PROCESSING OF VERTICAL TACHISTOSCOPIC DISPLAYS WITH CONTROLLED ORDER OF CHARACTERS AND SPACES

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ABSTRACT

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By

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Four subjects participated in a visual detection task to examine the effect of a blank space before or after the critical letter in vertical arrays. The controlled order of processing procedure developed by Shaw (1969) was modified for an upwards scan and for a downwards scan. The results indicated that the blank space after the critical letter facilitated detection ($p < .01$); the preblank appeared to have an intermediate facilitation effect between that of the control and the postblank. The results are consonant with the finder-reader serial processing model proposed by Shaw. Unexpectedly, the upwards scan produced performance superior to that of the downwards scan.

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To

Cindy, Earl, Rita, and Tom

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INTRODUCTION

In the classical span of apprehension experiment the subject is required to report as many of a briefly exposed set of stimuli as he can. Unfortunately, this full report procedure does not estimate the total amount of information that the subject obtains from the display because (a) forgetting occurs very rapidly following the initial exposure (Estes and Taylor, 1964; Neisser, 1967; Sperling, 1960) and (b) the very act of giving a report may interfere with retention in ways that are not yet fully understood (Estes and Taylor, 1964; Neisser, 1967). Sperling's (1960) partial report method decreased the influence of memory and output effects by requiring the subject to report only a single row of the matrix of letters presented in the display. One of several tones, each tone corresponding to one row of the matrix, indicated to the subject which row he was to report. As the interval between stimulus presentation and tone increased to one second, the data approached values very similar to full report values.

To better assess the number of elements an individual can effectively sample in a display, Estes and Taylor (1964) developed a detection method. In the detection method the displays contain one of two critical elements that are both known to the subject before the displays are presented and other elements that are randomly drawn consonants designated as noise elements. The subject's task is to report which of the two critical elements is present in the display. It is assumed that since the positions of critical elements vary randomly from one display to the next, to perform perfectly it is necessary for the subject either to sample and process information from all of the elements in the display or to continue sampling until the critical element is processed. Since the subject reports only one letter, problems of retention loss are minimized. Guessing is handled easily within the framework of this two alternative forced choice task.

Data obtained by Estes and Taylor using this detection method supported a serial processing model. There are various ways that the subject is assumed to scan the display; for example, in a serial processing model it is assumed that the subject scans the displayed elements along some spatially connected path until the critical element is processed. A later step was to use reaction times in this forced choice detection situation to test the assumption of a serial scanning process (Wolford, Wessel, & Estes, 1968). Using displays that contained varying numbers of redundant critical letters, Wolford et al. (1968) found that the proportion of correct responses increased systematically with the number of redundant critical letters per display, but that the latency of correct responses was invariant with respect to redundancy. These results favored a parallel rather than a serial processing interpretation, that is, the elements of the display are sampled independently with the sampling probabilities varying over the field. They concluded:

> Since the forced choice detection technique has been developed expressly for the purpose of separating perceptual and memory aspects of the visual apprehension task better than preceding methods, it seems quite possible that parallel and serial processing mechanisms have to do, respectively, with these two aspects. (Wolford, Wessel, & Estes, 1968, p. 444)

Shaw (1969) designed a method to optimize control of the direction of the scanning process in the subject. The standard detection task, other than insisting on central fixation, does not attempt to control the subject's scanning path. Shaw's basic paradigm consisted of tachistoscopically presenting horizontal arrays of letters with a critical letter in one of the positions. The subjects, with eyes fixated on a focusing dot, were to "read" the display from left to right and indicate which letter, the verification signal, they saw immediately to the right of the focusing dot (this was to verify that they were focused on the dot) and then which critical letter they saw. This visual detection task was designed for the purpose of controlling the subject's processing order. The subjects are forced consistently to use the same processing order. Thus, the size and the nature of the portion of the display processed before and after the signal are exactly known and can be systematically varied.

Based on the assumptions that a blank space takes less processing time than a letter, and that the subject scans in the instructed way, Shaw designed his experiment to provide evidence for or against serial processing. If a serial process occurs, and each visual representation decays after a constant time, then a blank space before the critical letter should facilitate detection of it. The probability that the critical letter will be reached and processed should increase because the processing time before the critical letter should be less. In this same case Shaw assumed that a blank space after the critical letter would not be as effective as a blank space before it. While if a parallel process occurred, the blank spaces before and after the signal should prove to exert equivalent effects on detection performance. But, Shaw found that detection performance was significantly facilitated only by the blank space after the critical letter.

