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THE UNIVERSITY OF MICHIGAN
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Report of Project MICHIGAN

THE EFFECT OF TARGET VELOCITY IN A FRONTOPARALLEL PLANE ON BINOCULAR SPATIAL LOCALIZATION AT PHOTOPIC ILLUMINANCE LEVELS

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Ann Arbor, Michigan

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PREFACE

Project MICHIGAN is a continuing research and development program for advancing the Army's long-range combat-surveillance and target-acquisition capabilities. The program is carried out by a full-time Willow Run Laboratories staff of specialists in the fields of physics, engineering, mathematics, and psychology, by members of the teaching faculty, by graduate students, and by other research groups and laboratories of The University of Michigan.

The emphasis of the Project is upon basic and applied research in radar, infrared, acoustics, seismics, information processing and display, navigation and guidance for aerial platforms, and systems concepts. Particular attention is given to all-weather, long-range, high-resolution sensory and location techniques, and to evaluations of systems and equipments both through simulation and by means of laboratory and field tests.

Project MICHIGAN was established at The University of Michigan in 1953. It is sponsored by the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps. The Project constitutes a major portion of the diversified program of research conducted by the Willow Run Laboratories in order to make available to government and industry the resources of The University of Michigan and to broaden the educational opportunities for students in the scientific and engineering disciplines.

Progress and results described in reports are continually reassessed by Project MICHIGAN. Comments and suggestions from readers are invited.

The work herein was conducted by the Vision Research Laboratories.

Robert L. Hess
Technical Director
Project MICHIGAN

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ABSTRACT

Binocular settings of equidistance have been obtained in a two-rod test apparatus that provides real-depth cues. The magnitude of the localization error for a black vertical rod which oscillates in a given frontoparallel plane has been studied as a function of target velocity at each of three specified photopic levels of binocular retinal illuminance.

For one observer (F.C.), the oscillating target under all conditions was localized in frontoparallel planes nearer than that defined by the actual distance of the plane of oscillation (negative errors); for the second observer (M.M.), the oscillating target was consistently localized in planes lying beyond the actual plane of oscillation (positive errors). For both observers, however, the absolute magnitude of the localization errors progressively increased as target velocity was increased at each of the three illuminance levels.

Also, illuminance level has an effect on spatial localization. The data for observer M.M. showed that at many target velocities the magnitude of the localization errors increased slightly as level of retinal illuminance was increased. For observer F.C., the absolute magnitude of the localization error at each target velocity decreased markedly as illuminance level was increased. Thus, for both observers, the oscillating rod was localized at increasing distances from the eyes as level of retinal illuminance was increased at a given target velocity.

These new data are discussed in relation to comparable data obtained in earlier experiments on depth settings for stationary targets and on depth settings for oscillating targets viewed under conditions of unequal binocular retinal illuminance (Pulfrich stereophenomenon).

1
INTRODUCTION and SUMMARY

Concerned with an important but relatively neglected aspect of battle area surveillance, this report provides new data for visual theory about the binocular spatial localization of moving stimulus targets. The experiment investigated a localization error that arises when a transversely oscillating target is observed under conditions of equal binocular retinal illuminance. Application of the experimental results to problems of the military surveillance task should lead to more effective operation of binocular optical aids that are utilized for spatial localization of moving battlefield targets.

The present experiment provided new data which demonstrate that spatial localization of a target oscillating in a given frontoparallel plane clearly depends on target velocity: as target velocity is progressively increased, the target appears to be located at increasingly displaced positions either consistently in front of or consistently behind the actual plane of oscillation, depending on the given observer. To a somewhat lesser extent, target localization is also influenced in a systematic way by photopic illuminance level: as the level of binocular retinal illuminance is increased, the oscillating target becomes localized at increasing distances from the observer.

The purpose of the present study was to investigate the effects of target velocity on settings of depth equality obtained under each of several photopic levels of binocular retinal illuminance. The equality settings were performed for a black vertical rod which was made to oscillate in the upper visual field in a frontoparallel plane located 100 cm from the observer's eyes. A second black vertical rod, located in the lower visual field and movable in the observer's median plane, served as a binocular fixation target. In performing these equality settings, the observer was required to move the fixation rod to and fro along his vertical median plane until the rod appeared to be located directly below the path of the oscillating target. Equality settings were made at each of 10 target velocities ranging from 1.49 deg/sec to 39.09 deg/sec as measured at the observer's eyes. The three photopic levels of binocular retinal illuminance used were 2.06, 3.13 and 3.64 log trolands.

