Some Time Factors in Stereopsis

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Prepared Under Contract No. NAS 9-8224

Indiana University
Division of Optometry
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For Manned Spacecraft Center, Houston, Texas
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NASA CR 102108

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The effect of monocular changes in the retinal illuminance on the threshold of stereopsis

Introduction:

It has been shown that stereopsis is at least partially a time dependent phenomenon. The encoded messages from the two retinal image points in each eye must start at nearly identical times in order to allow an accurate perception of depth. According to Ogle, 1963, and Wist and Gogel, 1966, as the time between the presentation of the two images of a stereo pair is increased, the threshold of stereopsis increases. The presentation of the two images can be separated in time about 150 milliseconds before the stereoscopic threshold becomes quite large and judgments based on stereopsis become quite unreliable. Further, Bower, 1966, has indicated that a small difference in latency, and therefore, "arrival time", encodes the information which allows the discrimination of crossed disparity from uncrossed disparity. That is to say, the angular separation of a point located beyond the horopter (uncrossed disparity) is identical to the angular separation of a point located at an equal angular displacement in front of the horopter (crossed disparity). Therefore, the angular disparity arising from these two points would be identical and the judgments of relative position ambiguous. Since angular disparity is a sufficient stimulus with respect to the identification of target location, then some means of discrimination of crossed from uncrossed disparity must be added to the information provided by angular disparity.

In the Pulfrich stereoscopic phenomenon an object moving with a constant angular velocity in the objective frontoparallel plane appears to describe a displaced path. The effect is induced in normal observers by reducing the retinal illuminance in one of the two eyes. Lit, 1949, has shown that the effect results from the fact that reducing the retinal illuminance increases the reaction time or latency.

While the Pulfrich effect depends upon the perception of a moving object as in two disparate locations, the disparity being introduced by the monocular reduction in retinal illuminance, monocular alterations of retinal illuminance do not alter depth sensitivity for bright stationary targets. Charnwood, 1950, Gillot, 1958, and Ogle and Groch, 1956, could not measure a decrease in stereoscopic sensitivity by reducing the monocular retinal illuminance while using exposure times of no shorter than 200 milliseconds. Lit, 1959, however, found reductions in stereoscopic sensitivity using dark targets on a light surround and presenting the targets for continuous viewing when the retinal illuminance was between -2.34 and -0.60 log trolands. At higher levels of retinal illuminance the effect was greatly reduced.

Nevertheless, if the exposure time is greatly reduced, then some alteration of stereoscopic sensitivity for bright targets on a darker surround should be easily measured, because changes in monocular illuminance change latency which "delays" the image and because, as Wist and Gogel and Ogle found, delaying the presentation of one image with respect to the presentation of the other causes a decrement in the precision with which subjects can make stereoscopic judgments.

General description of the apparatus:

A schematic representation of the apparatus is illustrated in Figure 1. Each component is labeled with a letter which is explained below. Test targets and standard targets are designated by T_1, T_2, T_3, and T_4. The configuration of these targets is shown in Figure 2. The subject was positioned flat on his back with his head supported by sand-bags. He looked into a 30 cm by 30 cm semi-silvered mirror, which

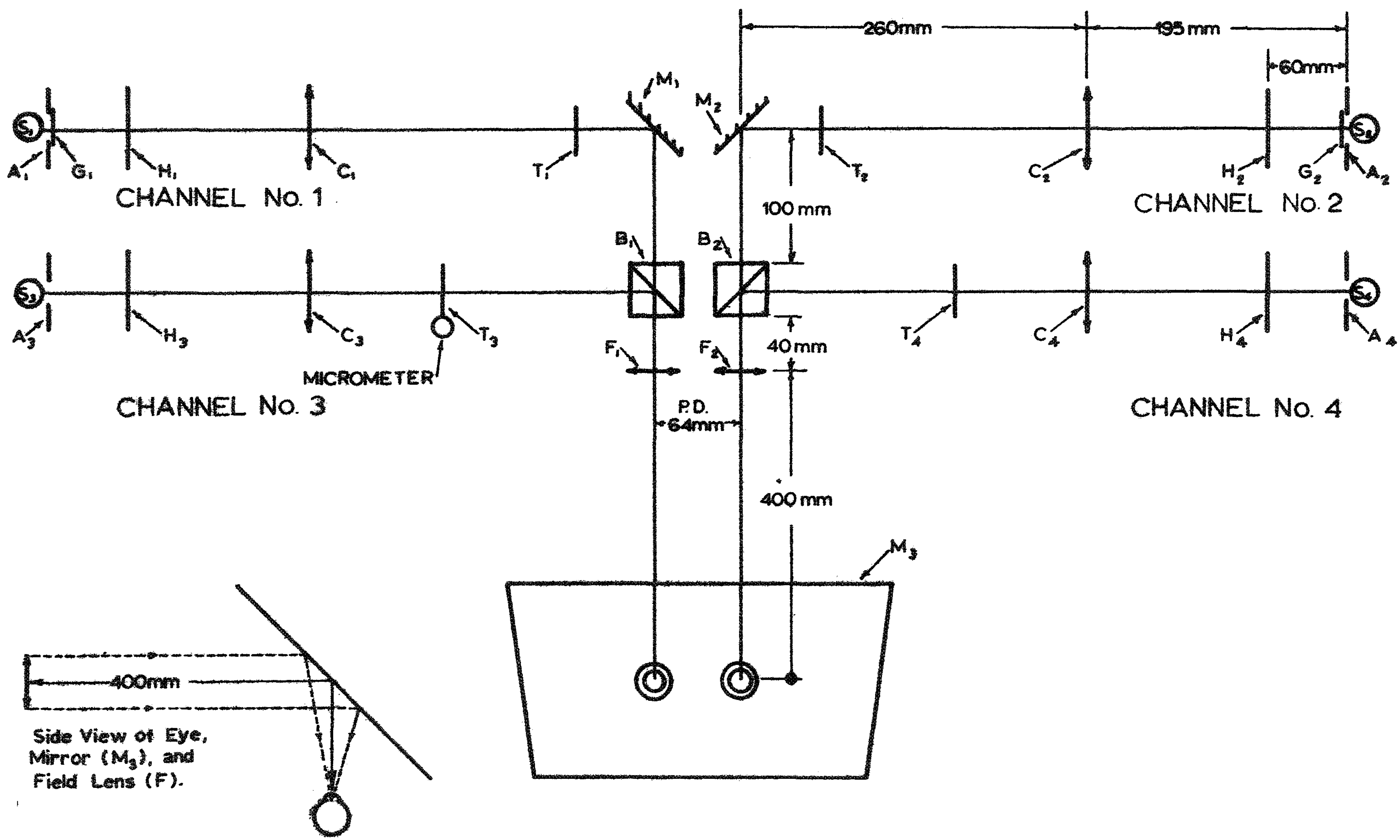
260mm
195 mm
60mm
M1
M2
S1
A1
G1
H1
C1
T1
T2
C2
H2
G2
A2
S2
CHANNEL No. 1
CHANNEL No. 2
100 mm
B1
B2
S3
A3
H3
C3
T3
MICROMETER
T4
C4
H4
A4
S4
40 mm
F1
F2
CHANNEL No. 3
CHANNEL No. 4
P.D.
64mm
400 mm
M3
400mm
Side View of Eye,
Mirror (M3), and
Field Lens (F).

