DECISION-TIME WITHOUT REACTION-TIME: EXPERIMENTS IN VISUAL SCANNING

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It has become common to regard human beings as processors of information, but not much is known about the underlying functions. Accurate measurement of the *time required* to execute cognitive operations may help us to interpret them. In the classical reaction-time experiment, processing-time is confounded with the time used to prepare and execute the physical response itself. In the present experiments, a procedure involving visual scanning was used to circumvent this problem. An *S* who scans a list of items, to find one of a certain kind, must examine each item he encounters, but he makes no response until he comes upon the particular item for which he is searching. The rate at which he scans measures the time he uses to analyze the items that elicit no response.

The five experiments reported here serve two purposes. First, they 'calibrate' the scanning method, which can be considered trustworthy to the extent that different *S*s in different experiments produce comparable results. Secondly, they provided preliminary information about the depth, breadth, and flexibility of the processes involved in recognizing printed letters.

The experiments are designed and interpreted on the assumption that the process of recognition is hierarchically organized. Before an *S* 'decides' that the letter *Z*, for example, is present in the input, he must make prior 'decisions' about subordinate features such as parallel lines and angles; these in turn are probably based on processes of a still lower order. We should expect processing-times to depend on the depth of the hierarchy required by a problem. If, however, several operations are at the same level in the hierarchy, *S* may be able to execute them simultaneously[1] The scanning method may enable us to determine whether simultaneity actually is possible. It may also provide information about

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[1] The theoretical significance of such simultaneity is explored in Ulric Neisser, The multiplicity of thought, *Brit. J. Psychol.*, 54, 1963, 1-14.

the flexibility with which S can shift from one mode of processing to another, to take advantage of altered circumstances.

Method. A list of 50 items arranged in a singe-spaced column is presented to S. Each item is a string of letters. As soon as the list is exposed, a clock starts, and S begins to scan down the list from the top. When he finds the single item that has the *critical property,* he turns a switch which stops the clock. If the critical property is the absence of Z, for example, the list might contain 49 items like *JZTXVB, DQFJHZ, MBZJSV, ZXLSMT, RLZQXS,* and one critical item like *VXRLFH.* A series of 15 such trials (lists) with the same critical property usually

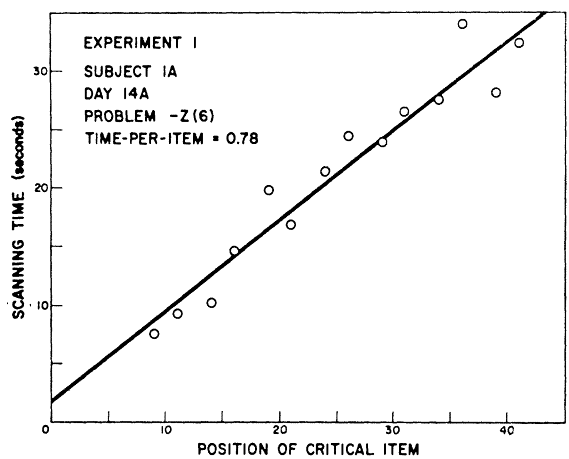

FIG. 1. SCANNING-TIME AS A FUNCTION OF THE POSITION OF THE CRITICAL ITEM: A TYPICAL GRAPH

is given; the critical item appears in an unpredictably different position on each trial. Afterwards, scanning-time is plotted as a function of the position of the critical item, *i.e.* of the number of items scanned. These graphs usually are fitted fairly well by straight lines. An example appears in Fig. 1. Linearity implies that the time taken to scan each item does not change from one end of the list to the other. The most important property of such a line is its *slope:* the average time per item scanned. The slope represents the time S needs to assure himself that each item does *not* have the critical property. In the example above, he must identify a Z in each item.