Data were obtained from two practiced observers. One observer (F. C.) characteristically localized the oscillating target in a plane nearer than that defined by the actual distance of oscillation (negative localization errors); the other (M. M.), characteristically localized the oscillating target in a plane located beyond the actual distance of oscillation (positive localization errors). Under each of the three given illuminance levels, the absolute magnitude of the localization errors for both observers progressively increased as target velocity was increased. No appreciable localization error for either observer was obtained at the lowest target velocity. At the highest target velocity, the average value of the localization errors for observer F. C. was -1.08 cm, and that for observer M. M. was +1.19 cm. These linear depth-difference values correspond to stereoscopic parallax angles of 140 sec of arc for observer F. C. and 164 sec of arc for observer M. M. Intermediate target velocities gave rise to localization errors of intermediate values.

Also, level of illuminance had an effect on the equality settings. For observer M. M., the data seem to show that an increase in illuminance level slightly increased the localization error at many target velocities. The data for F. C. demonstrate that the absolute magnitude of the localization error decreased markedly as illuminance level was increased at each of the given target velocities. Thus, for both observers, the oscillating rod was localized at increasing distances from the eyes as the level of retinal illuminance was increased.

2
BACKGROUND of the PROBLEM

The present experiment is a direct outgrowth of a continuing research program concerned with an analysis of the major stimulus factors that influence the magnitude of the Pulfrich stereophenomenon. In the Pulfrich situation (Ref. 1) a vertical rod which is oscillating in a frontoparallel plane appears to rotate out of its plane of oscillation when the oscillating rod is binocularly observed under conditions of unequal binocular retinal illuminance. That is, the oscillating rod appears to rotate in a horizontal elliptical path that locates the rod nearer than it really is for one direction of stroke and farther than it really is for the return stroke. The near and far displacements of the oscillating target have been accounted for (Ref. 1) by a difference in the hypothesized visual latent periods of the two eyes that results from the inequality of binocular retinal illuminance. A detailed analysis of the geometric relationships involved in the Pulfrich stereophenomenon has been given in previous reports (Ref. 2-5).

Quantitative data on the magnitude of the localization error that exists for transversely oscillating targets viewed under conditions of equal binocular retinal illuminance were first obtained in connection with some control experiments performed in our earliest studies on the Pulfrich stereophenomenon (Ref. 2, 3). In one study (Ref. 2, pp. 179-180), the control experiment was designed to account for the fact that the near displacements obtained in the Pulfrich situation were consistently larger than the corresponding far displacements. In the second study (Ref. 3, p. 575), the control experiment was designed to account for the fact that for small inequalities of binocular retinal illuminance, the apparent far positions of the oscillating target were frequently located at distances nearer than that defined by the true plane of oscillation, that is, to account for the fact that the apparent elliptical path of the oscillating target was frequently reported to lie completely in front of the actual plane of oscillation. In both studies, the results of the control experiments showed that for all conditions of equal binocular retinal illuminance the oscillating target was characteristically localized in a plane lying in front of the actual plane of oscillation by a depth-difference angle of about 1-2 min of arc. Wölfflin (Ref. 6) had earlier reported the reverse effect in that, for many of his observers, the oscillating target appeared to lie in a plane located beyond the fixation target when the fixation target was placed directly below the actual plane of oscillation. He gave no indication of the magnitude of the localization errors.

The present experiment provides additional quantitative data on localization errors for transversely oscillating targets observed under conditions of equal binocular retinal illuminance. The effect of target velocity is systematically investigated at each of three photopic levels of retinal illuminance.

3
APPARATUS and PROCEDURE

The apparatus[1] used to perform the experiment is shown schematically in Fig. 1(A). A detailed description of each component is available in previous reports (Ref. 3, 4).

The oscillating target (OT) is a blackened steel rod, 1/8 in. in diameter, that is vertically suspended downward to eye level from a Jacobs chuck in which it is retained. The chuck is centrally mounted on the undersurface of a supporting carriage which rides on horizontal tracks (T) located in a frontoparallel plane 100 cm from the observer's eyes. A Zero-Max (Revco, Inc., Model 143) variable-speed transmission device replaced the electrically driven gear train (M) shown in Fig. 1(A). The calibrated transmission device allows adjustments of the linear velocity of the oscillating target over a wide range of specified values.

