1040-5488/89/6612 -0871 $02.00/0
OPTOMETRY AND VISION SCIENCE

Vol. 66, No. 12, pp. 871-876

instruments /techniques

Behavioral Control of Visual Field Screening Using a Microcomputer

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ABSTRACT

A computer algorithm is described which automatically controls the presentation of visual field targets and analyzes the subject's responses. Data relating to the procedure's reliability and validity are reported along with experience using it with normal subjects on an IBM PC compatible. Suggestions are made for the further development of the microcomputer approach to visual field investigations.

Key Words: visual field, behavioral control, microcomputer, IBM PC

Advances in computer screen technology suggest that in the future it may no longer be necessary to resort to specialized stimulus presentation hardware in visual field investigations much beyond that which normally accompanies a microcomputer. When this is so, attention will focus more on the mode of presenting targets in such a way that thresholds can be measured accurately and swiftly with the minimum of operator intervention.

A substantial part of the high cost of the more sophisticated visual field instruments lies in the low-volume production costs of specialized stimulus presentation devices. If these can be replaced by suitable quality, mass-produced, consumer electronic display units (hen the cost of such equipment should be greatly reduced. The resolution, precision, and general quality of computer monitors is improving all the time, and televisions with high resolution tubes or large, non-CRT, flat screen displays are already available. These will facilitate more sophisticated stimulus presentations.

Received May, 3 1989; revision received July 21, 1989.
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The other major hardware component of specialized visual field instruments is the computer. The cost of microcomputers which can easily handle such high resolution devices continues to fall. Thus, all that will be needed for a cheap, effective, and sophisticated visual field investigation instrument in the future may be a general purpose microcomputer and a suitable computer program.

Behavioral psychology long ago solved the problem of how to measure the sensory capabilities of animals.[1] Using operant methodology, the animal is rewarded for a correct response and punished for an incorrect one. Usually not more than one or two responses are available to the animals, yet with suitable programming a simple peck, for example in the case of pigeons, can be used to establish dark-adaptation and spectral-sensitivity curves.[2] Today, operant techniques are used routinely to determine the visual capabilities of young children who cannot understand verbal instructions and whose responding may be limited to a simple head tilt.[3]

The same technology can be used with adult humans.[4] Operant technology is also used to control human behavior in computer-assisted learning[5] and computer games. The enormous numbers of home computers and computer games sold are testimony to how effective such control can be. In visual fields analysis one can augment the method with verbal instructions and if the technique is effective it should be able to virtually eliminate the need for an operator. Probably the most crucial factor with operant conditioning is that reinforcements (rewards) should follow very closely on the behavior that one wishes to strengthen.

This article describes the use of a simple program run on an IBM PC compatible microcomputer. A conventional CGA monitor is used to present the static suprathreshold screening using single stimuli. Such a low resolution screen limits the usefulness of the present arrangement but the behavioral principles could be developed and applied to more advanced graphical devices as these become available.

METHODS

The program used was written in Turbo Pascal and runs on the IBM PC/XT/AT family of computers. In its present form it uses a CO A screen in HiRes mode. 'This gives a single-intensity screen (choice from around 11 levels with a monochrome display) with a resolution of 640 pixels horizontally by 200 vertically.

The monitors used were a conventional monochrome (display area utilized approximately 150 by 230 mm) at a distance of about 230 mm for screening one-half the visual field up to 30°, and a color monitor (approximately 180 by 260 mm) at about 600 mm distance for screening the blind spot. Both were flicker-free and used low-persistence phosphors. A black cloth was draped over the subject and monitor to reduce screen reflections as the room was being used for other purposes. The fixation cross was 5 pixels high and 9 pixels wide on the monochrome monitor and 3 by 5 pixels on the color. On the monochrome monitor the brightness range available was 0.23 ash (apostilbs) to 114 asb in 11 steps. For fixed, brightness-detection stimuli the brightness used was 114 asb, whereas with variable brightness-detection stimuli it varied from 1.4 asb to 114 asb (9 steps). For the color monitor the detection-stimulus brightness was 144 asb. Pixel diameters were about 1 mm. In all cases the screen background luminance level was adjusted so it was black.