Shaw's basic displays consisted of control slides of linear arrays of 10 letters, slides of linear arrays of letters with a 3-letter blank space immediately before the critical letter, and slides of linear arrays of letters with a 3-letter blank space immediately after the critical letter. He presented these horizontal arrays tachistoscopically to the subject whose eyes were fixated on a focusing dot. The subject "read" the display from left to right and indicated whether A or N was the first letter to the right of the dot and which of B or R, the critical letters, appeared elsewhere in the display. Detection of the critical letters was considerably more accurate with the slides having a blank space immediately following the critical letter in the processing order than with the control slides having no blank space or the slides having a blank space immediately before the critical letter. He found this result regardless of the position of the critical letter; knowning in which position the critical letter would be made no significant difference in the results. Testing the possibility that the asymmetric features of the critical letters caused the postblank facilitation effect, he used the symmetrical critical elements, Φ and Θ , and still found the same postblank facilitation. To be sure that lack of a mask was not the cause of facilitation, he replaced the blank spaces with solid black rectangles of the same size. These rectangles should have created a mask equivalent to the noise letters that the spaces replaced. He still found that performance on the slides with black rectangles after the critical letters was significantly improved. He even instructed the subjects to "read" from right to left. The same facilitation effect occurred on the slides with the blank space immediately after the critical letter.

In his discussion Shaw proposed two level finder-reader serial processing model that allows extra processing time on a letter followed by a blank space. This model postulates a character finder that processes the area within a processing path at a constant rate independent of the number and nature of the visual objects within the path. The finder examines the global properties of the visual objects in its path and feeds characters worthy of further analysis to the character reader. The reader begins processing each character as the finder inputs it and stops processing whatever character was there. The time spent by the reader on the _i_th character in the processing order depends on the time taken by the finder to locate the character (_i_ + 1). The critical function of the reader is to read letters out of the initial visual representation before the trace has decayed too much. Shaw assumed that any increase in the processing time on a character yields an increase in the amount of information read out of the initial image. Therefore, assuming that the average duration of the processing of the decayed signal representation is determined by the extent of the area in the processing path following the signal but preceding the next letter, the blank space and the rectangle immediately following the signal take up some kind of processing time but not letter processing time and thus increases the time the character reader spends on the critical letter. The improved detection performance with the postblank follows directly from this; the finder-reader serial processing model thus accounts for the data from Shaw's experiments.

Estes and Wolford (1969) questioned whether or not Shaw's results were due to the central-peripheral dimension in the visual field. Their paradigm consisted of tachistoscopically presenting horizontal arrays of letters with or without blanks of the same type as Shaw's but with their starting points being systematically varied around the fixation point. They taught their subjects to process and read out information in either a left-right or a right-left order. There were 18 positions for letters, labeled -9, -8,..., -1, 1,..., 9, with a focus point between -1 and 1. The arrays of nine letters could start at positions: 9, 6, 3, or -1 for a right-to-left read out, or at positions: -9, -6, -3, or 1 for a left-to-right read out. In order to tell how well the subjects conformed to the instruction to read out in a prescribed direction, they used a report procedure rather than the detection procedure. They found that the effect of a space is much greater on the letter preceding than on the letter following the space in the read out order, and that the effect is much greater on the letter central than on the letter peripheral to a space in the central-peripheral dimension; this conclusion was based on the absolute difference between proportions correct at positions adjacent to spaces and corresponding positions in the control strings. They found that displays placed nearer the fixation point yielded more accurate reports than those more peripheral, but that relative position in the read out order is an even stronger determiner of reportability. Their results suggest that the confounding of position in the read out order with position relative to the fixation point in the visual field might be a factor to consider in the detection procedure also. They suggest that instead of spaces modifying the sensory processing time devoted to adjacent letters that possibly spaces function as signals to a read out response mechanism, but further study of the above variables in their combined effects under both detection and report procedure is needed before a model can be formulated.

There is nothing stated in the above assumptions which would not allow a process like Shaw described to occur if the scanning were vertical instead of horizontal. The specific purpose of this experiment is to determine whether a blank space either immediately preceding or following the critical letter in a vertical tachistoscopic display facilitates the detection performance for the critical letter.

This experiment was designed using Shaw's detection method with controlled scan direction in the vertical situation. Vertical arrays of letters with or without blanks were presented on the tachistoscope. One of the two critical letters, B or D, appeared in the sixth position from the focus point. Subjects were instructed to "read" upward from the focus point or "read" downward from the focus point depending on the experimental condition at the time. Subjects reported the first symbol at the focus point and the critical letter which they detected.