The slope is unaffected by the time required to begin scanning, to decide upon a response, or to turn the switch. There is no reason to believe that any of these response-factors varies with the position of the critical item on the list. They affect only the intercept of the fitted line—its height above the X-axis.[2] The slope, or

[2] Some non-linearity is to be expected at the beginning of the list, as S begins to scan. For this reason, the y-intercepts of the fitted lines do not provide reliable information.

time-per-item, therefore is a relatively pure measure of the time required to process the information. If *S* scans at the fastest rate consistent with relatively error-free performance, his rate (in the example) should be limited only by the speed with which he can analyze the items for the presence of *Z*. (Physiological limitations on eye-movements may limit the speed to some maximum, but would not affect the conclusions drawn here.) In some problems (*i.e.* with some types of critical property), *S* may process the items in groups rather than individually. In this case 'time-per-item' is a fiction, but a convenient one; it still enables us to compare 'processing-time' for different tasks.

The *Ss* were college students, paid for their services. The lists were exposed in a device which activated a Standard Electric Timer (calibrated in 0.01 sec.) when *E* opened a spring-loaded door, and stopped it when *S* turned a hand-held rotary switch in either direction. To discourage premature responses, alternate items on all lists were flanked by a pair of dots; *S* was instructed to turn his switch clockwise if the critical item had these dots, and counterclockwise if it did not. (Signal lights informed *E* of the direction of the response chosen.) *S* was urged to scan as fast as possible, consistent with making relatively few errors. If he failed to find the critical item on his first time through the list, or mistakenly turned the switch without reaching the critical item, an error was noted and the same list was later presented again. All items in all lists were permutations of a certain set of letters called the 'context,' which was varied in some of the experiments. The permutations were random except with respect to the critical property. All the lists, made up of randomized strings of letters having the desired properties, were prepared by a suitably programmed IBM 7090 computer, and printed on an ANELEX high-speed printer. They were taped to strips of cardboard for ease in handling.

In the first three of the five experiments, *S* worked on two different problems (critical properties) in each daily session. Twenty trials were devoted to each problem, but the first six trials were considered practice, and were not used in the determination of slope. A daily session took from 30-45 min. The critical items actually occurred at list-positions 5, 6, 25, 30, 45, and 46 (randomly ordered) during practice, and at 9, 11, 14, 16, . . . , 39, 41 (randomly ordered) during the experiment proper, but *S* did not know this. In Experiments 4 and 5, only 15 trials were given for each problem, the first three being practice. The position of the critical item in each trial was randomly chosen from the integers 1, 2, . . . , 50, except that it was never the same twice for any one problem on one day. In these experiments, *S* worked on 4-5 problems in each daily session.

In every case, the points were plotted and a straight line was visually fitted to them. The data reported here, however, are not taken from these visual fits but from lines fitted mathematically by the method of least squares. Slopes and intercepts of the best-fit lines, as well as standard errors of estimate around the lines, were calculated by an IBM 7090 computer. The computer-program disregarded any isolated points which deviated greatly from the line determined by the others. (Actually, the program discarded points which deviated from the line at 5% level by a *t*-test. This criterion was used for the sake of simplicity; it is not fully satisfactory because search-times are markedly more variable when the critical item is near the bottom of the list than when it is near the top.)

EXPERIMENT I: PRELIMINARY

The first experiment was a preliminary study of the effects of the following variables:[3] the identity of the target-letter (*Q* vs. *Z*); the number of letters in each item (2 vs. 6); the complexity of processing required (scanning items *without* the target-letter to find an item that contains it versus scanning items *containing* a letter to find an item without it); the number of acceptable alternative target-letters (1 vs. 2).

Procedure. The design of the experiment involved 14 conditions: 7 critical properties, each embedded in two sets of lists. In one set, each item was two letters wide (*e.g. ZD, JZ, LR, ZQ*), while in the other set each was six letters wide (*e.g. JZLXSH, QVZMXL, FDRVQH*). The critical properties were *Z, Q, ZvQ, —Z, —Q, —ZvQ,* and *—QvZ*. These terms are to be interpreted as follows. In Problem *Z*, the critical item alone contains a *Z*, which may be considered the target of the search; in *ZvQ* the critical item may contain either *Z* or *Q* or both, and *S* does not know which until he encounters it (parallel scanning); in *—Z*, all the items *except* the critical one contain a *Z*; in a problem like *—ZvQ*, all items except the critical one have a *Z* and no *Q*, while the critical one may lack a *Z*, may have a *Q*, or both. The lists were made up of *J, P, S, T, V,* and *X* in addition to *Z* and *Q*.