After establishing monitor size, screen to eye distance, which eye is to be screened, where the fixation target is to be on the screen, and prompting the operator to adjust, screen brightness, the computer responds with a chart of that eye including the theoretical position and shape of the blind spot with meridians and isopters.

The operator then moves a variable-size, rectangular region around the screen to indicate the area in which the program should present the target stimuli (arbitrarily set at around 120 in number). This having been done, the program gives a brief tutorial to the subject on the coming task before beginning the automatic screening. One run typically lasts for about 5 min and during this time the subject responds by just pressing the space bar as instructed. The response is simple and the subject has no need to look at the keyboard.

The algorithm used by the program is summarized in Mechner diagram form'[1] in Fig, 1. The subject is instructed to fixate the fixation cross continuously. From time to time, this disappears and is replaced at that point on the screen by another symbol, a dot. Nothing happens then until the subject presses the space bar to signify that he or she has defected the change. "The response is then reinforced by the return of the fixation cross.

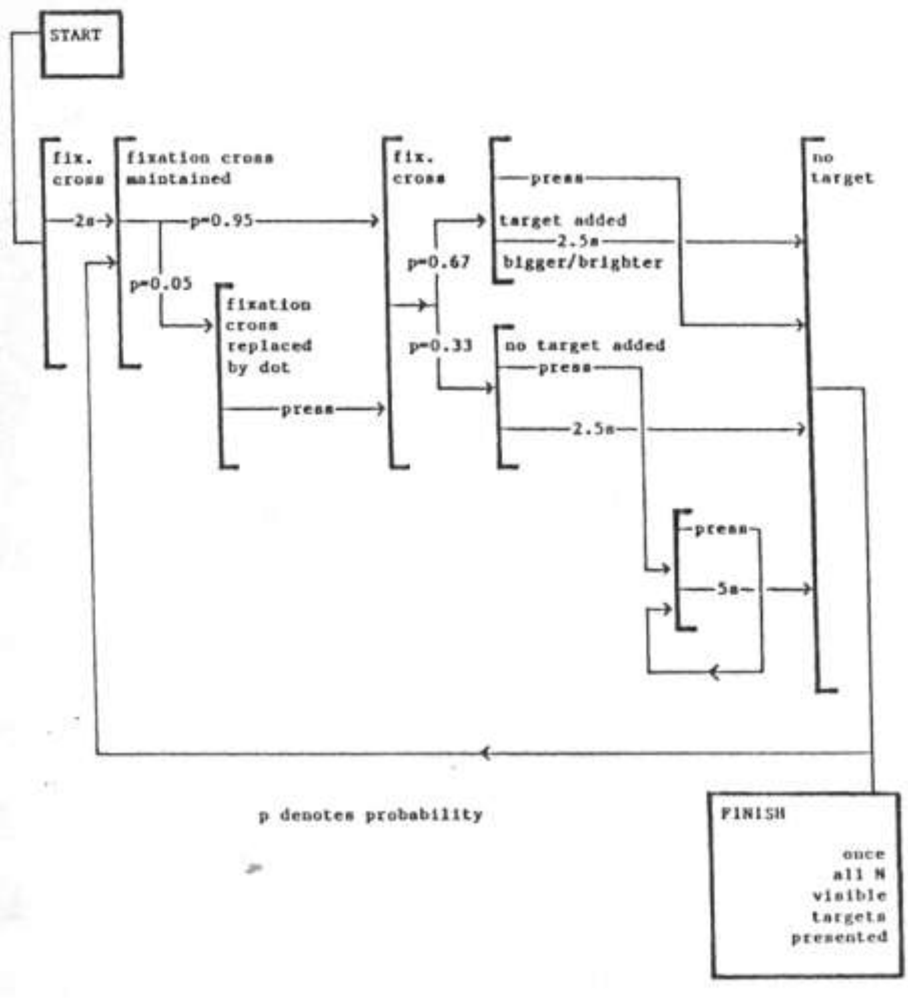

Figure 1. This Mechner diagram summarizes the main part of the visual fields algorithm. It does not detail changes in the target stimulus when this is added to the screen. The stimulus may remain fixed in size or become bigger. It may be of fixed luminance or become brighter. The steps at which these changes occur may vary in length but in this study have been maintained at 0.25 s in duration.