Shaw's method gave results in the horizontal situation; will it also work in the vertical case? Shaw's model predicts that a blank space after the critical letter will facilitate detection performance; will that blank space facilitate detection performance if the subject is "reading" up from the bottom to the top of a display, or "reading" down from the top to the bottom of a display? If the postblank facilitates detection performance, then the results would support Shaw's model and thus serial processing. If the preblank and postblank both facilitate detection, then a new model or a modification of the old one must be considered. If the postblank does not facilitate detection, then the effect of the vertical position on the scanning process must be questioned, that is, what are the differences between the horizontal and the vertical cases. If the horizontal and vertical situation give the same results, then there is the possibility of further research using the vertical situation in cases which are impossible using the horizontal display. For example, lists of words presented horizontally would project images that extended beyond the fovea, but this would not happen if the words were presented vertically.

METHOD

Subjects

Four Michigan State University graduate students served as paid subjects. Subject CN had previous experience on the tachistoscope. No subject wore contact lenses.

Stimulus Materials

The displays were typed with single spacing on plain white 5" X 8" cards using IBM Orator 10 pitch Selectric type. Each display subtended a visual angle of 3° 20'. In all displays the critical letter appeared six single spaced lines, 1° 47', from the verification signal. The 12 basic arrays for the upwards scan condition are shown in Table 1. For

TABLE 1

BASIC ARRAYS FOR UPWARDS SCAN

Control				Preblank				Postblank			
N	N	N	N	N	N	N	N	N	N	N	N
Z	Z	Z	Z	Z	Z	Z	Z				
N	N	N	N	N	N	N	N				
Z	Z	Z	Z	Z	Z	Z	Z				
D	D	B	B	D	D	B	B	D	D	B	B
N	N	N	N					N	N	N	N
Z	Z	Z	Z					Z	Z	Z	Z
Z	Z	Z	Z					Z	Z	Z	Z
N	N	N	N	N	N	N	N	N	N	N	N
-	=	-	=	-	=	-	=	-	=	-	=

each critical letter there were two displays: the chosen permutation, and one generated by replacing all N's by Z's and all Z's by N's. The displays for the downwards scan condition used the same characters but were typed with the verification signal, "-" or "=", at the top and the critical letter, "B" or "D", six spaces down. All cards appeared equally often in a session and all were equally likey to be presented on any trial.

Apparatus

The displays were presented in a Scientific Prototype 2-channel tachistoscope, model 800E. A rapid card changing device designed by David Laberge and Peter Shaw was added to the primary field of the scope. This modification lengthened the viewing distance to 28 inches. The viewing distance in the blank field was also lengthened to 28 inches to assure that the subject's accomodation response to the pre-exposure fixation field was appropriate for the stimulus field. The intensities of the pre-postexposure and stimulus fields were, respectively, 109 ft-L and 124 ft-L.

Procedure

Subjects participated in 6 sessions of practice and 4 sessions of data collection. Each data collection session had 192 subject-paced data-collection trials for the upwards scan condition and 192 for the downwards scan condition. All sessions began with a 4-minute adaptation period in the experimental room that was followed by 15 warm-up trials.

There was a 3-minute rest period in the middle of each session while the focusing field was changed to accomodate for the new condition of reading up or down depending on what the first block of trials had been. For the data-collection sessions, subjects were run twice daily with the two sessions always at least an hour apart, except for subject EW whose last two sessions were on separate days.

During the practice sessions the stimulus duration for each subject was decreased from 150 msec. to the final stimulus duration for that subject; this data-collection stimulus duration was chosen on the basis of the practice data and was intended to give each subject a proportion of correct detections of about .60 on the control cards. This procedure produced data-collection stimulus durations for the upwards scan condition of 70 msec., 60 msce., 20 msec., and 15 msec. for subjects, TN, EW, RL, CN, respectively, and for the downwards scan condition of 80 msec., 70 msec., 20 msec., and 30 msec. for subjects, TN, EW, RL, and CN, respectively.

The experimenter dropped the cards into the card holder by hand; the experimenter said, "Ready.", then the subject pushed a button that triggered the presentation of a display; the subject then made the verification and critical letter responses. The experimenter recorded the subject's verbal responses and indicated to the subject which response was correct. If the subject missed the verification response, the trial was not recorded, and the missed card was randomly placed in the remaining deck.

The instructions to the subjects were as follows:

This is a T-scope. With the T-scope we can get very precise durations and intensities for visual exposures. We're interested in the process of reading and are studying this through brief single visual exposures. To achieve these single exposures the stimulus durations are somewhere between 0 and 150 msec. Within this range the eye does not have a chance to move. Thus, a single fixation is formed on the retina.