Three *S*s were used.[4] Each was given 2 practice sessions, 7 experimental sessions in which the 14 problems were presented (in a different order to each *S*), and 7 additional sessions in which the 14 problems were presented again in the opposite order.

Results. Since data for the different *S*s are very similar, only mean times-per-item appear in Table I. We may draw certain tentative conclusions. (1) *–Z* takes longer than *Z*, and *–Q* takes longer than *Q;* (2) *QvZ* takes no longer than *Z* alone; (3) six-letter lists take longer than two-letter lists, but generally not three times as long; (4) *Z* takes longer than *Q*, and *–Z* takes longer than *–Q;* (5) in the two-letter lists, all problems involving the absence of a letter take about equally long. While many of these findings will be extended or confirmed in the four experiments to follow, we will pause at this point to consider their implications for the depth, breadth, and flexibility of the cognitive processes involved.

[3] Experiment 1 has been described earlier: Neisser, Time-analysis of logical processes in man, *Proc. West, Joint Computer Conf.*, 1961, 579-585). Since the results presented in that paper are based on visually fitted lines, they differ slightly from those appearing here.

[4] The assistance of Miss Emily Carota, Mr. Arthur Warmoth, and Mr. Norman Goldberg, who served as *E* in Experiments I, II, and III, of Mr. Robert Greenway, who served as *E* in Experiments IV and V; and of Mr. Paul Weene, who assisted in the construction of the apparatus is gratefully acknowledged. Experiments III and V were carried out at the Harvard Center for Cognitive Studies.

When S is looking for a particular letter (*e.g.* Z), each noncritical item gets only scant attention. S need only view each item long enough that the lower-order recognitive systems could (for the individual features of Z) be activated by the right input. That input does not appear, and the Z-recognizer as a whole is not activated, until the critical item is reached. This analysis is substantiated by introspective report: S does not 'see' the letters he passes; he 'sees' only a blur until the Z 'jumps out at him.' The situation is different when S looks for an item without a Z. Now the Z in each item must be identified; the full depth of the recognizer for Z is used on each line. Because of this greater depth, problems in which S looks for the absence of a letter take longer than those in which he need only find the letter. The effect of practice in this difference will be examined in Experiment IV.

Even in the rapid search for a target, Z, elementary analyses of the stimulus-input are being carried out. The elementary operations that could detect a Z, if it

TABLE I

MEAN TIMES-PER-ITEM (SEC.) IN EXPERIMENT I
(Each entry is the mean of the slopes of the 3 Ss, each slope based on about 14 measurements.)

No. of letters	Day	Problem						
		Q	$-Q$	Z	$-Z$	QvZ	$-QvZ$	$Qv-Z$
6	1	0.14	0.42	0.50	0.70	0.60	0.98	0.82
	2	0.08	0.42	0.55	0.64	0.45	0.72	0.65
2	1	0.09	0.32	0.23	0.37	0.21	0.30	0.34
	2	0.05	0.27	0.20	0.29	0.20	0.31	0.34

were to occur, must be different from those which could detect Q. Since Ss can be alert for *both* letters without slowing their scanning-rate, it seems that the different operations can be carried out simultaneously. (It may be argued that the operations for Q are somehow interleaved with those for Z, instead of being simultaneous with them, a point which will be considered further in the light of the data of Experiment V.) This evidence for the breadth of the processes involved is in contrast to a finding which seems to emphasize the opposite: wider lists take more time to scan. One might easily imagine a six-channel device able to handle two- and six-letter widths with equal speed, but no S behaves like such a device. In Experiment II, we shall consider whether this effect is due to the defects of peripheral vision; in Experiment IV, whether it disappears with practice.

