Manipulation of visual processing by varying the rewards associated with display locations*

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Ss were instructed to "read" displays of letters presented for several milliseconds and to indicate which of three signal letters had been present. The instructed reading path through the display was manipulated by assigning point values to display locations. The results indicated that the letters simultaneously presented were at some stage successively processed. It was suggested that the serial operation was a successive preservation of locations in an image of the display by means of a series of tests of category descriptions on each image location.

In a series of tachistoscopic experiments, Shaw (1969) found unexpected asymmetries in letter recognition accuracy and a sharp gradient of recognition accuracy as a function of retinal position. The paradigm used in these experiments is a modified version of a visual recognition task devised by Estes and Taylor (1964, 1966). The modified task used by Shaw required the S to begin each trial fixated on a focusing dot in a blank field, to "read" a horizontal linear array of capital letters which appeared for several milliseconds immediately to the right of the focusing dot, to report the letter next to the focusing dot with near perfect accuracy, and to report which one of the two signal letters, used throughout an experiment, was the signal in the array of 10 letters. The three relevant findings are: (1) accuracy of reporting the signal letter fell off sharply with distance of the signal from the focusing dot; (2) when two or three noise letters were removed from a 10-letter display to produce a blank space, accuracy on the signal was not appreciably changed from the accuracy for control, 10-letter displays, unless the noise letters were removed from immediately to the right of the signal letter—in which case accuracy was greatly improved; and (3) when the blank spaces in the arrays were changed to solid black rectangles the height of a letter and two or three letters wide, the accuracy was the same as for the corresponding displays with a blank space.

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These results, in the context of the experiments which generated them, indicate the existence of an operation which is begun successively, at least under some conditions, on the letter representations of letters simultaneously presented to the S for a few milliseconds. What this operation accomplishes is not clear at present. The data of Sperling (1960) and others since indicate that the initial representation of the display lasts only a few hundred milliseconds under usual experimental conditions and that for many letter displays most of the letters are lost after this initial representation has decayed. One job, which in this case must be performed, is to change a subset of the letters in the initial representation to a memory form which can last longer than a few hundred milliseconds. If this job is accomplished by an operation successively begun on the locations in the initial representation, then the loss of letters during the first few hundred milliseconds and the sharp gradient of recognition accuracy as a function of position are qualitatively explained: Letter representations are lost because there isn't time successively to perform a preserving operation on all the letters in the initial representation; the gradient occurs because letters in the representation farther from the focusing dot position are less likely to be operated on at all or the preserving operation has fewer features of a letter representation to preserve.

An unpublished reaction time experiment by Sternberg collaborates the accuracy data. On each trial, the S first memorized a list of 1, 2, 3, or 4 digits. After a delay and a warning signal, the S saw a row of 1, 2, or 3 black digits on a white field for 170 msec. On negative trials none of the digits in the memorized list were in the display. On positive trials the list and the display had exactly one digit in common; its locations in the list and in the display were random. The S was to push one lever on positive trials and another lever on negative trials.

Sternberg graphed reaction time against length of the memorized list for each display size and for positive and negative trials. These six curves were all well described as straight lines with quite different slopes. Sternberg's best fitting model gives a good account of the linearity and the simple relationships between the six slopes. In this model, an operation is successively performed on each display digit representation on negative trials; on positive trials, the process stops after the display digit representation having a match in the list. The operation is further specified to be a successive comparison of the display digit representation with the representations of each of the list digits. Thus, the good fit of the model is evidence for the successive application to the display digits in memory of a particular operation.

The experiments of Shaw (1969), showing a gradient of recognition accuracy as a function of position of the signal, had a confounding of signal position in the presumed processing path and distance of the signal from the focusing dot. While an argument based on the data appeared to eliminate an explanation of the accuracy gradient in terms of a gradient of retinal sensitivity, no direct evidence on this possibility was obtained. The present experiments were designed to provide the direct evidence and to extend the paradigm to a "reading" path of another shape.