In this way, it is possible to check that the subject is following instructions. If fixation drifts from the fixation cross (his should show up in abnormally long reaction times between fixation dot appearance and space bar depressions. These can be compared with target stimuli detection times and one would expect them to he similar. The average frequency of dot appearances is controlled by the program and is here set at 5%. Individual dot appearances arc random.

With the fixation cross present on the screen, the program enters one of two modes. Under the test mode (here set with a two-thirds probability) a target stimulus appears randomly in one of the previously chosen 120 loci. This stimulus then progresses in one of four ways at a predetermined speed depending upon the procedure adopted for the particular session. It may (1) remain as a single pixel, (2) increase in size, (3) become brighter, or (4) become bigger and brighter each step. Here, the program steps have been set to occur somewhat arbitrarily every 0.25 s and are limited in number to 9. The subject has been instructed to press the space bar as soon as the target is seen. When the subject presses the bar the response is reinforced by the target extinguishing. The position of the stimulus, its size and/or intensity, and the reaction time are recorded. A new cycle is then entered. Occasionally, impossibly short reaction times may be recorded and the associated response may be discounted because the subject has jumped the gun. (We did not in practice discount any early responses.)

On one-third of occasions, with the fixation cross on the screen, the program enters a null test mode—no target stimulus appears and usually the program waits for 2.5 s (the same maximum time if a visible target had been present) before proceeding. Responses by the subject here would be incorrect and when they occur they are punished by a "beep" and a 5-s "time-out." 'That is, the program delays the next cycle by 5 s. If, at the end of this time, the space bar is pressed again then another time-out is introduced. In this way, with no target stimulus on the screen, incorrect (false positive) response are discouraged and the chances of such responses being reinforced by the presentation of a new stimulus is greatly reduced.

Thus, the program controls the subject and facilitates adherence to instructions by simple reward and punishment. It provides initial training followed by checks and balances using the measure-ments. Poor fixation might be expected to show in cross disappearance reaction times substantially longer than those for detected target stimuli. Random responses should quickly extinguish as such responses will delay the opportunity for rewards. If they do not, then the lack of subject cooperation will be obvious from the number of time-outs recorded. The program re- cycles until all the target stimuli have been presented. A printout follows. This details the targets presented with their magnitude (size or intensity) when detected; the average reaction times to fixation cross disappearance and stimuli target detection; a 2 by 2 matrix giving number of true positives (stimuli defected), false positives (responses to invisible stimuli), true negatives (nonresponscs to invisible stimuli), and false negatives (stimuli not defected); and the program's parameters.

The basic procedures were tested with 82 undergraduate optometry students as a laboratory exercise over a 3-year period. Each subject ran the program for two tasks: (1) to plot the position and shape of the blind spot and (2) to screen the top or bottom half of the visual field (to 30° from the fovea). In (1) the screening procedure was run three times to assess test-retest reliability using a fixed intensity, variable size target progression; in (2) it was run four times to permit comparison of the four different target progressions.

RESULTS

The data for each task were analyzed using a balanced, complete, multifactorial repeated measure analysis of variance (ANOVA) design.[7,8] Occasionally data for a particular measurement were lost; subjects were then excluded from that particular analysis.

False positives were found to be infrequent (Table 1). In the blind spot study, when the target stimulus was omitted and 2.5-s pauses were inserted, the mean frequency of spurious responses was only 3% for 73 subjects and this did not change significantly over the two subsequent screenings (F = 0.13; df = 2,144; NS), suggesting that control was maintained over the full 15-min period. With the half-field screenings (42 subjects), the only significant difference amongst the four procedures was a main effect due to intensity with variable intensity false positives higher at *1%* (F = 7.1; df = 1, 41; $p < 0.01$). A substantial number of false positives would cast doubt over the validity of some of the true positives, but with fixed intensity stimuli in the first blind spot, screening the proportion of false positives exceeded 10% in only 1 of 78 subjects.

As is very common with data where the criterion is in terms of a time scale, the reaction time data tended to be skewed and a log transformation was used before parametric statistical analysis to improve the normality of the distribution.[8] Target detection reaction times were similar but slightly shorter than those for fixation cross disappearance (Table 2). With the fixed intensity stimuli used in

TABLE 1. Average proportion of false positives; responding during 2.5-s pauses when target stimulus is omitted.

