item information during a short-term memory task. Hence, correct serial recall was emphasized for these monitoring tasks. The similarities in recall trends in all three experiments support the hypothesis that Ss were processing the items in similar ways in all three tasks. The similarity between recall data for "catch" trials of the monitoring task and recall-only

trials of Experiment 1 provides a control condition in this light.

Now compare the RT data, when Ss must monitor for item or order information. The absolute times are greater in Fig. 3A than in Fig. 4A, as Ss in Experiment 2 responded after the second digit in each pair (anticipatory responses for both experiments are low and show little difference). Note that RTs, as a function of serial position and digit duration, show similar trends when Ss must identify the *items themselves* (Fig. 4A) or the *order* in which they occur (Fig. 3A). These similarities between Experiments 1 and 2 are consistent with the hypothesis that the listener uses the pauses between items for identifying them in a particular order. When this pause time is reduced, as for the normal digit sequences, the resultant identification delays lead to order errors in recall. Aaronson (1968) drew similar conclusions from monitoring and recall experiments that varied pause time but kept speech duration constant.

Our experimental results are directly relevant to problems in using compressed speech to enable blind people to receive verbal information faster than the normal speech rate. Fairbanks et al (1957a, b, c), Foulke (1969), and others have shown that recall and comprehension decrease when speech is compressed *uniformly* by deleting segments from the words *and* from the intervals between words. The present experiments suggest that for maximum recall and comprehension, for a fixed amount of compression, it may be optimal to delete more from the words than from the intervals between words. English is so redundant that much of the word can be eliminated without decreasing intelligibility, but the interword intervals are needed for perceptual processing.

ALTERNATIVE THEORIES

Masking

Forward and backward masking (Licklider, 1951) might increase perception time for the more closely spaced normal digits. Such intelligibility differences should also produce more item errors. For Experiments 1, 2, and 3, the differences in item errors between N and C were, respectively, zero, slightly negative, and slightly positive, contradicting this alternative.

Psychological Moments and Prior Entry

Psychological time may consist of discrete "moments" of attention, each about 100 msec, during which we cannot simultaneously attend to, or discriminate order between, two events (Schmidt & Kristofferson, 1963; Stroud, 1955; Harter, 1967). Hence, differences in order

perception between N and C may result if the end of one digit and the start of the next occur within the same "moment" for N (108-msec pauses), but not for C (180-msec pauses). This hypothesis is insufficient, as it does not predict the serial position effects for RTs and errors.

Expectancy

For variable foreperiods, simple RT varies inversely with time between the warning and stimulus, perhaps due to decreased expectancy or readiness to perceive (Snodgrass, 1969). Analogously, the pauses may provide shorter foreperiods for N than for C. However, expectancies regarding (1) the event time of each digit and (2) the occurrence of the particular critical digit or pair should increase over the series, predicting decreased RTs with serial position, in contradiction to our data.

Digit Duration

Shorter digits may require less identification time, reducing RTs and errors for C. First, this doesn't account for differences between C and N in shape of the serial curves of item errors and in ratio of order to item errors. Second, according to Brown (1958) and Crossman (1961) a shorter and less redundant code for C should lead to *more* item and order errors. To compare the digit-duration and pause-time theories, one might keep pause time fixed and vary digit duration. The digit-duration theory then predicts better performance for shorter digits, and consequently faster presentation rates. We could not locate such experiments for auditory stimuli, but sequential immediate recall studies using visual items contradict this prediction (Mackworth, 1962; Sitterly, 1968; Haber & Nathanson, 1969).

Attention

Because compressed speech differs from our usual acoustic input, Ss might attend more closely to C than to N, resulting in faster RTs and fewer order errors. One test of this hypothesis (as in the above paragraph) is to vary digit duration by compression but to hold pause time fixed. Secondly, for an attention theory, one would expect habituation and consequent degradation of performance over the session. On the contrary, performance improved with practice, and recall accuracy improved more for C than for N.

In summary, theories based on masking, psychological moments, expectancy, digit duration, and attention can each account for some aspects of our data. But hypotheses based on identification delays more completely account for the present results and for many related short-term memory studies.

PARAMETRIC EFFECTS

In reviewing short-term memory studies that vary the ratio of on-to-off time, we found that none shows better performance for longer on-time. The advantage for longer off-time depends on other stimulus parameters: stimulus modality, number and complexity of stimuli, and presentation rate.