Vertical displays will be flashed before you on the T-scope under your control. Notice the button switch before you which you can hold in your hand. When you place your head against the tubing. you will notice two horizontal fixation indicators. You are to focus carefully on the space between the lines. To get ready for an exposure, first, put your head against the tubing; second, have your eyes carefully focused on the space between the horizontal lines; then after I say ready when you feel that you are ready, push the button. The display will flash on and then off with the fixation field returning. The exposure is fast so you must concentrate and pay attention.

The displays will consist of the following things. A - or an = sign but not both will always appear between where the fixation indicators have been. This is our test or verification to see whether you are paying attention. It is important that you get this first symbol. Half of the time it will be a - sign, the other half it will be an = sign. Next will be a string of letters in which a B as in boy or a D as in dog, but not both, will appear with equal probability (half of the time it will be a B, the other half a D). You are to read up or down from the fixation point depending on where it is and report whether you saw the B or D.

In summary,

1) You are to focus on the point between the horizontal lines.
2) After I have said ready and you are properly focused, you are to press the button.
3) You are then to read the display either up from bottom to top or down from top to bottom dependingon the position of the focus point.
4) Your response (a verbal report) should consist of - or = and boy or dog depending on whether you saw a - or an = sign (remember it is important that you always be correct here) and whether you detected the B or the D (here you are to guess when unsure). I will give you feedback each time as to whether you are correct or not. Any questions?

RESULTS

The observed proportions of correct detection responses for each of the card types in both the upwards scan and the downwards scan conditions are presented in Table 2.

To provide at least a rough assessment of the reliability of the observed effects the proportion of correct detections for each card type having a blank space was compared with its control proportion by means of the statistic,

$$\underline{z} = \frac{P_1 - P_2}{\sqrt{PQ(1/N_1 + 1/N_2)}},$$

where N_1 and N_2 are the number of observations in the two proportions, and P and Q are the proportions of correct and incorrect detections, respectively, for the combined sample. The value of $\underline{z}$ may be interpreted as a deviate of the unit normal curve if N_1 and N_2 are reasonably large, and if P is neither very large nor very small. Ferguson (1958) suggests the rule of thumb that if min(P, Q) X min(N_1, N_2) is greater than five, then $\underline{z}$ may be considered normal.

With respect to this criterion, a two-tailed $\underline{z}$ test for comparison of each blank space proportion with its control proportion is reasonable. The number of observations for each of these proportions is 256; min(P,Q) has a range of .219 to .443; min(N_1, N_2) X min(P, Q) has a range of 56 to 113.5. Each comparison of a postblank proportion with its control

TABLE 2

CORRECT DETECTION PROPORTION

Subject: Condition (Stimulus Duration)		Card Type		
		Control	Preblank	Postblank
EW:	Upwards (60 msec.)	.695	.816	.867
	Downwards (70 msec.)	.516	.598	.633
CN:	Upwards (15 msec.)	.644	.746	.844
	Downwards (30 msec.)	.578	.695	.785
TN:	Upwards (70 msec.)	.617	.718	.820
	Downwards (80 msec.)	.578	.562	.715
RL:	Upwards (20 msec.)	.594	.641	.840
	Downwards (20 msec.)	.605	.746	.836

proportion is significant at the .00001 level for the upwards scan condition and at the .01 level for the downwards scan condition. In the upwards scan condition each comparison of the preblank proportion with its control proportion is significant beyond the .05 level except for subject RL whose is not significant. In the downwards scan condition comparison of the preblank proportion with its control proportion is significant at the .01 level for subjects CN and RL (the two female subjects).

Thus a blank space immediately preceding the critical letter improves detection performance except for subject TN. While a blank space immediately following the critical letter in the processing order facilitates detection performance for all subjects to an even greater extent than the preblank does.

Notice in Table 2 that the upwards scan stimulus durations were shorter than those for the downwards scan. Even with these shorter durations, in general, the proportions correct for the upwards scan were higher than those for the downwards scan. This indicates that it is easier to scan upwards.

DISCUSSION

The results show that both the blank space before and after the critical letter facilitate detection performance in this vertical situation with the postblank condition being most effective. The results from the postblank comparisons were consistent with Shaw's (1969) results.

The preblank facilitation found in these results is similar to the preblank facilitation in Shaw's results. For example, in his Experiment 3, where he used Φ and Θ , two of his three subjects' preblank comparisons were significant corresponding to the present results. Estes and Wolford (1969) also found a preblank facilitation effect. In all three cases, this preblank facilitation was not as consistent or as strong as the postblank facilitation, but it existed and cannot be ignored. Three possible explanations for this preblank facilitation could be the following: (a) the preblank decreases the confusability of the noise letter preceding the blank with the critical letter; (b) the preblank reduces the amount of contour interaction; (c) the preblank allows the critical letter to be processed sooner than a corresponding critical letter in the control array (Shaw's original hypothesis).

