Scanning strategies and differential sensitivity in a visual signal detection task: Intersubject consistency

DAVID E. CLEMENT and JOSEPH J. SCHIERECK
University of South Florida, Tampa, Fla. 33620

Forty Ss (20 of each sex) were run individually for 480 trials of a 16-alternative forced-choice visual signal detection task. Ordinal differential sensitivity to target locations (indicated by d' values) across all Ss pooled was similar to that previously found (Clement & Hosking, 1971), $r_s = .90$. Individual Ss performed in a manner indicating a common general scanning strategy ($W = .48$) with idiosyncratic differences. The outcome indicated that the consistent portion of the scanning strategy was a combination of fixation effects and reading habits, with the scan operating from the upper-left corner to the lower-right corner of the display. The scan was postexposural, as the exposure duration (200 msec) was too brief to allow more than one fixation.

When a human S processes a visual display, the elements attended to on any one trial are not randomly drawn from the display (Taylor, 1970). Ss appear to develop fixed "scanpaths" in eye movements when viewing patterns, and these scanpaths are specific to S and to pattern (Noton & Stark, 1971). Estes & Taylor (1966) showed that there is high test-retest reliability for the elements sampled by a S from a particular display, suggesting stable relative sensitivity to parts of a display. This intra-S reliability was confirmed by Clement & Hosking (1971) for a 16-alternative forced-choice (16-AFC) task. They found extremely strong scanning biases existing prior to the experimental task and demonstrated that fewer than 400-500 trials are quite sufficient for reliable estimation of the differential sensitivity among all 16 target locations in such a task.

The evidence concerning the kind of scanning or differential sensitivity displayed by human Ss is far from consistent. Hershenson (1969), using seven-letter displays and brief exposure, found target position to be the major determinant of perceptibility, yielding an inverted U-shaped function about the fixation point. At least two studies have suggested that a scan from the outside of a display to the fixation point is primary and prevalent over a reading type of scan (Mackworth, 1965; Schissler & Baratta, 1970). Averbach & Sperling (1968) found that in a 2 by 8 array of letters, the upper row was reported more accurately than the lower, and the outer positions were reported more accurately than the center positions, despite the use of a

central fixation point. However, Winnick & Bruder (1968) found no accuracy difference between up and down or between left and right. They suggested that the dominance of one field over another was an artifact of the order of reporting. Enoch (1959), on the other hand, found most attention focused on the center of a display, with little fixation on the upper-left quadrant. Better detection in central locations was found also by Baker (1963) in a forced-choice situation, but he found that Ss bias guesses toward such locations. This bias could inflate detection rates artificially and emphasizes the need for measures of detection independent of criteria (response) biases. One such measure is d' , the sensitivity index of signal detection theory (Swets, 1964; Green & Swets, 1966).

White (1970) found that targets exposed for 100 msec were generally reported better if they were to the right rather than to the left of fixation, though targets at the left of a display were reported first. Following previous suggestions (Heron, 1957; Bryden, 1967), he proposed that there is a postexposure directional scanning mechanism which operates sequentially upon a stored information trace. Crovitz & Schiffman (1965), in contrast, found fewer errors for the leftmost target in a line but agreed that such tasks should be categorized as involving memory rather than perception. Studies using 4 by 4 arrays of stimuli also found better detection in the left than in the right portion of the stimulus array (Lincoln & Averbach, 1956; Holmgren, 1968). A study using sequential presentation

(Krueger, 1971) showed that left-to-right presentation improved short-term recognition memory, attributing this to peripheral processes (eye movements) more than to central processes (reading).

Other studies have found still different patterns of relative sensitivity in visual tasks. Ford, White, & Lichtenstein (1959) obtained an annular distribution of fixation, with both the center and outer portions of a circular search field being neglected. An ovaloid region of rapid search was found in two related studies (Volkman, Corbin, Eddy, & Coonley, 1964; Volkman & Corbin, 1965), and the unlikely shape of this area was suggested to be determined either by the shape of the stimulus array or by the S's uncertainty regarding the location of the critical element. These findings suggest that the search or scanning pattern is determined chiefly by the configuration of the field of search (White & Ford, 1960). Taylor (1970) further suggests that differential *fixation* hypotheses do not warrant further investigation, emphasizing other factors, such as postexposure scan and the effect of instructions.

To summarize these disparate findings, it appears that differences in sensitivity to portions of a visual display are rather stable and are specific to the task involved and to the instructions given to the Ss. The locus of such effects appears not to be fixation but, rather, a postexposural directional scanning mechanism (e.g., Heron, 1957). This study was designed to measure the consistency of ordinal relations among d' values across Ss given nonbiasing instructions in order to determine preferred scanning strategies for a 16-AFC task using a 4 by 4 visual display.