Figure 1.

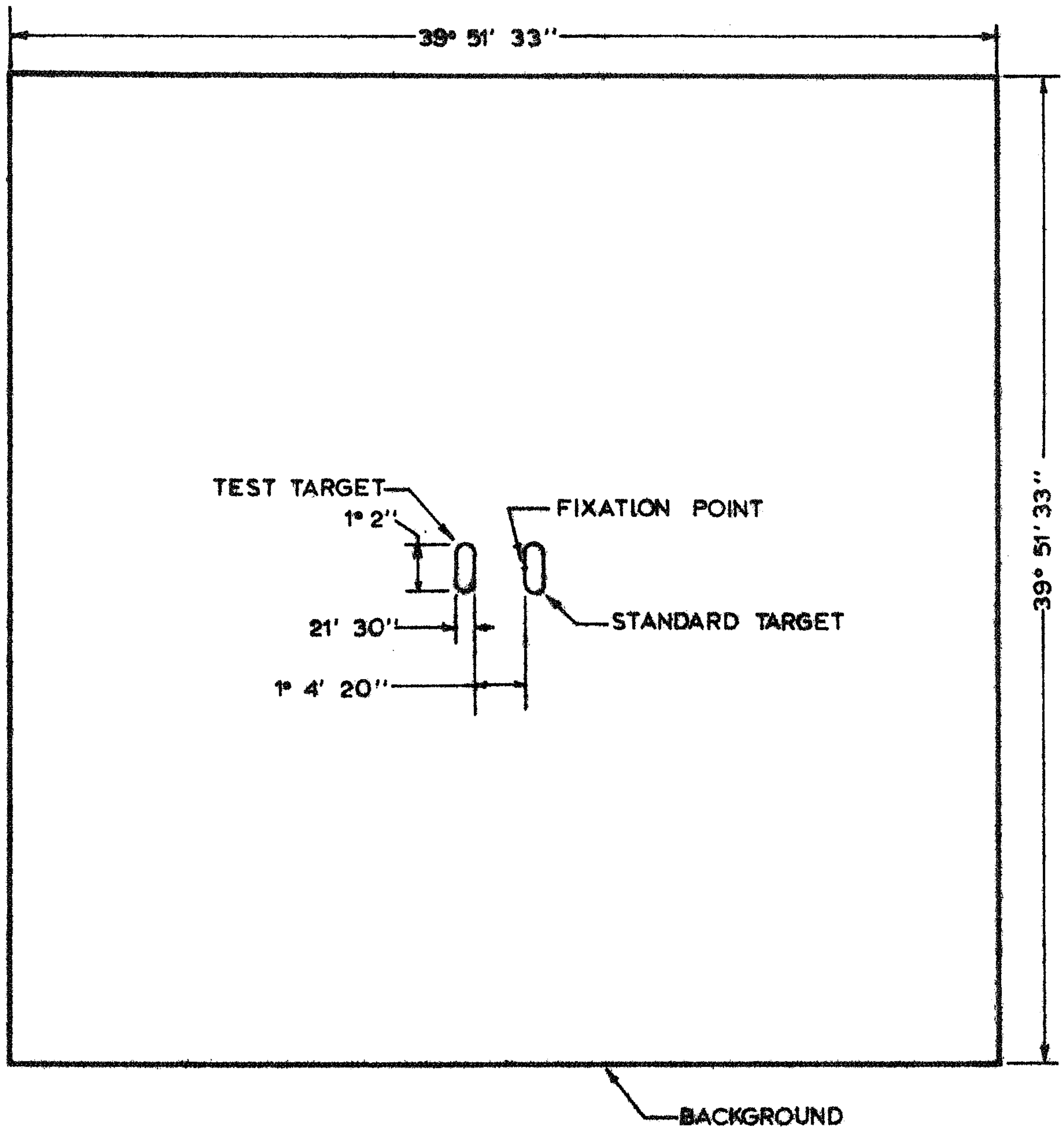
39° 51' 33"
39° 51' 33"
TEST TARGET
1° 2'
FIXATION POINT
STANDARD TARGET
21' 30"
1° 4' 20"
BACKGROUND

Figure 2.

reflected the test and standard targets into the plane of his pupils. Positioned directly behind the mirror was a 29 cm by 29 cm white luminescent panel. He saw a bright standard target (standard target in Figure 2) and, when he pressed a button, he also saw a brief, bright, test target (test target in Figure 2). Both of these targets appeared on a broad background of low, even luminance. His task was to judge the relative depth of the test target with respect to the standard target while fixating a predesignated point on the standard target (fixation point in Figure 2).

In order to study the effects of monocular changes in retinal illuminance independent of fluctuations in pupil size, a four optical channel Maxwellian view haploscopic device was used. Optical channel 1 presented the standard target to the right eye; optical channel 2 presented the standard target to the left eye; optical channel 3 presented the test target to the right eye, and optical channel 4 presented the test target to the left eye. In each optical channel, light from a source (S in Figure 1) passed through a circular aperture (A in Figure 1), was attenuated by a filter (H in Figure 1), and collimated by an achromatic lens (C in Figure 1). Filters H_1 and H_2 were a combination of neutral density filters and different color filters to balance the luminance of the sources and to match the color of all targets used. Emerging from C_1 and C_2, the beams of light illuminating standard targets T_1 and T_2 were subsequently reflected 90 degrees by front surface mirrors M_1 and M_2. Then they passed through beamsplitters B_1 and B_2, objective lens systems F_1 and F_2, semi-silvered mirror M_3, and were brought to foci in the subject's pupils.

S_3 and S_4 were glow modulator tubes emitting single pulses of light which passed through circular apertures A_3 and A_4 and neutral density multiple-step filters H_3 and H_4 illuminating targets T_3 and T_4.

Target T_3 was mounted on a modified microscope stage which allowed lateral movements to produce changes in disparity of the test target. Attached to this was a dial-gauge. The units of this gauge were calibrated into seconds of arc. A change of one unit on the gauge was equal to 7 seconds of arc.