Screening Task	Target Progression	False Positives
blind spot area	fixed intensity, variable size	3%
one-half of 30° field	fixed intensity	4%
one-half of 30° field	variable intensity	7%

the blind spot study, the average reaction time (65 subjects) for target detection was 0.6 s and this was significantly shorter than the 0.7 s it took on average to respond to fixation cross disappearance (F = 78.2; df = 1, 64; $p < 0.001$). In the half-field study (N = 43) there were two significant main effects. With variable intensity stimuli the initial targets are much less visible and as expected the corresponding latencies were significantly longer (F = 299.4; df = 1, 42; $p < 0.001$) than for fixed stimuli. The target detection and fixation cross reaction time differences were once again significantly different (F = 14.6; df = 1, 42; $p < 0.001$). The means were 1.2 and 1.3 s for variable intensify detection and fixation stimuli reaction times. The latencies where target stimuli increased in size did not differ from those where just 1 pixel was presented. Target detection latencies increased toward the periphery of the field as expected.

There was a tendency for the recorded blind spot size to be a little smaller than the theoretical one with an average size of 22° square or 79% of a 7 by 5° ellipse. Reliability appeared good in that when the procedure was repeated a similar shaped and positioned blind spot was obtained. The results of an ANOVA to estimate the reliability of measurement[8] are given in Table 3. The standard error of measurement (SEM) of blind spot size was 3° square over three runs for a sample of 51 subjects for whom data had been recorded permitting an estimate of the absolute size of the blind spot. Size changes over the three consecutive runs were not significant.

DISCUSSION

The use of a simple microcomputer to screen visual fields is not new[9 H] but relatively little attention appears to have been given to the potential of behavioral control techniques. Accornero et al.[9] have argued that there is no need to monitor the stability of fixation as the subject will "instinctively" gaze at the fixation cross in the center of the screen, but if would appear sensible[1] not to take; subject compliance* for granted particularly when as in our study the fixation point may be at the edge of the screen and target stimuli may also be asymmetrically distributed. Also, it cannot be assumed that subjects will not cheat and anything which contributes to the tight, control of field measurements and reduces potential malingering should be welcomed.

Stimuli have been presented in blind spots to check for correct fixation[1"1] but (his technique can only be used when the blind spot's projection falls within the area of the computer monitor. Our presentation of "invisible" stimuli (monitored pauses in stimulus presentations) is a further technique for checking that the subject is following instructions, with responses during this time constituting false positives. Such responses can be indicated by "annoying beeps,"[16] but, from a behavioral point, of view it is far more effective to also accompany them by a time-out, a delay in the opportunity for reinforcement.

Frisen[1'] also used a changing fixation mark. His approach was to reduce the size of the mark smoothly just before target presentation as he thought this would attract fixation at the same time as it signalled the need for extra attention. 'This may be true, but it could also be argued that it might prompt the subject to start looking around for the stimulus. In our case the change of the fixation cross to a spot fulfilled a dual role: (1) it enabled a further measure of attention and fixation efficiency in terms of the latency to detect the change and (2) poor fixation and attention would lead to a time-out from opportunities for reinforcement.

In general, the results suggest good subject control with reliable blind spot measurements despite an arduous retesting task requiring 15 min.

Results also appeared reasonably valid because the average blind spot size was only one fifth smaller than expected. There we're some occasions when the blind spots appeared far too small. Discussions with the subjects concerned suggested that the problem here was due to the glass construction of the monitor. The instructions urged the subject to respond promptly whenever they "saw" a stimulus on the screen. Some subjects took on the task in a particularly competitive fashion which means that they responded as quickly as they could as soon as they "sensed" a stimulus was there without in fact exactly "perceiving" it. If seems clear that they were responding to a general lightening of the screen in the region of the target stimulus caused by internal reflection within the glass screen of the visual display. Although by and large[1] those who misconceived the task appeared to do (his relatively

TABLE 2. Average reaction times to stimulus changes.