The difference in speed between Z and Q may be an unchangeable property of the recognitive systems for these two letters. If, however, these systems are flexibly organized, we should expect the difference to be eliminated or reversed in a different letter-context or a different experimental situation. The first of these predictions is tested in Experiment III. The second is borne out, rather unexpectedly, by the observation that $-Z$, $-Q$, $-ZvQ$, and $-QvZ$ are equally fast in two-letter lists. A glance at the lists themselves provides an explanation. In these problems, there is a Z in every non-critical item; the result is a *column* of Zs which switches haphazardly from one side of the list to the other. Following such a column with the eye is very different from inspecting individual items. Evidently the *S*s discovered this, and promptly used it to increase the speed of their scan. No such columns are formed in six-letter lists.

Experiment II: Horizontal Spacing

Two reasons might be advanced for the fact that it takes less time to process a two-letter item than a six-letter item. First, the six-letter item extends farther horizontally, and thus may encourage real or incipient eye-movement, or may require parafoveal vision. (The six-letter item occupies about 5° of visual angle.) Secondly, the increase in amount of information to be processed may be the important variable. To decide this issue, horizontal spacing itself was varied in Experiment II.

Procedure. There were four conditions. In each case the target was *Z,* and the letter-context was identical with that of Experiment I. The conditions were *Z(2)* (items two letters wide as in Experiment I); *Z(4)* (items four letters wide); *Z(4w)* (items composed of four letters, but with two inserted dashes to increase the width of the item, as *P-TX-Q*); *Z(6)* (items six letters wide, as in Experiment I). Each of 4 *S*s scanned in each condition five times (two per day).

TABLE II

Mean Time-per-Item (Sec.) in Experiment II
(Each entry is the mean of the slopes of the 4 *S*s, each slope based on about 14 measurements.)

Day	Problem			
	Z(2)	*Z*(4)	*Z*(4*w*)	*Z*(6)
1	0.22	0.41	0.48	0.79
2	0.20	0.30	0.30	0.51
3	0.17	0.27	0.25	0.34
4	0.14	0.20	0.21	0.29
5	0.11	0.16	0.16	0.25

Results. Mean times-per-item appear in Table II. It is evident that Condition *Z(4w)* is just as fast a Condition *Z(4),* and systematically faster than *Z(6).* In other words, the critical factor is the number of letters per item, rather than their horizontal spread. Note that, on the first two trials, times-per-item for *Z(2)* and *Z(6)* are comparable with those of Experiment I, but that practice causes sharp decreases in time. The effects of practice will be considered further in Experiments IV and V.

Experiment III: Context

The difference in time-per-item between problems involving *Z* and those involving *Q* was one of the most striking results of Experiment I.

The difference might be ascribed to the two letters as such or to the letter-contexts in which they were embedded. The other letters in Experiment I were *J, P, S, T, V,* and *X.* Perceptually, the *Q* seems to stand out vividly from this assortment because of its roundness. For Experiment III, two letter-contexts were selected. One was intended to make *Z* even harder to see, the other to obscure the *Q*. The first, called the 'angular' context, consisted of the letters *E, I, M, V, W,* and *X;* the second, called the 'round' context, consisted of *C, D, G, O, R,* and *U.* Six-letter items were used.

Procedure. The 3 *S*s worked on six different problems, doing each problem twice in each context. In additión to studying the context-effect, we wished to confirm and extend the finding of Experiment I that it takes no longer to scan for two letters in parallel than for one alone. The problems used were, therefore, *Q,* *Z, QvZ, –Q, –Z,* and *–Qv–Z.* The last of these represents a list in which every item except the critical one has both a Q and a Z (in either order, not necessarily adjacent), while one or both of these letters are absent from the critical item. In other respects the design was like that of Experiment I.

TABLE III

MEAN TIMES-PER-ITEM (SEC.) IN EXPERIMENT III
(Each entry is the mean of the slopes of the 3 *S*s, each slope based on about 14 measurements.)