The fixation target (FT) is identical to the oscillating target in size, color, and form. It is held vertically upright to eye level in a Jacobs chuck that is mounted on the upper surface of a supporting carriage. The supporting carriage rides on a horizontal metal track (J) located below eye level in the observer's vertical median plane. The observer can adjust the position of the fixation target along the calibrated track (J) by means of a pulley-wheel (W) located in the dark room (D). The use of a vernier index permits the experimenter to estimate the distance of the fixation target from the observer's eyes to within 0.01 cm. When the oscillating target is at a position directly above the fixation target, that is, midway between the end-points of its swing, the targets appear contiguous in the observer's vertical median plane. At a distance of 100 cm from the observer's eyes, the diameter of each rod subtends a visual angle of 10.9 min of arc.

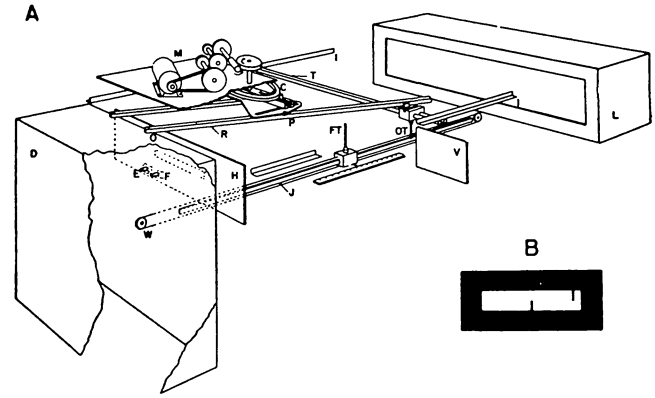

FIG. 1 THE APPARATUS. (A) Schematic Representation. The observer is seated in a dark room (D) and binocularly observes the fixation target (FT) located in the lower visual field and the oscillating target (OT) located in the upper visual field through a pair of artificial pupils (E). Movements of the oscillating target in a frontoparallel plane 100 cm from the observer's eyes can be varied over a wide range of constant linear velocities. The fixation target in the observer's vertical median plane can be moved either towards or away from his eyes by means of a pulley-wheel (W) located in the dark room. Background illumination is provided by a light-box (L). The retinal illuminance of each eye is controlled by neutral density filters placed in the pair of filter boxes (F). Horizontal (H) and vertical (V) screens provide a constant rectangular field of view. (B) View of targets as seen by the observer. The upper rod is the oscillating target; the lower rod is the fixation target. [From Lit and Hyman (Ref. 3).]

Conditions are provided for the observer to be seated in a dark room (D) where he may binocularly observe the oscillating and fixation targets through a pair of circular artificial pupils (E) that are 2.5 mm in diameter and adjustable for interpupillary separation. The artificial pupils are attached to eye-tubes which are mounted on the inner wall of the dark room. The experimenter can control the level of binocular retinal illuminance by pairs of neutral density filters placed in the filter boxes (F). The observer's head is kept immobilized by chin and forehead rests.

Uniform background illumination is provided by a light-box (L) located in a frontoparallel plane 250 cm from the observer's eyes. The illuminated surface is a white-matte screen that is attached to the inner rear wall of the light-box. The surface has a luminance of 854 ft-L as measured with a Macbeth illuminometer. The color temperature at the given lamp voltage (124 v a-c ± 1.0%) is 2735°K. With the 2.5-mm artifical pupil in use, the retinal illuminance without filters is 14,359 trolands, or

[1] The apparatus was originally constructed at Pupin Laboratories, Columbia University, partially through funds from a research grant-in-aid generously provided by the American Academy of Optometry.

4.16 log trolands. Screening units provide the observer with a horizontal rectangular field of view, 21.6° x 4.2°. The view of the targets as seen by the observer is shown in Fig. 1(B).

The observers were the same two as those used in previous experiments (Ref. 4, 5) on the Pulfrich stereoeffect. Both were emmetropic with normal visual acuity. At a fixation distance of 100 cm, the interpupillary separation for observer F. C. was 6.20 cm, and that for observer M. M. was 6.70 cm. At this fixation distance, the phoria for observer F. C. was 3^{Δ} exophoria and that for observer M. M. was 1^{Δ} esophoria.

In performing this type of equality setting, the observer continuously fixates the upper end of the movable fixation rod and adjusts this rod in the vertical median plane until it appears to lie directly below the frontoparallel path of the oscillating target. The apparent plane of oscillation is determined first by having the fixation rod moved away from the observer, and again by having it moved towards the observer. In this way multiple pairs of equality settings can be obtained under any given set of viewing conditions.

