Processing of sequentially presented letters[1]

RALPH NORMAN HABER[2] AND LINDA SUE NATHANSON[3]
UNIVERSITY OF ROCHESTER

The effect on the number of letters S can report of the duration of each sequentially presented letter was compared with that of processing time, defined as the time from the onset of a letter to the onset of the next letter. Four Ss were each shown 1250 common English words, from four to eight letters long, one letter at a time. Each letter acted as a visual noise field for the preceding letter. The duration of each letter and the interval between letters was varied independently. The S reported the letters he saw after each word was displayed. It was found that the processing time (onset to onset) predicted the number of letters correctly reported, regardless of the partition between on time and off time. A calculation was made of the number of milliseconds of on plus off time that are needed to ensure correct report of each letter. This time was independent of the duration of the processing time, but was positively correlated with the number of letters in the word. This correlation is probably in part artifactual, so that no claim can be made that it takes longer to process a letter of a long as compared to a short word.

Since stimulus duration correlates well with most of the dependent variables that are studied, it has usually served as the independent variable in studies of visual recognition. Sperling (1963, 1967) has shown, however, that a visual stimulus may persist in short-term visual storage for several hundred milliseconds after the offset of the stimulus. Thus, the stimulus duration may be shorter than the total perception time, since the S can extract information during the storage period as well as during the stimulus exposure.

Sperling (1963) has also suggested that visual storage can be masked by a field of visual noise that follows the stimulus. When the noise field follows immediately, the time available to process the stimulus is its duration. When the noise field is delayed, the time available is the duration of the stimulus plus that of the visual storage. Sperling thus suggests that the appropriate independent variable is the total *processing time.*

Experiments related to that question have been carried out with sequential letter and word recognition. With the sequential presentation of individual letters of a word, in which each letter occupies the same retinal location, each successive letter provides a visual noise that may interrupt the processing of the previous letter. The present experiment was designed so that the duration of each letter and the temporal interval between letters were independently controlled.

METHOD

Subjects

Four University of Rochester undergraduate students served in 10 sessions as paid Ss. They were unpracticed and naive concerning the purposes of the experiment.

Apparatus

The letters were presented on a single alpha-numeric display drawn on a 4 x 3 in. electroluminescent panel made by Massey Dickinson. The panel contained 15 segments, each of which could be controlled and displayed independently of the others. Rise and decay times for the segments were 0.5 msec. All letters were capitals, averaging 3½ in. high and 2 in. wide (8 x 5 deg at a distance of 2 ft). The luminance of each segment was 8 ft-L. A weak luminance (less than 0.5 ft-L) was present owing to stray light on the background of the panel when some segments were on. They were invisible when off. The room was dark except for a 25-W lamp located some feet behind the S and shielded from his view.

The display sequence for the panel was controlled by a PDP-8 digital computer. Each of the 15 segments was treated as a separate bit in the computer memory. A 15-bit buffer served as interface between the accumulator of the PDP-8 and the segments on the panel. The program specified, for each trial, the on time for each letter, the off time between successive letters, and the particular sequence of letters to be displayed. After S initiated the trial, and responded orally, E would type the responses on the computer typewriter.

Stimuli

Each S was shown 1250 words, subdivided into five lengths (4, 5, 6, 7, and 8 letters), five on times (10, 25, 50, 100, and 150 msec), and five off times (10, 25, 50, 100, and 150 msec). Thus, for each word length there were 25 cells representing different on-off combinations, each one of which was tested with 10 words per S.

The order of the 1250 words was randomly determined by the computer. The words were divided into blocks of 125 words which represented a complete replication of the experiment, one word per cell. Each of the four Ss received the 10 blocks of 125 words in a different order.

The words, taken from the Thorndike-Lorge lists, were the 250 most frequent words of each word length. The least frequent words appeared at least 50 times per million. There were no differences in the distribution of frequencies among the five word lengths.