Letter-Context	Day	Problem					
		Q	*–Q*	*Z*	*–Z*	*QvZ*	*–Qv–Z*
Angular	1	0.08	0.36	0.24	0.45	0.13	0.74
	2	0.07	0.35	0.22	0.49	0.17	0.61
Round	1	0.58	0.68	0.11	0.34	0.60	0.82
	2	0.46	0.61	0.09	0.32	0.56	0.77

Results. Mean times-per-item appear in Table III. It is evident that contextual background is of great importance in determining processing-time. In the angular context, problems involving *Q* take much less time than those involving *Z,* while the opposite is true in the round context. Indeed, the *S*s found the search for *Q* or for *–Q* very difficult against the round background, and made frequent errors based on confusions between *Q* and *O,* or *Q* and *G.*

The results confirm Experiment I in showing that it takes no longer per item to scan in parallel for *Q* or *Z* than for one of these targets alone: no longer than to scan for *Q* in the round context, and no longer than *Z* in the angular context. No such parallelism is demonstrable, however, at the more complicated level represented by *–Q, –Z,* and *–Qv–Z.* Here *S* must assume himself that each item he scans *does* contain the critical letter, or letters. To check for both takes consistently longer than to check for one alone.

Experiment IV: Extended Practice

The results of Experiment II demonstrated that scanning time decreases with practice, at least with a simple problem like *Z*. It is particularly important to determine whether the relation between the time-per-item

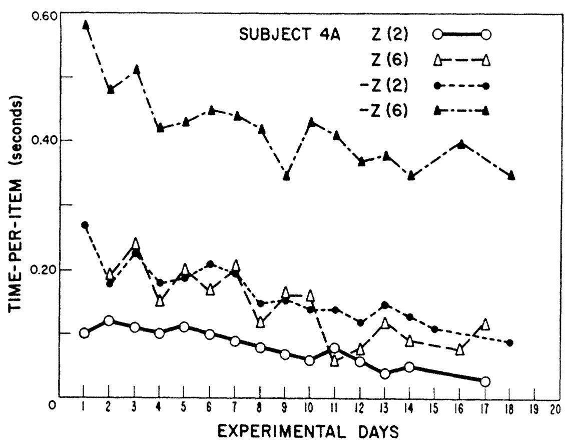

Fig. 2. Time-Per-Item as a Function of Day of Practice
Each point represents a single slope, based on about 12 measurements.

for different types of problems is also altered. Experiments I and II showed that wider items take longer to analyze; will this remain true after extended practice? Experiments I and III showed that problems involving letter-absence, which require *S* to identify the critical letter on each line, take longer than problems in which a single instance of a letter is to be located. Will this also remain true after extended practice?

Procedure. Each of 3 *S*s was given 17 or 18 sessions on more or less consecutive weekdays. Four problems were used: *Z* and *–Z*, each in two-letter and six-letter widths. The letter-context included *B, D, F, H, J, L, M, Q, R, S, T, V,* and *X* as well as *Z*. Usually, all four problems were presented each day, with the order of presentation varied from one day to the next.

Results. The results for one *S*, plotted in Fig. 2, show that items six letters wide take at least twice as long as those two letters wide, even after three weeks, and that *–Z* takes much longer than *Z* in items of both widths. The results for the other two *S*s (which cannot be presented for lack of space) substantiate these conclusions. There were, however, pronounced individual differences in the effect of practice. One of the other two *S*s began with times-per-item from 50-200% longer than those of the *S*, whose data are plotted, and much larger day-to-day variation. The third *S* began more slowly still, but improved dramatically, and attained speeds comparable to those of the first *S* by the third week. These differences are comparable to those stressed by Bryan and Harter in their classical study of telegraphy as a congnitive skill.[5]

Experiment V: Extended Practice with Parallel Scanning

Experiments I and III demonstrated that one scans for either of two targets as quickly as for a single target. It seemed important to determine whether this parallelism extends to more than two targets, and also whether it survives prolonged practice. Three *S*s served for 30 or 31 weekdays, more or less consecutively, in an attempt to answer these questions.