A configuration of letters was chosen which would take advantage of the previously discovered facilitating effect of a blank space immediately following a letter in the processing path. The right half of Fig. 1 is a typical display of Experiment 2. According to the previous data, for the instructed processing order of U to X to T, the X would have two processing advantages over the T: it would precede the T in the processing path and would be followed by a longer space before the next letter in the path. For a path from the U to the T to the X, the path would give the advantages to the T over the X. Thus, the effect of the Es in this display is to accentuate the processing differences between a X-space-T order and a T-space-X order. The Zs were put in the displays to reduce the set of reasonable interpretations of the data and were not expected to affect performance.

EXPERIMENT 1

Subjects

Three University of Minnesota undergraduates served as paid

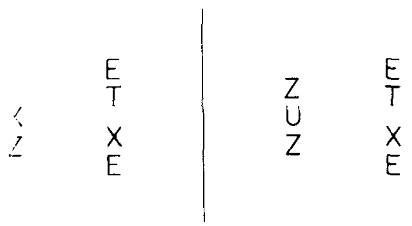

Fig. 1. The left-hand display is a typical stimulus of Experiment 1. The right-hand display is a typical stimulus of Experiment 2.

volunteers. No S wore contact lenses.

Apparatus and Stimulus Material

A Scientific Prototype Model GB three-field tachistoscope was used for stimulus presentation. The tachistoscope was modified by the addition of two card holders designed for rapid card changing. A card holder was mounted on the exterior wall of Field 1 of the tachistoscope and allowed a 2 x 5 in. area of a stimulus card to be seen centered in Field 1. The blank field was modified in a similar way and displayed a 2 x 5 in. area of a white card having a small focusing dot.

A typical display of Experiment 1 is shown in the left half of Fig. 1. The fixation-verification letter in this display is X, and the signal letter is T. In general, the verification letter was either X or E and always appeared in the position above the Z. The signal letter was A, T, or U and appeared either in the position of the T of Fig. 1 or in the position of the X below the T. These positions of the signal letter are called the upper and lower signal positions, respectively. The display of Fig. 1 has one of the two backgrounds of Xs and Es; in this display, the signal T replaces an X. To generate a display of the other background, each background X or E was replaced with an E or X, respectively, and a signal letter was put in either the upper or lower signal position. The set of stimulus cards for Experiment 1 contained two identical displays for each choice of a verification letter, a signal letter, a signal position, and a background pattern, making a deck of 48 stimulus cards. Thus, for any block of trials, the signal letter appeared equally often in each position.

The displays were typed on white cards using an IBM Orator Selectric type. The verification letter was seven spaces of the width of a letter from the column of the signal letter. The vertical spaces between letters were all half the height of a letter except for the space between the upper and lower signal position, which was 1.5 times the height of a letter.[1] The angle subtended by a verification letter and a signal in either the upper or lower signal position was 1.1 deg. The angle subtended by the upper and lower positions was 0.6 deg.

Procedure

Each session began with 3 min of dark adaptation and 48 warm-up trials. The warm-up trials were followed by five blocks of 48 trials each. Between blocks, the deck of stimulus cards were shuffled and errors were recorded. A session lasted about 30 min. All sessions occurred on separate days.

Each trial began with the S fixated on a small focusing dot in the white background field, which was front lighted and had a luminance of 9.0 fL. When ready, the S stepped on a footpedal, and a stimulus card, which was front lighted and had a luminance of 4.0 fL, appeared 200 msec later. The verification letter of the stimulus appeared immediately to the right of the position of the focusing dot.

For a clockwise session, the S was instructed to fixate on the focusing dot and to "read" the display, when it appeared, from the verification letter to the upper signal position and then to the lower signal position. For a counterclockwise session, the S was to "read" from the verification letter to the lower position to the upper. He was to report either X or E as the verification letter and then A, T, or U as the signal letter. In the rare event that he was not sure of the verification letter, the trial would not be counted and the display would be presented again later in the block of trials. He was to report a signal letter, whether he was confident or not. Instruction stated that it was especially important to maintain almost perfect accuracy on the verification response.