It should be mentioned that no Pulfrich stereoeffect was elicited at any given target velocity when filters of equal optical density were placed before the eyes. The optical densities of the three sets of filters used were 0.52, 1.03, and 2.10. Thus, the three photopic levels of binocular retinal illuminance produced were 3.64, 3.13, and 2.06 log trolands.

Equality settings were obtained from both observers at each of 10 target velocities: 2.59, 5.90, 8.16, 13.76, 19.96, 26.86, 35.56, 45.01, 55.53, and 68.17 cm/sec. These values of linear velocity correspond to the following angular velocities: 1.49, 3.38, 4.68, 7.88, 11.44, 15.39, 20.37, 25.78, 31.81, and 39.05 deg/sec.

In a given experimental session, 5 pairs of equality settings (10 readings) were obtained at one illuminance level for each of the 10 target velocities. A total of six experimental sessions was held for each observer. In the first three sessions, target velocity was presented in order of increasing magnitude; in the last three sessions, in order of decreasing magnitude. During the course of the six sessions, the three illuminance levels were presented in a counterbalanced order. This procedure yielded for each observer a total of 20 equality readings for a

TABLE I

DEPTH-DISCRIMINATION DATA

Target Velocity (deg/sec)	Log E (trolands) 2.06		3.13		3.64	
	F.C.	M.M.	F.C.	M.M.	F.C.	M.M.
1.49	-0.06	0.00	-0.05	0.02	-0.02	0.11
3.38	-0.10	0.05	-0.14	-0.03	-0.07	0.18
4.68	-0.17	0.06	-0.11	0.04	-0.03	0.12
7.88	-0.25	-0.01	-0.19	0.03	-0.09	0.11
11.44	-0.50	0.07	-0.29	0.39	-0.13	0.35
15.39	-0.74	0.13	-0.38	0.32	-0.22	0.34
20.37	-0.83	0.49	-0.40	0.49	-0.28	0.61
25.78	-1.07	0.64	-0.83	0.73	-0.40	0.83
31.81	-1.38	0.91	-0.88	0.95	-0.35	0.89
39.05	-1.72	1.09	-1.02	1.18	-0.51	1.29

Binocular localization errors (ΔR) for a vertical rod oscillating in a frontoparallel plane 100 cm from the observer's eyes. The average constant error of two groups of 10 equality settings (20 readings) obtained under each condition of target velocity and retinal illuminance is given in centimeters for each of two observers, F. C. and M. M. A negative value of ΔR indicates that the oscillating target was localized at a distance nearer than that defined by the actual plane of oscillation.

given target velocity under a given level of illuminance.

4
RESULTS

The results obtained from both observers are presented in Table I. Each entry represents the average value of the constant errors of the two sets of 10 equality settings taken under each of the specified conditions of target velocity and retinal illuminance, log E. The constant error for each set of 10 equality readings has been computed from the formula $\Delta R = R_V - R_S$, where R_V represents the mean adjusted distance of the comparison rod and R_S (= 100 cm) represents the distance of the actual plane of oscillation. Thus, ΔR gives in each case the linear magnitude of the localization error. The depth difference is expressed in centimeters.

It can be readily seen from Table I that the direction of the localization errors (that is, the sign of ΔR) is opposite for the two observers. Thus, for observer F. C., the oscillating target is located at a distance consistently nearer than that of the actual plane of oscillation (ΔR is negative) whereas for observer M. M. the apparent plane of oscillation is consistently located beyond the actual plane of oscillation (ΔR is positive).

A graphical representation of the data in Table I is given in Fig. 2. The magnitude of the localization errors is plotted as a function of target velocity, with retinal illuminance, log E, serving as parameter. The curves in Fig. 2 show that, for both observers, no appreciable localization error exists at the lowest target velocity. At the highest target velocity, the localization errors under the three illuminance levels decrease to an average value of -1.08 cm for observer F. C. and increase to an average value of +1.19 cm for observer M. M. Expressed in terms of equivalent stereoscopic parallax angles, η_t, these linear values of ΔR correspond to about 140 sec of arc for observer F. C. and about 164 sec of arc for observer M. M. (See Ref. 7 for details concerning the method of computing the stereoscopic parallax angle, η_t, given the magnitude of the linear depth-difference, ΔR.)