Screening Task	Target Progression	Target Detection	Fixation Cross Disappearance
blind spot area	fixed intensity, variable size	0.6 s	0.7 s
one-half of 30° field	fixed intensity	0.5 s	0.7 s
one-half of 30° field	variable intensity	1.2 s	1.3 s

TABLE 3. Blind spot size and its test-retest reliability.

Source of Variation	SS	df	MS	F	P
Between people	6613.2	50	132.3		
Within people	1208.0	102	11.8		
between runs	41.6	2	20.8	1.79	NS
residual	1166.4	100	11.7		
Total	7821.1	152			
Mean = 22° square					
SD = 7° square					
r = 0.72					
SE_{meas} = 3° square					

consistently, one would expect that the removal of this stimulus artifact would increase the reliability of the task as well as its validity. When all subjects were considered, the average blind spot size was one-fifth smaller than expected. This is a significant difference and as subjects usually removed their spectacles this suggests that the tendency to respond to screen lightening was a general one, although it is always possible that adjustments to fixation may have played a part. The test stimuli used were contiguous and always at a particular point on the screen for longer than 0.25 s. This may have encouraged unwanted eye movements, and durations less than 0.2 s would have been preferable.

With the color monitor used for blind spot plotting, it was not possible to adjust its brightness. Had target luminance been reduced, ambient lighting levels increased, or target stimuli used on a dimly lit screen background, it seems likely that the screen lightening problem could have been eliminated, but clearly this problem needs to be kept in mind whenever a glass-fronted screen is used. The problem could also be dismissed if subjects could be persuaded to ignore screen glow. However, this goal is unlikely to be completely attainable. Of course, conventional monitors have other shortcomings with variations in screen thickness, significant screen curvature, and the need to calibrate their luminance for precision work. Improvements in screen technology, with large, flat, non-CRO screens with adequate intensity control of individual pixels will be of considerable benefit to this work.

The basic behavioral procedure could be used with any test target, including Frisen's resolution ring targets. Detection targets were used here with four methods of stimulus target progression. Screenings where the target remained as 1 pixel or grew in size in regular steps appeared to give the best results with the fewest false positives. Target size made no difference to our results. Unfortunately, target detections here were all or nothing, with no threshold measurements being possible. Varying the intensity of the stimulus diminished the effective control of the task and led to an increase in false positives. The problem here lay not in the control procedures but in the computer video standard used. With an IBM CGA screen in HiRes mode all pixels plotted must be of the same intensity or color. Varying the stimulus target simultaneously varies the fixation cross. In practice, this confused the subject. Obviously, with a dim fixation cross the subject will either not see it or confuse it with the alternative fixation dot which periodically replaces if. As a result, when stimulus intensities varied spurious responses were more frequent.

It needs to be noted that with the CGA video standard only IB" colors (apart from black) are available for screen stimuli. Furthermore, these may translate into just 1 1 distinct levels of luminance on a monochrome display. They represent a rather limited range for threshold measurements. However, the important point is that this and the earlier limitation are a result of the current graphical standard and are in no way due to the methodology or the microcomputer itself. Ideally, one requires a free choice of three simultaneous colors—one for fixation, one for background, and one for target stimuli, and the last should be variable over a large range—the larger the graphics palette the better. The newer video standards on the PC compatible, e.g., VGA, are far better and also permit the use of high-pass spatial frequency letters as resolution test stimuli.[18]

With the present implementation, nine 0.25-s steps are used for target progression but a subject cannot respond within 0.25 s—just over 0.5 s was typical with our set-up. If intensity was to be varied realistically and a quantitative threshold field examination carried out using this particular method, then the step time would need to be increased to about 0.75 s to give adequate time for the subject to respond. Krisen[17] reported a range in mean reaction times for his Ring Screener of 0.32 to 0.66 s.

CONCLUSIONS

Behavioral control techniques are a promising method of ensuring quick and effective control of visual field investigations with the minimum of operator intervention because they are based on sound psychological principles. However, their full potential with a conventional microcomputer is unlikely to be realized until more sophisticated display units become widely available. A video standard which permits a free choice of at least three colors (one for fixation stimulus, one for target stimulus, and one for background) from a large palette at high resolution is an essential prerequisite. Also, if needs to be noted that monitors with glass-fronted screens have an inherent disadvantage which can compromise their effective use in some circumstances.

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