During either a clockwise or a counterclockwise session, the S lost 8 points for a trial on which he was wrong on the verification letter. During either type of session, if he was correct on the verification letter and incorrect on the signal letter, he received 0 points. If he was correct on both letters, the point value he received depended on both the type of session and the position of the signal. During a clockwise session on a trial in which he was correct on both the verification letter and the signal, he received 4 points if the signal was in the upper position and 1 point if the signal was in the lower position. During a counterclockwise session, the assignment of points to signal position was just reversed. The S who accumulated the largest number of points for all his data-collection sessions received a $5 bonus. The intent of the point assignment was to stress not making verification errors and to encourage the S to "read" the upper position, then the lower, during a clockwise session and to "read" the lower position, then the upper, during a counterclockwise session. Following each trial, the S was informed of the point value for the trial.

During the practice sessions, the display exposure duration was successively lowered for each S from 200 msec to between 12 and 17 msec.[2] The duration for data collection chosen for each S on the basis of his practice was one which would produce a recognition accuracy on the second signal position (lower position for clockwise, upper for counterclockwise) that was as low as possible, with the constraint of a verification accuracy of over 90%.

The sequence of sessions for each S was a series of practice sessions, two data collection sessions of one point assignment condition, three or four practice sessions on the second point assignment, and finally two data collection sessions on the second point assignment. For Ss NR and ST, the clockwise sessions preceded the counterclockwise sessions; VN had the conditions in the reverse order. Ss NR and VN had 10 initial practice sessions; ST had 8. To adjust for improved signal accuracy with practice, the exposure duration for each S was 2 msec less for the two data sessions run last.

The initial practice series was considerably lengthened by several procedural changes. For the first four sessions, clockwise and counterclockwise sessions alternated. During these sessions, Ss reported considerable difficulty in consistently using each session's new reversed "reading" order, and their accuracy was highly variable. The design was then changed to the sequence described above, having consecutive sessions of the same point assignment.

A light meter was used every session to determine whether or not a tachistoscope light bulb had burned out or changed its illumination. If a change had occurred, a tachistoscope dial setting was adjusted for a new bulb such that a light meter in a standardized position with respect to the relevant field had been brought back to its previous dial position.

Results

Table 1 shows the correct verification and signal recognition proportions for each S and for each signal position. The left-hand table for a S shows the proportions for the two clockwise data sessions; the right-hand table for a S shows the counterclockwise proportions. In the

Table 1
Correct Verification and Signal Proportions for Displays Having the Signal in the Upper or Lower Position

S		Clockwise		Counterclockwise	
		Verification	Signal	Verification	Signal
NR	Upper	.98	.91	.92	.73
	Lower	.98	.71	.92	.77
ST	Upper	.92	.95	.92	.88
	Lower	.97	.70	.91	.83
VN	Upper	.93	.91	.97	.90
	Lower	.92	.68	.98	.90

Table 2
Correct Verification and Signal Proportions for Displays Having the Signal in the Upper or Lower Position

S		Clockwise		Counterclockwise	
		Verification	Signal	Verification	Signal
SE	Upper	.99	.85	.99	.62
	Lower	.97	.49	1.00	.86
NR	Upper	.90	.92	.85	.79
	Lower	.89	.68	.89	.90
VN	Upper	.77	.80	.84	.75
	Lower	.79	.72	.82	.89
GZ	Upper	.90	.81	.92	.78
	Lower	.89	.46	.94	.75

upper row for a S are the verification and signal recognition proportions for trials in which the signal letter appeared in the upper position; in the lower row are the proportions for trials in which the signal appeared in the lower position. The signal recognition proportions do not include trials on which the verification letter was reported incorrectly.

For each S and for each point assignment condition, the upper verification proportion (uv) was compared to the lower verification proportion (lv) and the upper signal proportion (us) to the lower signal proportion (ls). The results of computing a two-tailed test for each comparison were as follows: for no S and neither condition did the uv and lv proportions differ significantly at the .05 level; in the clockwise condition, the us-ls comparison was significant far beyond the .001 level for each S. No tests were made for the counterclockwise us-ls comparisons, because the differences were inconsistent and small. A multiple comparison test did not seem necessary.

In summary, verification performance did not vary with signal position; in the clockwise condition, signal accuracy was appreciably superior for the position associated with the higher point value, but in the counterclockwise condition, signal accuracy did not appear to vary with signal position.