METHOD

Stimuli were on 35-mm slides and were presented by means of a Lafayette two-field projection tachistoscope, with a blank frame identical in size to the stimulus frame projected at all times other than during stimulus presentation. Each stimulus consisted of a square field containing 16 black outline circles in a 4 by 4 array. Fifteen of the circles contained a black outline "upright" equilateral triangle (base down), and the 16th circle contained an "inverted" equilateral triangle (base up). For purposes of analysis (but not during the experiment), the circles were numbered consecutively, beginning with the upper left corner and progressing from left to right in each row. The data in Table 1 are presented in a spatial arrangement similar to that of the original target locations. Ss were seated

Table 1
Proportion Correct (P_c) and Sensitivity (d')
for All Ss for Each Target Location

	Location			
	1	2	3	4
P_c	.38	.39	.40	.22
d'	1.57	1.42	1.58	1.29
	5	6	7	8
P_c	.53	.81	.80	.46
d'	1.73	2.40	2.44	1.82
	9	10	11	12
P_c	.53	.61	.65	.37
d'	1.75	1.80	1.94	1.54
	13	14	15	16
P_c	.13	.24	.17	.13
d'	.82	1.18	1.08	1.14

approximately 3.4 m from the projection screen, and the projected stimulus frame measured 30.5 cm on a side. Each projected circle measured 4.6 cm in diam, containing a centered equilateral triangle, 2 cm on a side. The visual angle subtended by the 16 circles was approximately 4 deg, with each circle subtending an angle of about 48 min and each triangle subtending an angle of about 20 min.

Forty Ss (20 male, 20 female) were used in the experiment, each run individually for a total of 480 trials. Each trial consisted of a presentation of a stimulus slide for 200 msec, with about 6 sec between trials. During the intertrial interval, Ss recorded the location of the target (inverted triangle) on a schematic drawing of the stimulus, together with a confidence rating concerning the judgment. Confidence ratings were made by means of a check mark on a horizontal line which was divided into five segments. The statements "sure" and "???" were written under the two end segments, and the responses were coded as one of the digits from 1 to 5 (1 = not sure . . . 5 = highly certain). The experiment was run in one 1½-h session, with brief rest periods after blocks of 40 trials and longer rest periods after blocks of 240 trials. Stimuli were presented in a pseudorandom order, with the target occurring in each location five times in consecutive series of 80 trials and, thus, 30 times in the experiment. Ss were instructed to "try to pay attention to all 16 possible target locations," were told that the target was placed in a random fashion, and were given a brief description of the meaning of random ordering. A prize of \$10 was offered for the S with the highest number of correct responses, as a means of maintaining high motivation. Five practice trials were run prior to the experiment to assure appropriate interpretation of the

instructions by the Ss. There was no feedback given to the Ss during the experiment.

RESULTS

Proportion correct (P_c) was obtained for each target location for each S over all trials, for all Ss of each sex, and for all Ss combined over all trials and over consecutive blocks of 160 trials. Table 1 contains P_c values for all Ss for each target location across all trials. Proportion of hits (correct identifications of target locations) and proportion of false alarms (trials on which a target location was specified when, in fact, that location was not correct) were calculated across all trials for each S for each target location, for all Ss of each sex for each target location, and for all Ss combined for each target location. In addition, these summary data were calculated for all Ss combined for each target location over consecutive blocks of 160 trials. These data were used to obtain d' values for the specific target locations, using conversion tables in Swets (1964). Table 1 also contains d' values for all Ss for each target location across all trials.

P_c ranged from .09 to .85 across Ss for all trials and for each block of 160 trials. The range for d' was .77 to 2.73 across Ss for all trials and for each block of 160 trials. The ordinal consistency of d' for different target locations across blocks of 160 trials (for data pooled across Ss) was exceptionally high, with a coefficient of concordance (W) of .96.

An analysis of variance (mixed design) was run on d' values for each S for each target location, with sex of S (G) and target location (L) as the independent variables of interest. Sex of S was not important, as both the G effect, $F(1,38) = .424$, and the G by L interaction, $F(15,570) = .628$, failed to reach significance at the .05 level. Target location was significant, as expected, $F(15,570) = 33.783$.