Procedure

Each S was given two practice sessions to famliarize him with the letters on the display. A practice program displayed the alphabet, first in sequence and then randomly, at varying rates determined by E. The S was instructed to name each letter as it appeared, and if he was uncertain about it, he was to say he did not know. For the first 5 min of each of the remaining eight sessions, S was again shown the alphabet display, first in proper sequence and then in a random order, to provide a warm-up. Following this, a block of 125 trials was begun. Typically, slightly more than one block was run per session.

The S was told that he would be presented with sequential displays of letters of common English words. He was to make no attempt to name the word, but only to name the letters that he was sure he saw. If he was uncertain, he was not to guess, but to say he did not see a particular letter. No payoff matrix was used to insure a high criterion other than these instructions, which were repeated frequently. The S was told that he need not begin his response until after the last letter appeared (in fact, even the slowest rates of presentation were too fast for an S to start responding before the last letter had appeared). The average intertrial interval was 5-10 sec, which included the time for S to report, and E to record.

RESULTS

Each trial was scored for the number of letters correctly reported in their proper position. These data were categorized by word length, on time and off time, for each of four Ss. Figure 1 presents the results for the four Ss combined.

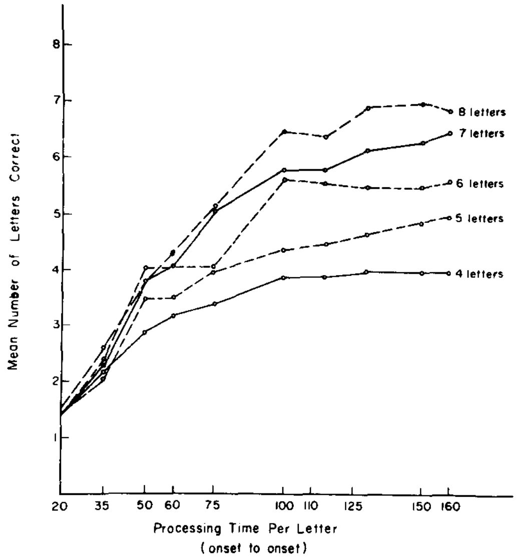

Fig. 1. Mean number of letters correct as a function of total processing time, in milliseconds, for each of five word lengths. Data are combined over four Ss, and within each S for different on-off combinations. The functions are terminated at a processing time of 160 msec where they approach close to their asymptotic values.

To determine whether total processing time or stimulus duration time is a more relevant independent variable, an analysis was made for all pairs of cells in which total processing time was equal but the distribution of on and off times varied. Is an S more accurate, for example, when the stimulus is on for 50 msec and off for 10, or when it is on for 10 and off for 50? The analysis compared eight pairs of on and off times: 10 to 25; 10 to 50; 10 to 100; 10 to 150; 25 to 50; 25 to 100; 25 to 150; and 50 to 100. Although pairs with even longer times were presented, no meaningful comparisons could be made because Ss were nearly always correct on all letters with long processing times. Several analysis-of-variance tests were used to determine whether the variation within each cell of Table 1 due to on vs off time was significant (cells in which either score was asymptotic were not included since they would produce a bias in favor of the null hypothesis). No on-off difference was significant. From Table 1, it is apparent that differences are rarely larger than .1 or .2 letters. Thus it appears to make little difference how the on and off times are distributed within a total processing time.

Since Sperling (1963) had shown that about 10 additional milliseconds between stimulus onset and visual noise onset is needed to read out each letter when the letters are presented simultaneously, the question arises whether a comparable analysis can be applied to sequential presentations. If it takes X msec to read out a letter, then any rate yielding a processing time per letter greater than X should yield perfect performance. Processing times less than X should produce less accuracy—sometimes the letter will read out and sometimes not—with a higher probability attached to longer processing times. Given these assumptions, it should be possible to work backward from the data to estimate X. For example, 1.4 letters of four-letter words were reported correctly when the processing time was 20 msec (see Fig. 1). Dividing 4 into 1.4 gives 0.35, the probability of reading out any single letter, given 20 msec of processing time per letter. Dividing that probability (0.35) into the processing time (20 msec) gives an estimate of the time needed to read out a letter perfectly (57.1 msec). Following this rationale, the values of Fig. 2, as averages of the four Ss, were computed.