Procedure. All items were six letters wide (with a minor exception noted below), and the letter-context was the same as that of Experiment 4. On each of the first seven days, every *S* worked on four single-target problems: *H, M, Q,* and *Z*. These four problems also were presented later, on four different days interspersed in the later portion of the experiment, to provide a baseline with which parallel scanning could be compared. Beginning on the eighth day, each *S* was presented regularly with three two-target problems instead: *HvM*, *HvZ*, and *QvZ*. On the thirteenth day, a four-target problem, *HvMvQvZ,* was introduced and became a regular part of the procedure. In this problem, the critical item might contain *any* of the four target letters, and *S* did not know which until he found it. Of course, no non-critical item contained any of the four letters. On the last few days of the experiment (Day 26 or later), another problem was introduced for exploratory purposes. This was *HvMvQvZ* in a format *eight* letters wide instead of six. After 4-6 days of practice with this problem, none of the *S*s has achieved the speed with which they were doing *HvMvQvZ (6).* As far as it goes, this finding seems to confirm the results of Experiment IV, but we will not consider it further here.

Results. The results for one of the *S*s are plotted in Fig. 3. The other two *S*s produced very similar data. It is evident that parallel scanning can be sustained and that it applies to situations involving four targets. All three *S*s were scanning the two- and four-target problems with about equal speed in the last week. This speed was generally within the range of speeds used on the single-target problems, although slightly above the mean of the speeds on the four single targets. It appears consistently possible to be on the lookout for several things at once.

[5] W. C. Bryan and Noble Harter, Studies in the physiology and psychology of the telegraphic language, *Psychol. Rev.* 4, 1897, 27-53.

It would be difficult to maintain that these results are due to interleaving. There might indeed be enough dead time between analyses for slanting lines, say, to carry out the detection of roundness, but one would expect these dead times to diminish with practice; *Z* should gain more from practice than *ZvQ*. The data contradict this prediction, because times-per-item for the different problems converge with practice instead of

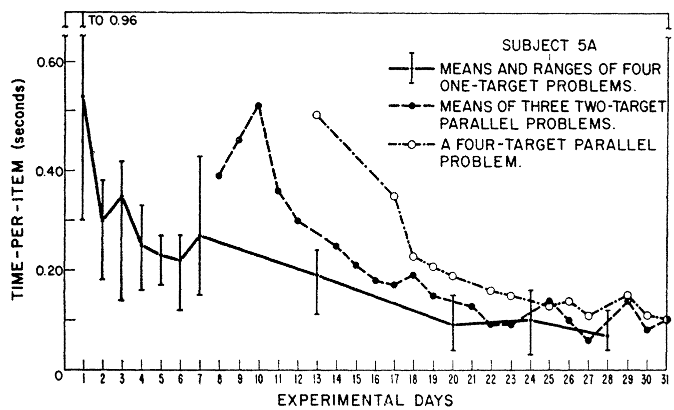

FIG. 3. TIME-PER-ITEM AS A FUNCTION OF DAY OF PRACTICE
For the one-target problems, each point is based on four slopes; for the two-target problems each is based on three; there is a single four-target problem. Each slope is based on about 12 measurements.

separating. The finding with *HvMvQvZ* also argues for simultaneity rather than for interleaving. How much dead time can there be?

SUMMARY

The method of visual scanning was employed in five experiments to obtain direct measures of the processing time of human information. The results indicate that the method is reliable and permit several tentative conclusions about the organization of cognitive processes in the identification of printed letters. (1) At simple levels, several distinct processes of recognition can function simultaneously in the analysis of a single stimulus-configuration. (2) No such simultaneity appears in the analysis of *spatially distinct* parts of the input, even after extended practice. (3) The recognitive hierarchy for a given task can be altered to take advantage of different contextual or other conditions. (4) Positive identification of a letter (such as is necessary when a response is contingent on its absence) takes longer than the simple search made when the response is to be contingent on its presence.