The curves of Fig. 2 demonstrate that illuminance level also has an effect on localization errors. For observer M. M., the effect is slight: ΔR tends

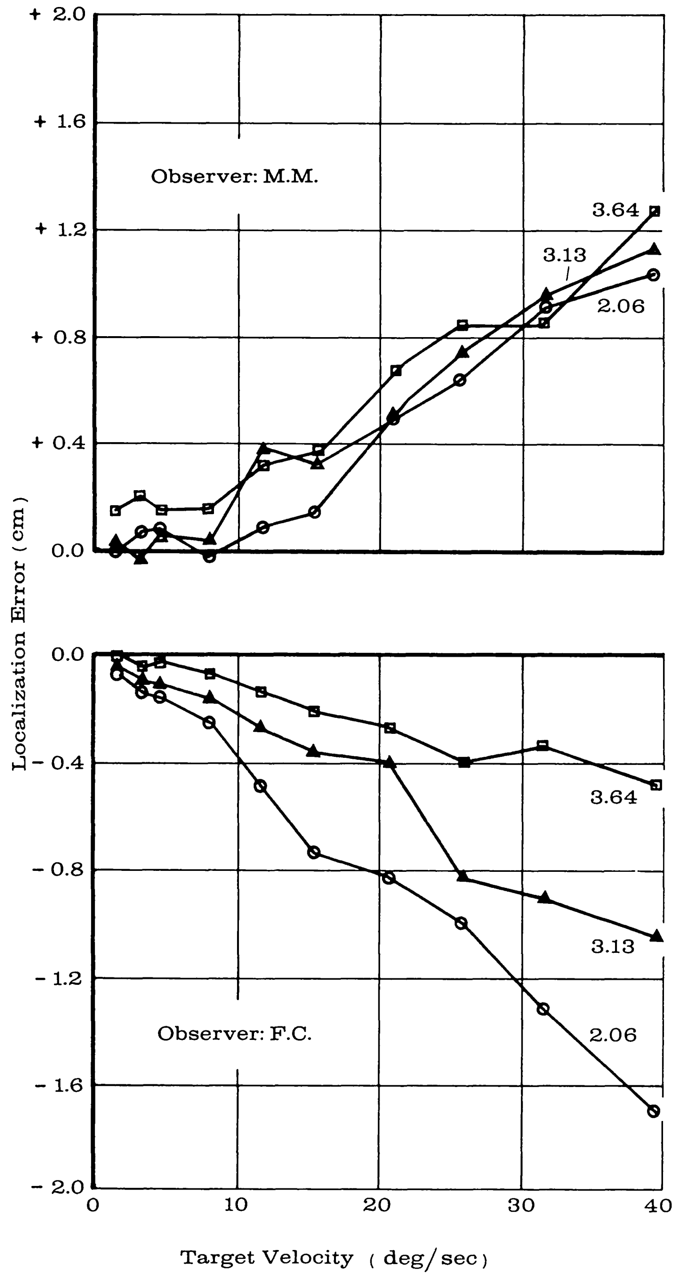

FIG. 2 LOCALIZATION ERRORS. Localization error (in centimeters) as a function of target velocity (in deg/sec). The number accompanying each curve represents the prevailing level of binocular retinal illuminance in log trolands. Each point is based on the average value of the constant errors of two sets of 10 equality settings (20 readings) for a vertical rod oscillating in a frontoparallel plane 100 cm from the observer.

to increase at many target velocities as illuminance level is increased. For observer F. C., $|\Delta R|$ decreases markedly at all target velocities as illuminance level is increased. Thus, for both observers, the oscillating target appears progressively displaced away from the eyes as illuminance level is increased.

5
DISCUSSION

The new data demonstrate that, as target velocity is progressively increased, the target appears to be located at increasingly displaced positions either consistently in front of or consistently behind the actual plane of oscillation, depending on the given observer. Target localization is also influenced in a less systematic way by photopic illuminance level: as the level of binocular retinal illuminance is increased, the oscillating target becomes localized at increasing distances from the observer.

The data for observer F. C. in the present experiment can be related to comparable data for the same observer obtained from previous experiments concerned with depth settings of equality for a stationary stimulus target (Ref. 7, 9). In those experiments, his localization errors for the stationary target were measured at photopic and scotopic levels under conditions of equal and unequal binocular retinal illuminance. Under all conditions, the errors were consistently positive in sign. That is, the stationary target was characteristically localized at distances greater than its actual distance. When, in the present experiment, the target was made to oscillate with increasing velocity in the given frontoparallel plane, the localization errors at all illuminance levels became negative in sign and progressively increased in absolute magnitude. That is, the oscillating target appeared to be located at progressively nearer distances than the actual distance of the plane of oscillation.