The targets were matched in brightness, hue, and saturation and produced a maximum retinal illuminance of 3.36×10^5 trolands. Table I presents the retinal illuminance produced for each neutral density step inserted into the beam. The luminescent panel provided an adapting field of 39 degrees 51 minutes 33 seconds with a retinal illuminance of 7.26×10^5 trolands, assuming a 3 mm pupil diameter.

Each target subtended an angle of 21 minutes 30 seconds and an average separation of the test and standard targets of 1 degree 4 minutes 20 seconds was utilized.

Experimental Procedure:

Using a five millisecond exposure time, five retinal illuminance combinations were used in a random order to measure the stereoscopic threshold on three subjects. Table II presents the retinal illuminance of each test target used and the log ratio of retinal illuminance ($\log E_r/E_1$) for each of the five conditions. The standard target was maintained at a retinal illuminance of 2.05×10^5 trolands throughout the study.

Two of the three subjects (S.M.V. and E.R.T.) were given approximately one-half hour of training at making stereoscopic judgments on the apparatus. The third subject (T.S.T.) was extensively trained while serving as the subject of other studies in connection with this topic.

The method of constant stimuli, as described by Hirsch and Weymouth, 1948, was used. However, instead of determining the one-hundred per cent

Table I

Step	Diffuse Density (D)	Transmission (T)	Retinal Illuminance (E) (in trolands)
1	.05	.88	2.96×10^5
2	.21	.61	2.05×10^5
3	.36	.43	1.44×10^5
4	.51	.31	1.04×10^5
5	.66	.21	0.71×10^5
6	.82	.15	0.50×10^5
7	.97	.10	0.34×10^5

Table II

E_r	E_1	Log E_r/E_1
Illuminance presented to right eye in trolands	Illuminance presented to left eye in trolands	Log E_r/E_1 Designation
2.05×10^5	2.05×10^5	0.00
2.05×10^5	1.04×10^5	0.29
2.05×10^5	0.71×10^5	0.46
2.05×10^5	0.34×10^5	0.78
1.04×10^5	2.05×10^5	-0.29
0.71×10^5	2.05×10^5	-0.46
0.34×10^5	2.05×10^5	-0.78

response limits for each threshold, six convenient disparity settings were chosen from preliminary estimates of the largest threshold to be encountered and used throughout the experiment. Forty responses were recorded for each of the subjects at each of these six settings for each of the five retinal illuminance combinations. Computer generated response curves were used to check the accuracy of the technique. These sets of hypothetical responses indicate that the threshold of stereopsis can be measured by this technique with an accuracy of plus or minus 10 seconds of arc.

Each threshold determination is based on 240 responses. Each response consisted of a forced choice judgment as to whether the test target was located "closer than" or "farther than" the standard target.

Per cent responses for each of the six disparity settings were transformed into probits, plotted, and the best fit straight line determined by inspection and checked by the method of least squares. The reciprocal of the slope of the best fit line is an estimate of the threshold.

Results:

Figure 3 presents the threshold of stereopsis in seconds of arc as a function of the log ratio of the retinal illuminance of the images presented to the two eyes for each of the three subjects.

Clearly, dimming one image of the test target causes a reduction in sensitivity to small displacements in depth measured by the stereoscopic threshold for all three subjects. Sensitivity is defined as the reciprocal of the threshold. Either T.S.T's greater sensitivity to almost all conditions is due to his superior ability to judge depth differences, to his extensive training, or to both.

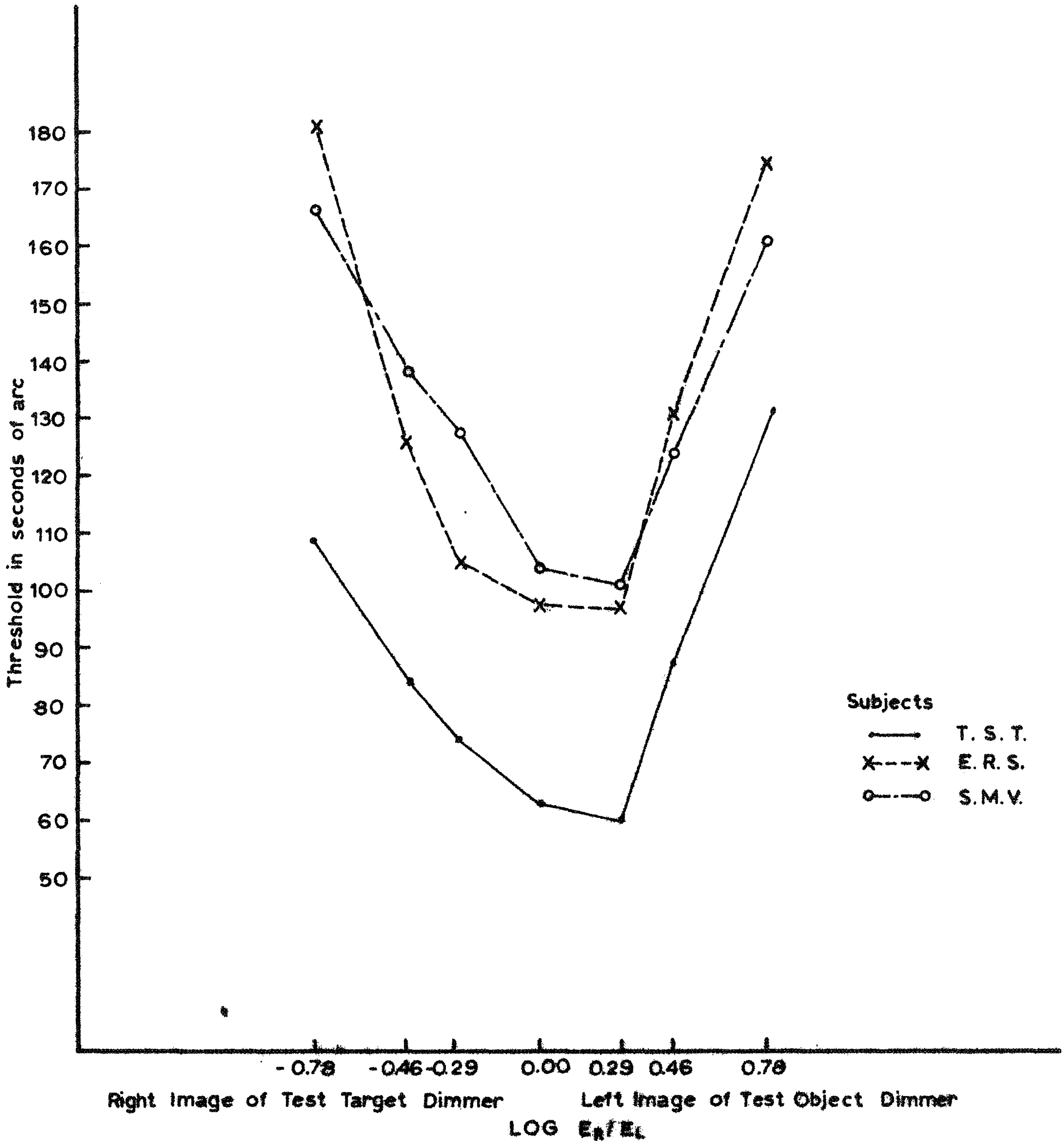
Threshold in seconds of arc
180
170
160
150
140
130
120
110
100
90
80
70
60
50
- 0.78
-0.46
-0.29
0.00
0.29
0.46
0.78
Right Image of Test Target Dimmer
Left Image of Test Object Dimmer
LOG E_R/E_L
Subjects
T. S. T.
E. R. S.
S. M. V.