The first explanation has not yet been tested. Shaw tested for thesecond interpretation by placing black rectangles in the spaces; he found no consistent pattern of preblank facilitation with his three subjects. These results do not decisively rule out the contour interaction reduction hypothesis. The third explanation follows from Shaw's finder-reader serial processing model and his original assumption that a blank space takes less processing time. Thus, assuming that the character finder slips across the blank space faster than it would three letters, the character finder inputs the character in the sixth position into the character reader slightly before a similar character in the control would have been inputed. This catches the character earlier in its decay and increases the probability that the character reader will identify it. Thus the slight facilitation of the preblank might be explained.

Using this third explanation, the present results are consonant with the serial processing model suggested by Shaw.

A question to consider is the simultaneous effect of the blank space on the letters on either side of it. Because the detection procedure was used in the present experiment, it is impossible to examine this effect in the present data, but it is possible to look at Estes and Wolford's (1969) data where the report procedure was used. Eyeballing the percentages of correct response in their Table 1, there are many cases where the percentage of correct responses for both the letter preceding the blank and the letter following the blank are higher than for the corresponding controls. Thus, the blank is in general facilitating, although it is more facilitating for the letter preceding it. Since the preblank and post-blank effects from this experiment and the present one are not equal, a parallel processing model is not suggested.

Shorter stimulus durations in the upwards scan than in the downwards scan were needed to maintain a proportion of correct detection of about .60 in the control condition. Even with these shorter durations the upwards scan conditions resulted in higher proportions of correct detection; the exact magnitude of this effect is difficult to ascertain because of the different exposure durations. A search of the literature failed to uncover any similar perceptual asymmetries between the upper and lower visual fields. Three explanations are immediately apparent. Firstly, there could be an acuity difference between the upper and lower visual fields. Perhaps the retinal mosaic is arranged such that the upward visual field (lower part of retina) acuity is better than the downward visual field (upper part of retina) acuity. Secondly, the scanning rate could be more rapid in the upwards scan. This could be tested in a situation where the subject's reaction times to scanning upwards are compared with scanning downwards. A question to consider here is whether this internal scanning rate is affected by the rate of the external eye movements. For example, can an internal scan only be as fast as an external eye movement? Thirdly, perhaps there is an upwards eye movement preference. This possibility could be tested by presenting a flash and then observing whether the eye moved upwards more often. Is there a connection between the observable physical eye movements and the internal unobservable scanning trajectory? Crovitz and Daves (1962) found congruence between the side of the visual field more accurately perceived and the direction of the initial postexposure eye movement (that is, the eye movement made immediately after the stimulus offset). Here the internal scan appears to be reflected in the external eye movement. If there is an upwards preference, the higher proportions of correct detection in the upwards scan would be explained by Crovitz and Daves' findings. Another question to consider here is whether the instructed order of "reading" in the present experiment affects the subject's initial postexposure eye movement. A comparison of the initial postexposure eye movements before and after instructions is needed to answer this. Another question to consider, assuming there is a preference, is how the eye movement preference is affected by the instructed order of "reading". Many experiments have been suggested above, but the equipment needed is technical and involved. For example, Crovitz and Daves used an electrooculograph technique to record initial postexposure eye movements which involved using a Grass Model III-D high efficiency EEG machine equipped with converter-demodulators (Grass Model CD-3) with one channel connected to the eye by electrodes and a second channel connected to the tachistoscopic timer. Therefore, it is not suggested that these studies be done immediately.

The horizontal and vertical results (of Shaw's and the present experiment) are very similar. It appears that the vertical situation can be substituted for the horizontal. This opens the way to further research (involving less complicated equipment than the above studies).

If words are processed as spelling pattern units in the word-apprehension effect as suggested by Neisser (1967), then an interesting extention from the single-letter units in the present experiment would be to examine the same situation with words as the units. Shaw (personal communication) has done an experiment with words arranged in a horizontal line. His results show consistent improvement in detection only when the word is both preceded and followed by a blank space. This seems reasonable because it sets the word off as a unit. But what would happen in the vertical case? Here each word would already be set off as a unit; the spelling pattern would play a significant role. There would also not be the problems with retinal eccentricity that the horizontal situation creates. Just what is the function of the blank space? Would a block of X's function in the same way? An experiment is presently being set up to examine these questions. The paradigm will be the same as in this experiment except that 4-letter words will be used instead of letters. There will also be two more experimental conditions where a block of X's replaces the blank spaces. It is hoped that this will help answer some of the questions.

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