It should be stated, however, that level of binocular retinal illuminance had an opposite effect on the localization of the stationary target than it did on the localization of the oscillating target. When the level of retinal illuminance was increased for the oscillating target, it appeared progressively displaced away from the observer's eyes. When the level was increased for the stationary target, it appeared progressively displaced toward the observer. This new finding is important and requires additional experimental verification.

The two observers (F. C. and M. M.) used in the present study also served as observers in experiments on the Pulfrich stereophenomenon (Ref. 4, 5). In the Pulfrich situation, the near and far displacements of the oscillating target in the observer's median plane are each measured from the actual plane of oscillation. Hence, if a localization error exists for the oscillating target when viewed under conditions of equal binocular retinal illuminance, the complete apparent elliptical path of the oscillating target in the Pulfrich situation will be displaced either in a forward or in a backward direction, depending on whether the sign of the localization error is respectively negative or positive. Accordingly, the observed relationship between the magnitude of the corresponding near and far displacements (and of their computed equivalent near and far latency differences) can be expected to depend on the sign of the localization error. Thus, when the localization error is negative (as in the present case for observer F. C.), the near displacements of the oscillating target will be consistently larger than the corresponding far displacements; the computed near latency differences will be larger than, instead of equal to, the corresponding far latency differences. When the localization error is positive (as in the present case for observer M. M.), the near displacements of the oscillating target will now be smaller than the corresponding far displacements; the near latency differences will now be smaller than, instead of equal to, the corresponding far latency differences. Analysis of the results obtained for observers F. C. and M. M. on the Pulfrich stereophenomenon show complete confirmation of this predicted relationship between the relative magnitude of the corresponding near and far displacements and the prevailing sign of the localization error. It should be pointed out, however, that an unexplained residual discrepancy still remained between the magnitude of the corresponding near and far displacements (and of their corresponding computed near and far latency differences) even when the displacements were "corrected" for their respective localization errors, that is, even when the displacements were measured from the position of the apparent plane, rather than that of the actual plane of oscillation. Fortunately, in each of the previous experiments on the Pulfrich stereophenomenon, the magnitude of the localization errors was usually too small, relative to the magnitude of the displacements, to obscure the specific functional relationship being investigated. In all cases, the average of the near and far latency differences, computed on the basis of the corresponding near and far displacements, remained virtually unchanged when the respective displacements were "corrected" for the prevailing localization errors.

Although the localization errors obtained in the present experiment cannot be readily accounted for, it is nonetheless encouraging to have found at least one, and possibly a second, specifiable stimulus variable that exerts a controlling effect on this type of depth setting. It becomes important to perform additional experiments which systematically explore other stimulus factors that might be expected to influence this type of binocular depth discrimination (that is, such factors as stimulus wavelength, luminance difference between target and background, induced ametropia and aniseikonia, etc.). Of particular theoretical interest would be an attempt to relate experimental data on binocular localization of oscillating targets to data obtained under comparable conditions in experiments on fixation disparity and on horopter settings (Ref. 8). The present data on the effect of level of binocular retinal illuminance on depth settings should be extended to cover a wider range of photopic levels, including extension into scotopic levels. Also, a population study should be performed to help account for the fact that the localization errors obtained for different observers are consistently opposite in direction.

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The University of Michigan, Willow Run Laboratories, Ann Arbor, Michigan.

Report of Project MICHIGAN, The Effect of Target Velocity in a Frontoparallel Plane on Binocular Spatial Localization at Photopic Illuminance Levels, Alfred Lit.

Report No. 2900-18-T, April 1959, 10 pp., 2 illus., 1 table, Project 2900 (Contract DA-36-039 SC-78801, DA Project No. 3-58-01-401) UNCLASSIFIED

Binocular settings of equidistance have been obtained in a two-rod test apparatus that provides real-depth cues. The magnitude of the localization error for a black vertical rod which oscillates in a given frontoparallel plane has been studied as a function of target velocity at each of three specified photopic levels of binocular retinal illuminance.

The direction of the localization error was opposite for the two observers used. For both observers, however, the absolute magnitude of the localization errors progressively increased as target velocity was increased at each of the three illuminance levels.

Also, illuminance level has an effect on spatial localization. For both observers, the oscillating rod was localized at increasing distances from the eyes as level or retinal illuminance was increased at a given target velocity.

These new data are discussed in relation to comparable data obtained in earlier experiments on depth settings for stationary targets and on depth settings for oscillating targets viewed under conditions of unequal binocular retinal illuminance (Pulfrich stereophenomenon).

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