Figure 3.

In order to determine the effect of increasing the exposure time on the degradation of stereopsis with unequal monocular retinal illuminances of the test target, the experiment was repeated on one subject using exposure times of 10, 20, 30, and 40 milliseconds. For pulse widths of greater than 10 milliseconds, the effects reported for 5 millisecond pulses essentially vanished and no systematic variation of the threshold of stereopsis could be measured.

Discussion:

The decrease in stereoscopic sensitivity as measured by the size of the threshold for test conditions in which the right (temporal) image is dimmer than the left (nasal) image can be explained by hypothesizing a longer reaction time for the dimmer images and therefore a subsequent delay in the arrival of the message from this point at the convergence point (or cell) in the central nervous system. The fact that dimming the nasal image slightly so that the difference in retinal illuminance between the temporal and nasal images produced no degradation in sensitivity suggests that there exists an intrinsic reaction time difference between the nasal and temporal hemiretina which can be further reduced by delaying the presentation of the nasal image or by dimming the nasal image without degrading stereoscopic sensitivity.

Assuming an intrinsic difference in the latency of the nasal and temporal hemiretinae, in a similar way, dimming the nasal image would change its latency. However, here, gradual dimming initially produces less of a time gap in the two images, subsequently produces no time gap and eventually produces a situation similar to that described for the dimming of the temporal image. Under these circumstances the stereopsopic threshold should get larger, reach a point where all judgments are reduced to chance, and finally produce a reversal in judgments so that when the target was presented at a disparity where it would normally be seen in front of another target, it would, under these conditions, be seen in back of the other target and vice versa.

The fact that no such reversal was noted suggests that the encoding of the direction of disparity may be a much more complex problem than is suggested by Bower or that the effects of dimming one image in a stereoscopic pair results in an effect which is not totally described as a simple latency difference.

Decreasing the retinal illuminance of the test object produces a measurable increase in the threshold of stereopsis for all illuminance differences used excepting for log E_r/E_1 equal to 0.29. At this latter ratio of retinal illuminances, the threshold is very nearly the same as for the condition of balanced illuminances. Since the various illuminances were carefully measured, and accurately reproduced for each subject, this finding cannot represent a misalignment of the apparatus, but in fact a lack of change in the threshold as a function of this particular difference in retinal illuminance.

An investigation was conducted to assure that this latter finding was not the result of the level of illuminance of the test object used. This investigation showed no appreciable change in the stereoscopic threshold occurred as the retinal illuminance was reduced to 0.34×10^5 trolands in each eye, using one subject.

The quantitative relationships indicated in Figure 3 requires some qualification. At large luminance differences the linearity of the probit plot can be seriously questioned. Perhaps methodological refinements which include a strict determination of the 100 per cent responses limits and subsequent presentation of the stimuli at equal intervals within this limit or which utilize two single forced choice experiments with equal probability that the target will appear in crossed and uncrossed disparity and the establishment of some constant reward or pay-off factor may allow a rectification of these particular results and therefore a more accurate assessment of these quantities. Nevertheless, stereopsis is substantially reduced by these particular conditions. It is only a question of to what degree that is subject to some uncertainty.

The effects of monocular changes in the retinal illuminance and delay time on the threshold of stereopsis

Introduction:

If the effects measured in the experiment in which the retinal illuminance of the test object presented to one eye is reduced are due to simple differences in the latency of the two images, then by delaying one or the other image, the effects of illuminance should cancel out and stereopsis should return to the sensitivity measured for equal monocular retinal illuminances and for presentation of the two images simultaneously.

Method:

In order to test this hypothesis, the threshold of stereopsis (the dependent variable) was measured with both retinal illuminance and delay time as the independent variables. Dealy times of 10, 20, and 30 milliseconds were provided by timing the current pulses to the glow modulator tubes (see appendix). Since a pulse duration of 5 milliseconds was used, a delay time of 10 milliseconds means that 5 milliseconds elapsed between the offset of the first pulse and the onset of the second pulse (called hereafter the interstimulus interval or I.S.I.). Similarly for 20 milliseconds of delay, an interval of 15 milliseconds occurred between the end of the early pulse and the start of the late pulse (I.S.I. equals 15 milliseconds). The I.S.I. was 25 milliseconds for a delay time of 30 milliseconds. For three of the conditions using these I.S.I.s, the early pulse was presented to the right eye and for three of the conditions, the early pulse was presented to the left eye. The remaining condition consisted of presenting the two pulses simultaneously. Each of the retinal illuminance conditions previously used and each of the aforementioned I.S.I.s were presented in a random order, making a total of 49 separate threshold determinations.

The technique of measuring each threshold of stereopsis was as previously described. One subject was used for this lengthy investigation which consisted of 8,400 judgments of test target location relative to the standard target and took over two months to accomplish.

Results:

Figure 4 illustrates the threshold of stereopsis determined for each of seven ratios of retinal illuminances and each of seven presentation sequences. The presentation sequences are: left target presented later, using an I.S.I. of 5, 15, and 25 milliseconds, right target presented later using an I.S.I. of 5, 15, and 25 milliseconds, and the simultaneous presentation of the two images (I.S.I. equal to 0). The figure presents the thresholds of stereopsis in seconds of arc as a function of the I.S.I. in log milliseconds. The parameter is the log ratio of retinal illuminance.