The ordinal consistency of d' as a function of target location was demonstrated further by rank-order correlation (Spearman's ρ , r_s) of the values pooled across all Ss in this study with those from the prior study (Clement & Hosking, 1971). The obtained value, $r_s = .90$, was comfortably high, and, in fact, there was identity in the ranks of the six target locations with highest d' as well as the location with lowest d' .

The major interest was in the consistency of the ordinal values of d' for different target locations across Ss. Correlation of differential sensitivity among all 40 Ss was obtained by means of the coefficient of concordance, $W = .48$. Although reasonably high, this value could

reflect either of two conditions. One would be a basic agreement across Ss, plus some rather specific alternative processing biases shared by groups of Ss; the second would be some basic processing strategy with individual variation. To obtain information relevant to these possibilities, r_s was obtained between the ranks for d' for each S and the ranks of d' for all Ss pooled. Values of r_s ranged from .28 to .93, with a mean of .67. Although not conclusive, this lends some support to the idea of basic similarity among all Ss, with deviations due to idiosyncratic processing biases. In general, the higher r_s was between each S and the pooled total, the higher r_s was between that S and each other S.

DISCUSSION

The results were similar to those obtained by Clement & Hosking (1971) in that d' was best for the second row, then the third, first, and fourth rows. Detection was best in the center of the second row (fixation effect?), but somewhat better for the left than the right in the upper row and better for the right than the left in the bottom row. The correlation between the average results for this experiment and those of the prior study (Clement & Hosking, 1971), $r_s = .90$, indicated high stability for ordinal sensitivity in the display for data pooled across individual Ss, as well as confirming the previous finding of high individual S stability across trials.

The existence of individual differences was apparent in the correlation among Ss ($W = .48$). The differences seemed to derive from use of a strategy that was consistent across Ss, together with strategies that were idiosyncratic, rather than the use of several major strategies among clusters of Ss.

The results were not "instruction-free" but might be considered "instruction-fair." They indicated that with a square array, the consistent portion of scanning strategy was determined by a combination of effects of fixation (better detection in the center of the best row) and reading habits, with the scan operating generally from the upper left of the display to the lower right of the display. The scan obviously was a postexposural scan (e.g., Heron, 1957), as the exposure duration (200 msec) was too brief to allow more than one fixation.

The results of this study can serve as baseline data for individual performance and should be worthwhile in evaluating the differential effects of instructions as well as the performance of Ss making group decisions.

REFERENCES

- AVERBACH, E., & SPERLING, G. Short-term storage of information in vision. In R. N. Haber (Ed.), *Contemporary theory and research in visual perception*. New York: Holt, Rinehart, & Winston, 1968. Pp. 202-214.
 BAKER, C. H. Location preferences when choice is forced. *Perceptual & Motor Skills*, 1963, 16, 746.
 BRYDEN, M. P. A model for the sequential organization of behavior. *Canadian Journal of Psychology*, 1967, 21, 37-56.
 CLEMENT, D. E., & HOSKING, K. E. Scanning strategies and differential sensitivity in a visual signal detection task: Intrasubject reliability. *Psychonomic Science*, 1971, 22, 323-324.
 CROVITZ, H. F., & SCHIFFMAN, H. R. Visual field and the letter span. *Journal of Experimental Psychology*, 1965, 70, 218-223.
 ENOCH, J. M. Effect of the size of a complex display upon visual search. *Journal of the Optical Society of America*, 1959, 49, 280-286.
 ESTES, W. K., & TAYLOR, H. A. Visual detection in relation to display size and redundancy of critical elements. *Perception & Psychophysics*, 1966, 1, 9-16.
 FORD, A., WHITE, C. T., & LICHTENSTEIN, M. Analysis of eye movements during free search. *Journal of the Optical Society of America*, 1959, 49, 287-292.
 GREEN, D. M., & SWETS, J. A. *Signal detection theory and psychophysics*. New York: Wiley, 1966.
 HERON, W. Perception as a function of retinal locus and attention. *American Journal of Psychology*, 1957, 70, 38-48.
 HERSHENSON, M. Stimulus structure, cognitive structure, and the perception of letter arrays. *Journal of Experimental Psychology*, 1969, 79, 327-335.
 HOLMGREN, J. Visual detection with imperfect recognition. *T. R. No. 128*, March 1968, Institute for Mathematical Studies in the Social Sciences, Stanford University, Stanford, California.
 KRUEGER, L. E. Effect of duration of sequential presentation and redundancy on short-term recognition memory. *Perception & Psychophysics*, 1971, 9, 121-124.
 LINCOLN, R. S., & AVERBACH, E. Spatial factors in check reading of dial groups. *Journal of Applied Psychology*, 1956, 40, 105-108.
 MACKWORTH, N. H. Visual noise causes tunnel vision. *Psychonomic Science*, 1965, 3, 67-68.
 NOTON, D., & STARK, L. Scanpaths in eye movements during pattern perception. *Science*, 1971, 171, 308-311.
 SCHISSLER, D., & BARATTA, M. An addition to the reading scan hypothesis. Paper presented at Psychonomic Society meeting, San Antonio, 1970.
 SWETS, J. A. (Ed.) *Signal detection and recognition by human observers: Contemporary readings*. New York: Wiley, 1964.
 TAYLOR, H. A. Context and learning in the processing of information from brief visual displays. *Perception & Psychophysics*, 1970, 7, 15-18.
 VOLKMANN, J., & CORBIN, H. H. Further experiments on the range of visual search. *USAF ESD TDR No. 65-169*, 1965.
 VOLKMANN, J., CORBIN, H. H., EDDY, N. B., & COONLEY, C. The range of visual search. *USAF ESD TDR No. 64-535*, 1964.
 WHITE, M. J. Retinal locus and the letter-span error function. *Perception & Psychophysics*, 1970, 8, 107-109.
 WHITE, C. T., & FORD, A. Eye movements during simulated radar search. *Journal of the Optical Society of America*, 1960, 50, 909-913.
 WINNICK, W. A., & BRUDER, G. E. Signal detection approach to the study of retinal locus in tachistoscopic recognition. *Journal of Experimental Psychology*, 1968, 78, 528-531.