Thor and Spitz (1968) and Fraisse (1966) required Ss to report (and hence remember) which of two visual displays occurred first. Accuracy was determined primarily by total presentation time (on + off + on) and increased to 100% by 200 msec. However, Fraisse's graphs do indicate better performance with longer off time for fixed values of total time, in agreement with our results.

In several immediate recall tasks, on-off ratio was varied for visual stimuli. For displays of one letter at a time, Haber and Nathanson (1969) report that recall increased with total time, regardless of on-to-off ratio. However, their data matrix indicates that the proportion of cells favoring longer off-times increases with overall presentation rate (35 to 160 msec/letter) and with sequence length (4 to 8). Sitterly (1968) used a greater range of on- and off-times, each varying from 100 to 1,000 msec per digit (4 to 14 digits). Again, the critical variable was total time, although longer off-times had a slight advantage in four out of six possible time comparisons, and interactions between sequence length, duration, and off interval were significant. For pairs of displays, containing one, three, or five letters each, Greenberg et al (1968) varied on + off + on time from 11 to 225 msec. They report a strong advantage of longer off-time for fixed values of total time, and this advantage increases slightly for longer sequences.

Taub, Monty, and Laughery (1967), with visual displays, and Glucksberg and Laughery (1965), with auditory recordings, did parallel experiments in which Ss remembered the number of times Q, R, S, and T occurred in sequences of 8 to 20 letters. Taub found longer off-times highly superior for overall rates of 2 and 3 sec/letter, no difference for 1 sec/letter, and a reversal for 4 sec/letter. Glucksberg, using 2 sec/letter, obtained significantly fewer errors for long than for short off-time. In both studies the advantage of longer off-times increased significantly with sequence length, suggesting that insufficient processing time was more critical for longer sequences.

For nine-digit (.3 sec/digit) auditory or visual sequences, Corballis (1966) gradually increased (I) or decreased (D) off-time over the sequence from .2 to 1.6 sec. Recall accuracy was slightly worse in the middle

of the sequence for I than for D but significantly better toward the end. This is consistent with the hypothesis that identification delays may cumulate over the sequence when insufficient processing time is available.

In summary, experimental parameters influence the advantage of longer off-time in short-term memory tasks. (1) Auditory tasks (Corballis, Glucksberg) are helped by longer off-time, but this is not always the case for visual stimuli: Thor found no advantage for longer off time; Fraisse, Haber, and Sitterly found a slight advantage; while Greenberg and Taub found stronger effects. (2) The improvement with longer off-time generally increases with number of stimuli (Glucksberg, Greenberg, Taub, Sitterly) and with stimulus complexity. Thor found no improvement using a single simple form (upright or inverted triangle), whereas tasks helped by off-time used verbal material. Greenberg found more improvement when the displayed letters formed words than for random letters. Indeed, the determining factor may be whether Ss code the material verbally or simply rely on a sensory image. (3) The effectiveness of longer off-time interacts with rate (Haber, Taub). Off-time may be more effective at presentation rates nearer the normal speech rate (Corballis, the slowest rates of Haber, intermediate rates of Taub) than for extremely fast (Thor) or slow (Taub) rates. The critical factor may be the presentation rate *relative* to the complexity of coding performed by Ss. Our present experiments are consistent with these trends: the stimuli are auditory, the sequences are moderately long, and the speech rate is close to normal.

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- the two levels. We are concerned here simply with two stages of processing that increase the permanence and usability of the internal representation.
3. Ss were instructed to recall seven digits, and to guess if uncertain. Responses of an incorrect length amounted to less than 1% of the data and were omitted from subsequent analyses.
4. A strictly random selection from the buffer produces a highly nonsymmetric curve with far too many errors at the end of the series. However, if selection probabilities are weighted, based on imperfect information about arrival order or "trace strength" of the items, bowed curves can be generated (Aaronson, 1966).
5. Digits on the original master tape were slightly clipped at the beginning and end to provide sharp transients for temporal reliability in activating electronic components.
6. Other short-term memory studies indicating nonindependence between item and order information have been done by Bertelson and Tisseyre (1969), Buschke and Lenon (1969), Cumming and Coltheart (1969), Aaronson (1968), Aaronson and Sternberg (1964).

NOTES

1. Similar trends were obtained for the visual presentations of Bergstrom (1907) and of Monty, Fisher, and Karsh (1967).

2. Some psychologists would question the inclusion of identification as a perceptual rather than a mnemonic process. However, data to date do not even justify a clear dichotomy between

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