Discussion:

For the condition in which the retinal illuminance of the two images is balanced (Log E_r/E_1 equal to 0.00) the effects of delaying either the right or left image produce a relatively systematic increase in the threshold of stereopsis. At delay times greater than about 40 milliseconds, the two images are perceived at distinctly different times and an apparent motion between the two targets changes in both magnitude and direction as a function of the geometric disparity of the targets. Since an observer could unwittingly judge target location on the basis of this apparent motion rather than on retinal disparity, no time delays of greater than about 30 milliseconds could be used.

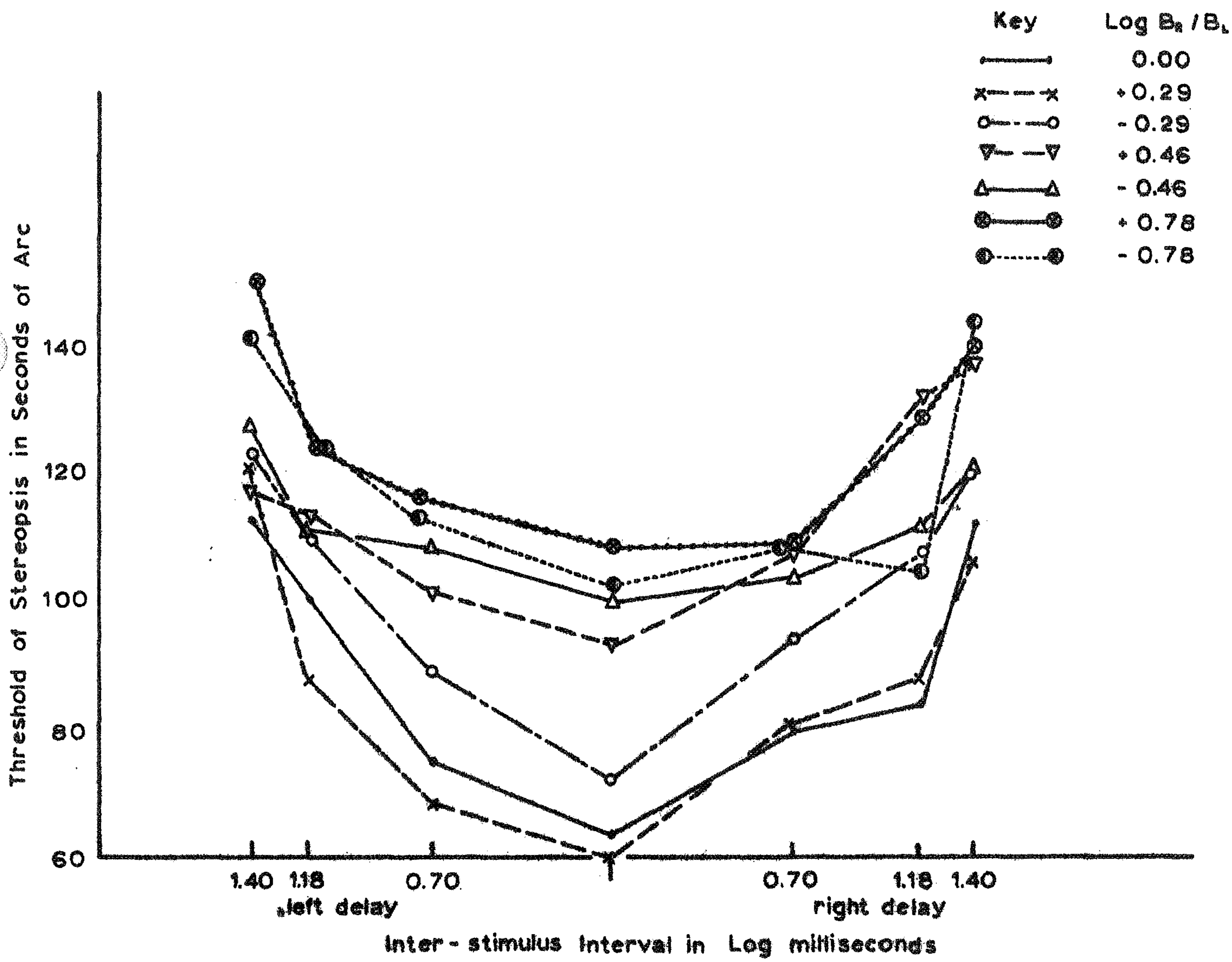
Key
Log B_R / B_L
0.00
+0.29
-0.29
+0.46
-0.46
+0.78
-0.78
Threshold of Stereopsis in Seconds of Arc
140
120
100
80
60
1.40
1.18
0.70
0.70
1.18
1.40
left delay
right delay
Inter-stimulus Interval in Log milliseconds

Figure 4.

The figure shows that the threshold of stereopsis increases with increased I.S.I. regardless of whether the right or left image is delayed and regardless of whether the right or left image is presented at a lower illuminance than the other image.

The only illuminance condition which does not produce an increase in the threshold of stereopsis is Log E_r/E_l equal to +0.29. For this condition, delaying either the right or left image produces no significant change in threshold from the condition of balanced illuminances (Log E_r/E_l equal to 0.00). Since reducing the retinal illuminances should have the effect of increasing the latency, then additional delays in this image introduced by its presentation at a later time than the presentation of the other image should have an effect similar to further lengthening of the delay time. Because the data did not conform to this scheme, the simple equivalence of alterations of retinal illuminance and latency has to be seriously questioned.

In terms of electrophysiological studies of single cell recordings, reducing the retinal illuminance of a single pulse of light produces two effects: an increase in the latency and a decrease in the total number of spikes of electrical activity. The data presented here seem to indicate that stereopsis is dependent on both of these effects. The general trend of the data indicates that reductions in monocular illuminance coupled with various delay times produce higher thresholds of stereopsis.

The only variance with this description is for thresholds measured for Log E_r/E_l equal to 0.29. Here, since dimming the left image while delaying either the left or right image produces no essential change in the threshold, it can be hypothesized that the left image produces a sensation of greater magnitude than the sensation produced by the right image. A slight reduction in the illuminance of the left image does not alter this situation sufficiently to effect the threshold.

A report of attempts to measure the threshold
of stereopsis on an amblyopic subject

In order to facilitate data taking on a number of subjects, the apparatus was modified (see Figure 5). Both achromatic lenses (C_1, C_2, C_3, and C_4) and targets (T_1, T_2, T_3, T_4) were removed. S_1 and S_2 were replaced by glow tube modulators. Each glow tube modulator (S_1, S_2, S_3, and S_4) was masked off with electrician's tape except a 4 mm diameter circular aperture in the center which served as the target. Front surface mirrors M_1 and M_2 were substituted by beamsplitters B_3 and B_4. An additional optical bench was also used. S_5 and S_6 were incandescent light sources formerly designated as S_1 and S_2. Beams of light illuminated targets T_5 and T_6 which were 1 mm diameter transparent circles on an opaque background made from photographic negatives. T_5 and T_6 served as fixation targets of the right and left eyes respectively. They were mounted on microscope stages to allow lateral movements. Emerging from T_5 and T_6, the beams of light were reflected 90 degrees by front surface mirrors M_1 and M_2 and then passed through B_3, B_4, and B_1, B_2. All targets were imaged at infinity.