were not wearing any cologne or lotions.

MATERIALS

Fourteen odorants (Table 1), chosen to represent a wide variety of qualitative classifications, particularly the categories of Shultz (1964), were used in the study. The odorants were contained in stoppered 13 x 100 mm test tubes, taped at the bottom to reduce visual cues. Each test tube contained approximately 3 cc of odorant.

Twenty-four adjectival scales were used for S ratings. Each of the scales was a bipolar 7-point rating scale (Table 2). Twelve of these scales were taken from Yoshida (1964) because they appeared most applicable to odor scaling. The other 12 were chosen randomly from 76 scales found reliable in previous semantic differential experiments (Osgood, Suci, & Tannenbaum, 1957). The 24 scales appeared on a single sheet; the order of scales and position (left-right) of the adjectives in each scale were determined randomly. Position of the adjectives was reversed for half the Ss. A separate sheet was used for each S's rating of each odor.

PROCEDURE

The Ss were run individually, seated at a table in an air-conditioned laboratory room. An electric fan was used to circulate air in the immediate area.

Each S was instructed in the use of the semantic differential scales, then handed the first test tube. The S was allowed to keep the tube, smelling the odorant as necessary during the time he was marking the 24 scales. A 3-min interval preceded presentation of the following odorants.

RESULTS

The obtained data were in the form of a 20 (Ss) by 14 (odorants) by 24 (scales) matrix of ratings. The data were reduced to a 14 by 24 table by obtaining a median rating across Ss. These medians were then used as odorant scores on the 24 scales. Pearson rs were computed for each pair of scales. Factor analysis, using a Varimax rotation, yielded the factor loadings presented in Table 2.

DISCUSSION

It is indicated in Table 2 that a single factor accounted for a very large part of the responses to the odorants. This factor, which accounted for 51%

Identification of olfactory dimensions by semantic differential technique

MARK CUNNINGHAM and CAROL A. CRADY
Murray State University, Murray, Ky. 42071

Twenty Ss rated 14 odorants on 24 semantic differential scales. Scale scores for each odorant were obtained as the median rating across Ss. Factor analysis yielded four interpretable dimensions of olfactory perception.

For use in a study on olfactory adaptation, the authors needed to scale odorants along subjectively meaningful dimensions. The archives contain many works on the dimensionality of olfactory experience, but they show much dissimilarity. A study by Yoshida (1964), in which the semantic differential technique was used to find olfactory dimensions in a Japanese population, seemed to offer the best

approach for the projected studies. The study here reported was an extension of Yoshida's (1964) study and was designed to identify subjective olfactory dimensions in American college students.

SUBJECTS

Ten male and 10 female volunteers from an introductory psychology class served as Ss. They were not anosmic, were not suffering infections which would impair olfactory sensation, and

Table 1
Odorants Rated

Ammonia	Crotonic Acid
Amyl Acetate	Dodecanethiol
Amyl Alcohol	Milk of Asafoetida
Banana Oil	Oil of Sassafras
Benzaldehyde	Pentene
Butanol	Pyridine
Butyric Acid	Solution of Coal Tar