EXPERIMENT 2

If Ss were processing from the verification letter position to the position having the higher point value and then to the other position, performance on the verification letter should be independent of the signal position, and it was. Also, signal accuracy should be superior for the position having the higher point value. This was true only for the clockwise condition.

It was suspected that the position of the Z below the verification letter might have influenced the processing path from the verification letter to the signal letter in a way unfavorable to the counterclockwise condition. Therefore, a second experiment was run in which the Z appeared both above and below the verification letter. In this case, the beginning of a clockwise processing path is merely a reflection about a horizontal line through the verification letter of the beginning of a counterclockwise processing path. The other change in design is that in Experiment 2, A, T, and U replace X and E as the verification letter set.

Subjects

Two Ss of Experiment 1 and two other students participated. One of the new Ss (SE) had been in a previous experiment using the same paradigm as the present experiment but having linear displays. The other new S had had no previous experience with a tachistoscope. No Ss wore contact lenses.

Apparatus and Stimulus Materials

The apparatus and the method of making stimulus cards were the same as in Experiment 1. The distances between letters were the same as in Experiment 1. A typical display is shown in the right half of Fig. 1. In this display the verification letter is U and the signal letter is T. The new deck of stimulus cards differed from the deck of Experiment 1 only in that each display had a Z both above and below the verification letter and that the verification letter was A, T, or U rather than X or E. The stimulus deck was generated by twice picking one of two background patterns, one of three verification letters, one of three signal letters, and one of two signal positions to specify any one of the 72 displays.

Procedure

Sessions were identical to sessions for Experiment 1 except that there were 36 warm-up trials instead of 48, followed by three blocks of 72 trials with a small rest in the middle of each block. Ss now had to report A, T, or U as the veritication letter. Ss NR and SE began with 5 and 1 clockwise practice sessions, respectively, followed by 3 clockwise data sessions, followed by 4 and 3 counterclockwise practice sessions, respectively, and both finished with 3 counterclockwise data sessions. NV and GZ began with 6 and 8 counterclockwise practice sessions, respectively, followed by 3 counterclockwise sessions, followed by 4 clockwise practice sessions, and finished with 3 clockwise data sessions. Stimulus exposure durations for the clockwise data sessions were 13, 12, 13, and 25 msec for Ss SE, NR, VN, and GZ, respectively; durations for the counterclockwise data sessions were 15, 11, 15, and 23 msec. The same method as in Experiment 1 was used to insure a constant level of illumination for all sessions.

Results

Table 2 shows the correct verification and signal proportions for each signal position for the clockwise and counterclockwise data sessions. As in Table 1, the signal proportions are only for correct verification trials.

For each S and each session type, uv and lv trials were compared by means of two-tailed tests. For all Ss and both session types, verification performance again did not significantly vary (.05 level) with signal position. For each S, signal performance in the clockwise data sessions was higher (.04 level) for displays having the signal in the upper position than in the lower position, and, with the exception of S GZ, the lower position was superior (.04 level) to the upper for the counterclockwise data sessions.

EXPERIMENT 3

A final experiment was designed to test further two Ss run in Experiment 2, one of whom was the S who had failed to show counterclockwise superiority for the position of higher point value, and to test an implication of the assumption that Ss had managed with high

Table 3
Correct Verification and Signal Proportions

		Clockwise		Counterclockwise	
		Verification	Signal	Verification	Signal
S SE	Top	.96	.87	.95	.43
	Bottom	.95	.59	.97	.77
	First	.98	.87	.94	.83
S GZ	Top	.88	.81	.94	.69
	Bottom	.89	.72	.94	.80
	First	.89	.79	.93	.85

reliability over trials to process in the instructed processing order of the session.

Subjects

The Ss were SE and GZ of Experiment 2.

Apparatus and Stimulus Materials

The same stimulus deck and tachistoscope of Experiment 2 were used.

Procedure

Again, sessions had either the point assignment stressing counterclockwise processing or the assignment stressing clockwise processing. On two blocks of trials (regular blocks), the stimulus deck was the same as in Experiment 2; on the other two blocks of trials, which alternated with the regular blocks, the displays having the signal in the position of the lower point value for that session were put aside and the remaining half of the deck was gone through twice. Thus, during a clockwise session, two regular clockwise blocks of 72 trials alternated with two blocks of trials (upper blocks), in which the signal letter always appeared in the upper signal position. During a counterclockwise session, two regular counterclockwise blocks alternated with two blocks (lower blocks) in which the signal always appeared in the lower signal position. There were 36 warm-up trials and small rests every 36 trials.