The subject wore a trial frame with his distance ametropia corrected by trial lenses. Two artificial pupils of 3 mm in diameter were centered in the cells of the trial frame. To eliminate gross head movements during the experiment, the subject was required to use a mouth bite made of impression compound.

An electro-mechanical servo-system was attached to S_4 so that disparity changes could be introduced by the subject upon moving a knob with his right hand.

The subject was instructed to look at the fixation target. When he pushed a button with his left hand, he briefly saw two bright circular targets. His task was to judge the relative depth of the testing target

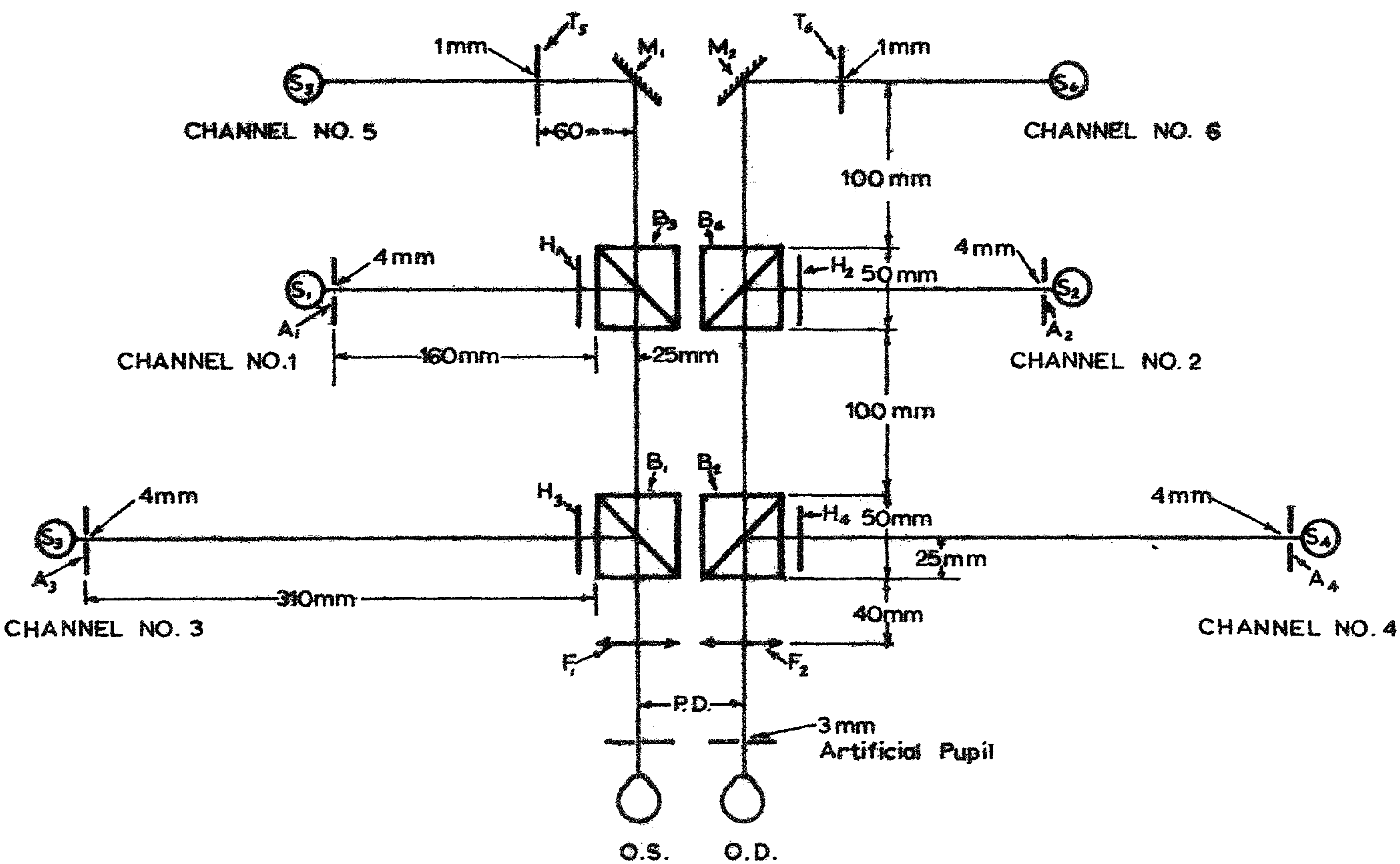
1mm
T5
M1
M2
T6
1mm
CHANNEL NO. 5
60mm
CHANNEL NO. 6
100 mm
B3
B4
H1
4mm
H2
50mm
4mm
A1
A2
CHANNEL NO.1
160mm
25mm
CHANNEL NO. 2
100 mm
B1
B2
4mm
H3
H4
50mm
4mm
25mm
A3
A4
310mm
CHANNEL NO. 3
40mm
CHANNEL NO. 4
F1
F2
P.D.
3mm
Artificial Pupil
O.S.
O.D.

Figure 5.

with respect to the standard target and the fixation target. He moved the dial of the electro-mechanical servo-system clockwise and counter-clockwise until the standard and test targets and the fixation target all appeared to be equally distant from him. This was termed as "an equality setting". Five such equality settings were made by the subject with equal luminance and zero delay time in the two eyes. The micrometer gauge was then moved to the mean position of the previous five equality settings with the numerical value 5 on the dial calibrated to represent a convergence angle of 11 degrees 16 minutes. Once this was determined, different combinations of delay time and luminance were presented to the subject. For each of these conditions, the subject made 5 equality settings. After each setting the experimenter moved the targets to a different disparity.

An amblyope served as the subject in this modified apparatus. The clinical description of the subject's visual status is as follows:

subject: R.R.
male, age 29, technician
subject has been wearing glasses since 1955
glasses prescribed for hyperopic anisometropia
R.E. +1.00 D.S. L.E. +3.50/-2.50 x 175
unaided visual acuity: R.E. 20/20 L.E. 20/80
corrected visual acuity: R.E. 20/15 L.E. 20/25-
lateral phoria findings: at distance 5 eso, at 40 cm . 4 exo
lateral duction findings:
at distance B.I. 0/8/4 B.O. 16/30/12
at 40 cm B.I. 15/18/6 B.O. 14/20/12
P.D. 70/66
ophthalmoscopy: negative

Out of 25 predetermined stimulus conditions of different combinations of delay time and luminance, only 5 sets of findings were available. The conditions actually used were shown in the following table.