Table 1
Mean Number of Letters Correct

Processing Time (msec)		Number of Letters Presented				
		4	5	6	7	8
35:	10-25	2.2	2.0	2.5	2.4	2.4
	25-10	2.2	2.2	2.4	2.1	2.9
60:	10-50	3.2	3.3	3.9	4.1	3.9
	50-10	3.2	3.6	4.2	4.0	3.6
75:	25-50	3.4	3.6	4.1	5.0	5.4
	50-25	3.4	4.3	4.2	5.1	5.0
110:	10-100	3.8	4.6	5.6	6.0	6.6
	100-10	3.9	4.5	5.6	5.6	6.1
125:	25-100	4.0	4.7	5.4	6.0	7.0
	100-25	4.0	4.6	5.6	6.4	6.8
150:	50-100	4.0	4.8	5.5	6.5	7.0
	100-50	4.0	4.9	5.4	6.1	7.0
160:	10-150	4.0	5.0	5.8	6.6	7.2
	150-10	4.0	5.0	5.4	6.3	6.4

An analysis of variance of the data in Fig. 2 showed a significant effect of word length ($p < .001$). No other effects were significant. Thus, for each word length, the more time available for processing, the more letters processed. The average time needed to process a letter is about 65 msec for a four-letter word, and rises to about 110 msec for an eight-letter word.

DISCUSSION

The foregoing results support the hypothesis that, when a noise field is used to terminate the processing of visual storage, processing time becomes the appropriate stimulus measure. For values less than the time required for processing, the duration of the stimulus itself does not correlate with recognition. In fact, for a particular processing time, the ratio of on to off can be varied as much as 15 to 1 (10 msec on to 150 off, and vice versa) with no change in the number of letters reported correctly. The on-off complimentarity suggests that, when temporal parameters are critical in a perceptual

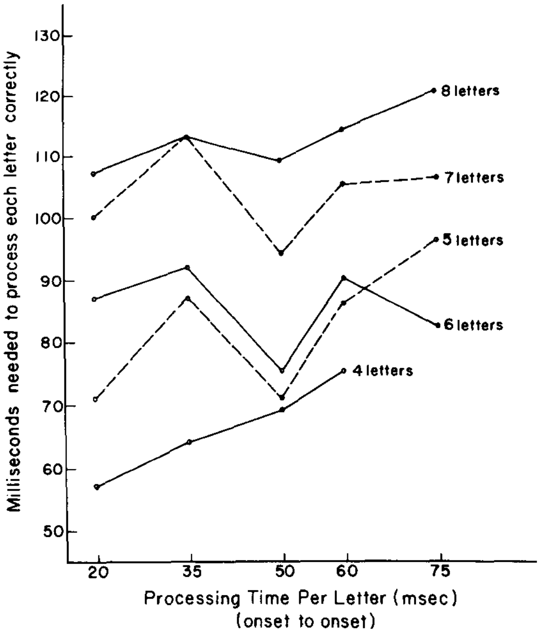

Fig. 2. Mean duration needed to process a letter as a function of processing time per item. The number of letters in the word is the parameter. Data averaged over four Ss.

experiment, a visual noise field should be used to control the duration of the processing time.

The variance of accuracy over wide ranges of on times accords with Sperling's (1960) finding that under some conditions the number of letters reported from a simultaneously presented display is invariant over a range of exposures from 15 to 500 msec. His interpretation, similar to the one offered here, is that exposure time does not correlate with accuracy when the processing time is left uncontrolled, because without a noise field there is created a short-term visual storage that may last many times longer than the exposure duration. Only when a masking field or some other interference is imposed at a fixed time after onset does stimulus duration correlate with accuracy.