Ss were instructed to do just what they had been doing in Experiment 2. They were told that in "upper" blocks the signal would always appear in the upper position, in "lower" blocks the signal would always appear in the lower position, and in "regular" blocks the signal would appear in each position equally often. At the beginning of each block, the S was told the block type.

After the last session of Experiment 2, GZ began counterclockwise data sessions and SE began clockwise data sessions. Each S had three data sessions of each point assignment separated by two practice sessions of the point assignment used in the final three data sessions. Display duration for SE was 13 msec for all data sessions; for GZ, display duration was 22 and 23 msec for clockwise and counterclockwise data sessions, respectively.

Results

Table 3 shows the verification and signal proportions for each S and for each session type. The First row in Table 3 for each S gives the verification and signal proportions for the trial blocks having the signal only in the position of the higher point value as defined by the session type. The Top row for each S shows the verification and signal proportions for the half of the "regular" trial blocks in which the signal appeared in the upper position. The Bottom row for each S refers to the proportions for the other half of the "regular" trial blocks in which the signal appeared in the lower position. For each S and each session type, the proportions in the Top and Bottom rows have about 200 observations, and the proportions in the First rows have about 400 observations.

Clearly, none of the verification proportions varied with position of the signal. For clockwise sessions for each S, the First signal proportion clearly was different from the Top signal proportion. For counterclockwise sessions for each S, the First signal proportion was not significantly different (.05 level) from the Bottom signal proportions. For each S and each session type, a signal was significantly more accurately recognized (.05 level) when it occurred in the position having the higher point value for the session.

In summary, the pattern of results of Experimnet 3 is in accord with an interpretation of consistent sequential processing in the instructed order. S GZ, who had not shown a superiority for the higher point position in the counterclockwise sessions of Experiment 2, did show a superiority in Experiment 3. Both Ss showed no advantage of knowing with certainty the position of the signal.

DISCUSSION

With appropriate training, Ss of the present experiments were correct on the signal letter appreciably more often when it was in the signal position associated with the higher point. Whether the signal appeared in the higher point position or the lower, the memory requirements were the same, i.e., one verification letter and one signal letter. There was no indication that Ss used a strategy of fixating on the focusing dot display in a manner which would differentially affect signal accuracy on the two signal positions. Previous data indicate that Ss cannot maintain a near-perfect accuracy on the verification letter if they are not fixated near the focusing dot. In the present experiments a small shift in the point of fixation toward one signal position constitutes a shift of almost equal magnitude toward the other signal position. There is no strategy or effort that could in principle improve the S's signal performance above the guessing level if he does not process successfully at least part of the signal representations. The conclusion appears to be that the Ss processed one position more effectively than the other and that with practice they could reverse the processing superiority. Since the two signal positions were equally far from the focusing dot and were used equally often as the higher point position, it seems likely that neither the present variation of signal accuracy with position nor that of Shaw (1969) can be attributed mainly to variation of sensitivity with retinal position.

A mathematical description of visual processing assigning different weights to different locations in a spatial representation of the display—a parallel model with attention unequally distributed—evidently would have several hurdles: (1) these weights would vary across locations that were related to equally sensitive retinal locations; (2) weights assigned to locations as close as 0.6 deg in the display would vary greatly with the motivations of the S; and (3) at present, an unknown function would be required to relate weights to locations in the display and to motivations of the S.

An alternative hypothesis to account for the present results would begin with the following assumptions: (1) a preserving operation, P, is successively begun on each location in a representation of the display; (2) locations in the representation of the display are preserved in the same order as the instructed "reading" order for the corresponding locations in the display (3) the later the preserving operation is applied to a location in the representation the less effective, given constant distances to the nearest locations containing characters; and (4) the greater the distance in the display between a character and the next character in the "reading" order, the more effectively the character is preserved. This last assumption is indicated by the earlier results of Shaw (1969).