Condition	Delay in millisecond (R/L)	Relative Luminance (B_R/B_L)
1	0/0	1/1
2	0/0	.32/1
3	0/0	1/.32
4	20/0	1/.32
5	0/20	.32/1

The range of variability in stereoscopic threshold findings of each of these 5 sets of conditions exceeded 20 minutes of arc. It was clearly beyond the range tolerable under our experimental condition. The response from the subject after these 5 sets of findings was that he could no longer fuse the fixation targets. The failure to do so might be attributed to the following two factors:

1. Low base in fusional limits at distance.
2. Low attention span of the subject.

In spite of the failure, further attempts to elicit stereoscopic thresholds from amblyopic subjects with the modified apparatus seems to be promising. However, before attempting to do so, more subjects with normal vision are required in order to determine the reliability and validity of the modifications.

Conclusions:

Measurement of the threshold of stereopsis under conditions in which the monocular retinal illuminance of the test target is altered indicate that the threshold increases as a function of the dimming of a monocular image regardless of which eye receives the less bright image. Only when the image of the test target presented to the left eye is dimmed from 2.05×10^5 to 1.04×10^5 trolands while the right image is maintained at 2.05×10^5 trolands is the threshold of stereopsis unaltered. The lack of change in threshold at this point is interpreted to mean that either the left (nasal) image has an intrinsically shorter latency or that the response initiated in the left (nasal) image elicites a larger subjective response than does the right (temporal) image.

The data suffer from sufficiently large variation to make any conclusive statements about the effects studied. However, it is suggested that both latency and magnitude of response must be important in encoding information about the external world which leads to the perception known as stereopsis.

Measurements attempted on an amblyopic subject proved totally unreliable due to the rather gross form of stereopsis encountered in the subject available for testing.

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APPENDIX

Appendix

Detailed Specifications of the Apparatus

Circular apertures and targets:

The diameter of each circular aperture (A_1, A_2, A_3, and A_4) was 4 mm. T_1, T_2, T_3, and T_4 were 7 mm x 2.5 mm apertures using the center hole of single-edged razor blades (Figure 6).

Condensing lens systems:

F_1 and F_2 were two identical condensing lens systems. Each of them composed of an achromatic condensing lens (55 mm in diameter and 335 mm in focal length) and a diverging meniscus lens (55 mm in diameter and 200 mm in focal length). The back vertex focal length of the system was 400 mm. The distance between the optical centers of F_1 and F_2 could be varied according to the interpupillary distance of the observer.

Steptablets:

Two steptablets, H_3 and H_4, with twenty-one steps each were used. They were calibrated by Eastman Kodak Co. (numbers 802 St 347 and 802 St 349). Their diffuse density numbers ranged from .05 (step 1) to 3.08 (step 21). Transforming these numbers into percentages of transmission, they ranged from 90% to 0% respectively. Luminances of T_3 and T_4 could be altered by adjusting to different steps at H_3 and H_4.

Semi-silvered mirror (M_3) and electro-luminescent panel P:

M_3 was placed at an angle of 45 degrees with respect to the lens systems F_1 and F_2 and the spectacle plane of the observer. It was at a distance of 230 mm from the former and 170 mm from the latter. Panel P was visible through M_3. The dimensions of P were 29 cm x 29 cm. It

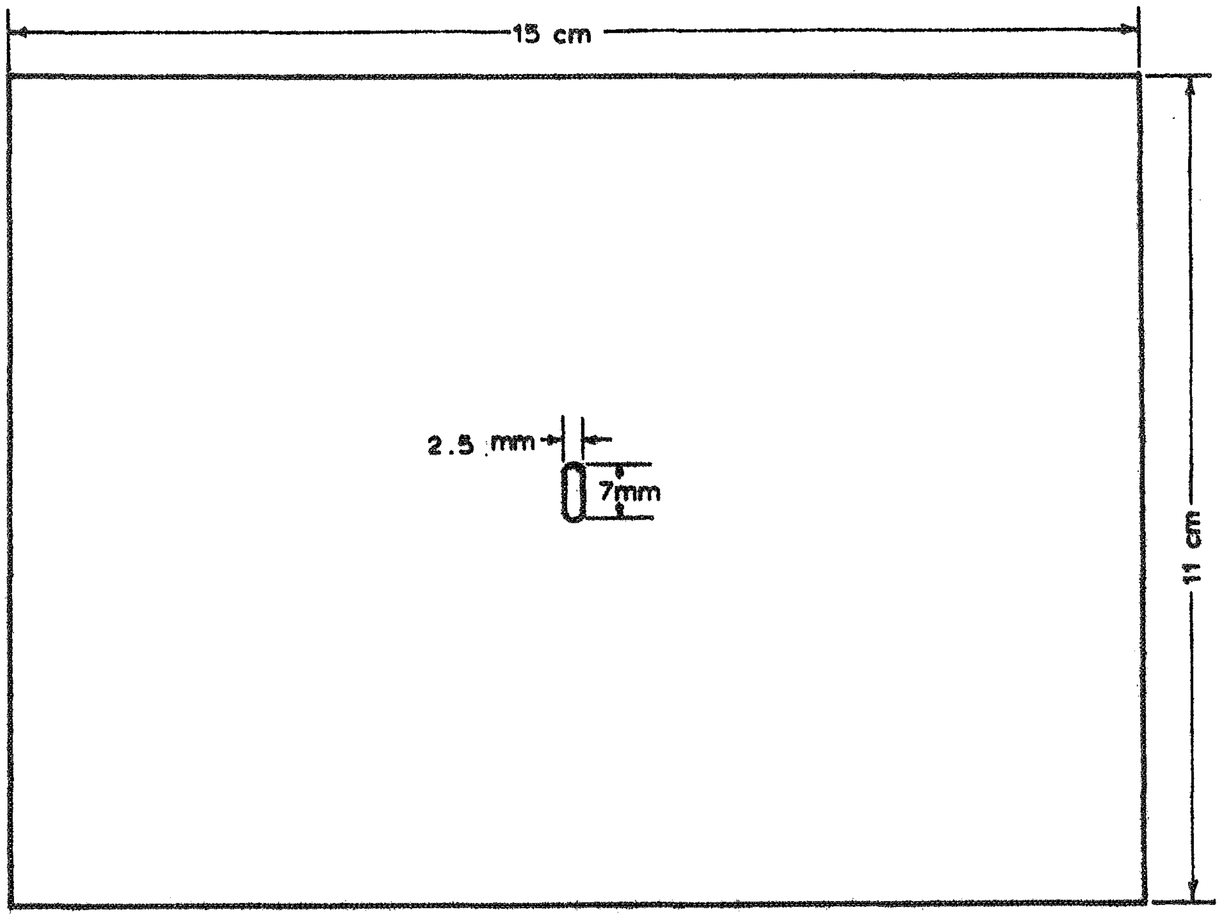

Figure 6.

was white (GE-E-Type F-663) and was connected to a variable transformer operating from a 110 volt A.C. supply. The function of this panel was to act as an uniformly lit adapting field. The subject saw the bright targets on a field of uniform luminance.