Haber and Standing (1969) measured visual persistance directly by asking S to locate the maximum interval between repeating flashes for which the figure seen appears to remain visible. The persistance times were between 200 and 400 msec (depending on luminance and adaptation), which implies that the perception of a stimulus persists as a visual image for that length of time. The authors also found that persistance remained constant when the stimulus duration varied from 4 to 200 msec. Thus a direct measure of visual storage gave the same values as Sperling's procedures and also showed an independence of stimulus duration.

Not all the evidence supports the foregoing interpretation, however. For example, Raymond and Glanzer (1967) found that performance improved continuously as duration increased. That proved true for lighted pre- and postfields, for dark pre- and postfields, and for a visual noise field present in the pre- and postfield. In order for those results to be consistent with the present interpretation, either some masking or process-stopping interference would have to be present, or, for the short durations, the display would have to be at or below threshold. Both factors could have operated in their experiment; the adapting fields were never at the same luminances as the displays, and the luminance levels were so low that short flashes must have been below threshold. In short, it is not clear whether the study by Raymond and Glanzer represents a contrary finding.

The analysis that culminates in Fig. 2 is not particularly appropriate to the experimental design. Even so, the constancy of the time needed to process a letter (holding word length fixed) suggests that a serial interpretation of information processing may be justified (Haber, 1969). The time needed to process each item is much longer here (65 to 110 msec) than in the words of Sperling (1963) or Scharf, Zamansky, and Brightbill (1966). However, they used a single flash to present all the information. The sequential presentations used in the present experiment seem intuitively to be a more confusing, unaccustomed, and inefficient procedure.

Care is needed in the interpretation of the absolute values of processing times found in the present experiment, and especially the differences found among the different word lengths. One of the assumptions made for the analysis in Fig. 2 is known to be untenable: the processing time for the various letter positions could not have been equal. No noise mask followed the last letter of any word, so its available processing time was much longer than that for any other letter position. Further, no mask preceded the first letter, so that it experienced no forward masking. There were significantly more ($p < .001$) correct reports given for the first and last positions than for the middle positions. The average letter should therefore have a greater probability of being correctly reported in a short than in a long word, a fact that would explain the increased processing time for letters of long words. In addition, memory span may be exceeded more often by long than by short words. Thus the S may process the letters of long words at a high rate, but forget some of them before he can make his report. Sperling's (1963) finding that the rate of 10 msec per item increased sharply above four items may also be due to a limitation of memory span rather than processing. For those various reasons, neither the difference between word lengths nor the absolute values of processing time can be accepted without qualification.

The complimentarity of on and off times found in the present visual experiment does not accord with the results of an auditory study reported by Aaronson (1967). She used a sequential auditory presentation of random digits and held processing time (onset to onset) constant. She varied on and off times by splicing segments of the phonemes without changing their discriminability. As on time decreased and off time increased, performance improved. Visual and auditory stimuli differ in many respects, and the importance of off time may be one of them.

In summary, the results cited above appear to support the following conclusions: (1) processing time, defined as onset to onset of sequentially presented visual letters, predicts recognition better than either the time each item is on, or the time between the offset of an item and the onset of the next item; (2) shortening off time can be exactly compensated by lengthening on time, and vice versa; (3) the processing of an item takes an amount of time that is independent of the rate of presentation, but dependent on the length of the words; (4) the stability of the processing time per item supports a serial interpretation of the processing of sequentially presented items. By implication, the results also suggest that once exposure duration becomes sufficient for initial registration (a duration that is perhaps as short as 1/10 to 1/2 msec), further increases in duration are irrelevant, provided the S is given noise-free off time in which to process the information.

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NOTES

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2. Address: Department of Psychology, University of Rochester, River Campus Station, Rochester, New York 14627.

3. Now at the University of Maryland.

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