An interesting possibility for the nature of the preserving operation, arises from considering the experiments of Sternberg (1966, 1967a, b, 1969a, b). In Sternberg's fixed-set procedure, the S memorizes s characters, usually digits, at the beginning of a series of trials and throughout the series sees one test stimulus per trial. The S's task is to push the positive response lever if the test stimulus of a trial belongs to the memorized list and otherwise the negative response lever. The result in a number of experiments is that reaction time to the test stimulus is a linear function of s, the number of characters in the memorized list, and the slope is about 40 msec per character for both positive and negative responses.

If we ignore for a moment the reaction time measurements, the protocol from a S in Sternberg's task consists of a sequence of test stimuli which are instances with particular physical characteristics of certain categories of visual stimulation, such as what is called "two," and a sequence of positive and negative responses which are nearly always correct for the associated test stimuli given the instructions. Thus, the S must be credited with recognizing, for example, a two of some particular size, printing style, rotation, brightness, etc., and with recoding its category as positive or negative.

But the reaction time measurements indicate that the S at some stage of processing compares a representation of the test stimulus successively to the representations of the positive set. Two possibilities are of interest: (1) the representation of the test stimulus is like a description of a category of stimulation, such as the class of visual stimuli which are called "two"; and (2) the representation of the test stimulus is like an image and has properties corresponding to the particular physical properties of the test stimulus. Let us assume that the representations of the members of the positive set are in terms of descriptions of categories of stimulation, as developed from previous experience. Then (1) and (2) place the serial comparison process in quite different stages of processing of the test stimulus.

If (1), then the linear reaction time as a function of the size of the positive set arises from the process of recoding the category of the test stimulus as positive or negative under the instructions from the E. This is an operation which must occur after the particular test stimulus is mapped into its category of stimulation, i.e., after recognition. If (1), then the brain, in effect, makes a description of the test stimulus and compares that description successively with the s descriptions of the s categories of the positive set. If (1), then the description of the test stimulus must vary with the instructions. A description adequate for distinguishing the members of any set of categories of stimulation that humans can discriminate would be tremendously long.

If (2) then the reaction time function reflects the process of recognizing instances of categories of stimulation and is addressing the old problem of interest to philosophers, pattern recognition programmers, and others. In this case, it is reasonable to identify the representation of the test stimulus in Sternberg's task as the same as that studied by Sperling (1960), Eriksen and Collins (1967, 1968), and others and to identify the comparison process of Sternberg's reaction time data as the preserving operation of the present experiments. In this view, the preserving operation consists of a series of tests of category descriptions on a location in the image of the display. In Sternberg's task, the s members of the positive set specify s category descriptions, which for this task may be letter feature lists, and the processing mechanism successively tests the s feature lists on the location in the display image containing the single test character.

With other task requirements and instructions, the category descriptions may be much shorter than in Sternberg's task. In several of the experiments of Shaw (1969), for example, the signal letters were B and R, and none of the noise letters had any curved features. For these experiments the following category descriptions would be sufficient, if the S is able to use them: (1) the location has no curved features (noise letter); (2) the location has at least one curved feature and has a feature across the bottom (B); (3) the location has at least one curved feature and has no feature across the bottom (R). A report task where the display would contain a randomly selected subset of a large set of possible characters would necessarily have more categories and longer descriptions.

A serial operation on the characters presented simultaneously appears necessary to account for the present data. The conjecture that this operation is a preserving of locations in an image of the display by a serial testing of category descriptions is not required by the present data. It has the merits of being compatible with Sternberg's results and of allowing for changes in the S's processing algorithm with minor changes in the instructions or the set of stimuli. The processing algorithm can be changed either by changing the sequence of category tests or by changing the set of categories.

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NOTES

1. During the initial practice series of sessions, the stimulus deck for S VN was changed for the remaining sessions of Experiment 1 from the displays described to ones which differed only in that the space between the upper and lower signal positions was 2 times the height of a letter instead of 1.5 times. The intent of this change was to increase the difference in signal accuracy between the two signal positions; this change did not, however, appear to make any difference.

2. For practiced Ss on this task a change of a couple of milliseconds in stimulus duration seemed to make a significant difference in signal accuracy.

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