Luminance measurements and retinal illuminance values:

Pritchard Spectra Photometer was used to measure the luminance output of the targets and the adapting field. Luminance of the targets was .315 ft. lambert and that of the adapting field was 3 ft. lambert.

By using the following formula (Westheimer, 1966):

$$E = 10^7 \times \bar{B} \times X^2/r$$

where

E = retinal illuminance in trolands

$\bar{B}$ = luminance of the reference surface in millilamberts

X = distance from the reference surface to the plane of the pupil in meters

r = reflectance factor of the reference surface

the retinal illuminance due to the target was calculated to be 3.36×10^5 trolands.

Assuming a 3 mm pupil diameter the retinal illuminance due to the adapting field was calculated to be 7.26 x 10 trolands in terms of the formula below:

$$E'' = 3.1416 \times B \times r^2$$

where

E'' = retinal illuminance in trolands

B = luminance in candles/meter^2

r = radius of the pupil in mm

Although the luminance measurement of the targets was less than that of the adapting field, the retinal illuminance of the former was greater than that of the latter due to the fact that the targets were placed in Maxwellian views and the latter was not.

Electronic components (Figure 7):

Each glow modulator (R1131C) was connected to the pulse generator (type 161A, Tektronix) which was in turn connected to the wave-form generator (type 162, Tektronix) that generated square wave pulses. The output of the glow modulators (S_3 and S_4) was monitored periodically on the oscilloscope by means of photodetectors. Exposure and delay time between S_3 and S_4 ranged from 0 millisecond to 20 milliseconds.

Calibration of disparity between T_3 and T_4 (test targets):

A gauge was attached to T_3. It consisted of 60 equally spaced units. Disparities between T_3 and T_4 could be changed by a knob on the target holder of T_3. Each unit on the micrometer was equal to .0005" which is equivalent to .01270 mm. The angular displacement induced by moving a unit on the micrometer was equal to .01270/400 x 206275 or 6.54923 seconds of arc.

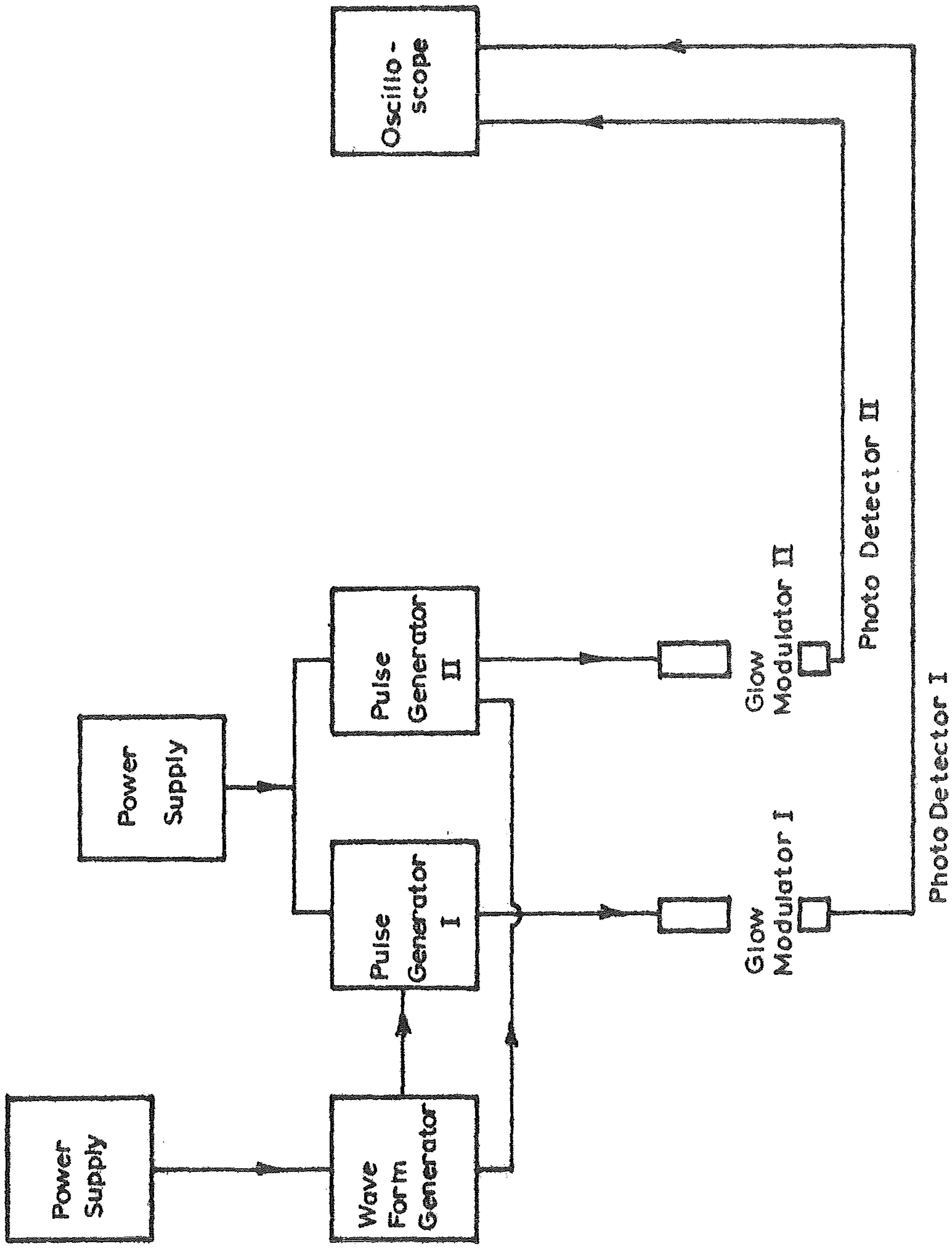
Power Supply
Wave Form Generator
Power Supply
Pulse Generator I
Pulse Generator II
Glow Modulator I
Glow Modulator II
Photo Detector I
Photo Detector II
Oscillo-scope

Figure 7.