JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 50, NUMBER 10 OCTOBER, 1960

# Effect of Target Velocity in a Frontal Plane on Binocular Spatial Localization at Photopic Retinal Illuminance Levels*

Alfred Lit

*Vision Research Laboratories, The University of Michigan, Ann Arbor, Michigan*

(Received June 1, 1959)

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 frontal 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 retinal illuminance 1evels.

Also, retinal illuminance level has an effect on spatial localization. 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

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[1] a vertical rod which is oscillating in a frontal 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[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.[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.[2,3] In one study[2] 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[3] 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[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.

## 2. APPARATUS AND PROCEDURE

The apparatus[7] used to perform the experiment is shown schematically in Fig. 1(a). A detailed description of each component is available in previous reports.[3-5]

The oscillating target (*OT*) is a blackened steel rod, 1/8 in. in diam. It is suspended downward to eye level

---

* This work was conducted by Project Michigan under contract with the department of the Army administered by the U. S. Army Signal Corps.

† Now with Bendix Aviation Corporation, Systems Division, Ann Arbor, Michigan.

[1] C. Pulfrich, *Naturwissenschaften* **10**, 553, 569, 596, 714, 735, 751 (1922).

[2] A. Lit, *Am. J. Psychol.* **62**, 159 - 181 (1949).

[3] A. Lit and A. Hyman, *Am. J. Optom.* **28**, 564 - 580 (1951).

[4] A. Lit, *J. Exptl. Psychol.* **59**, 165 - 175 (1960).

[5] A. Lit, *J. Opt. Soc. Am.* **50**, 321 - 327 (1960).

[7] 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.

[6] E. Wolfflin, *Arch. Augenheilk.* **95,** 167 - 179 (1925).

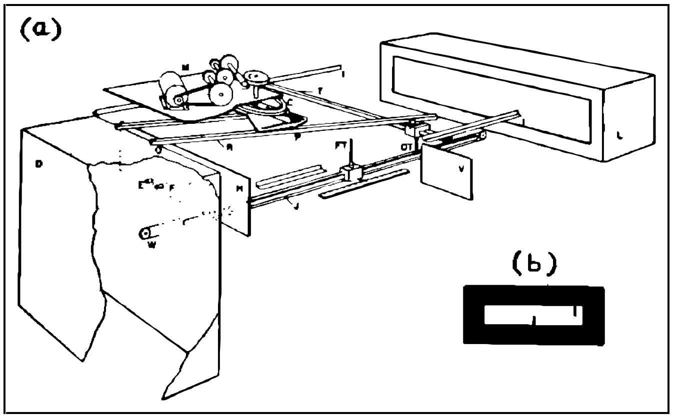

FIG. 1. Schematic representation of the apparatus and observer's view of stimulus targets. (a) The observer is seated in a dark room (*D*) and binocularly observes the fixation target (*FT*) located in the lower visual field and the oscillating target (*OT*) located in the upper visual field through a pair of artificial pupils (*E*). Movement of the oscillating target in a frontal 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 median plane can be moved either toward or away from his eyes by means of a pulley wheel (*W*) located in the dark room. Back- ground illumination is provided by a light-box (*L*). The level of binocular retinal illuminance is controlled by matched 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) The upper rod is the oscillating target; the lower rod is the fixation target. (From Lit and Hyman.[3])

------------------------

from a Jacobs chuck in which it is held. The chuck is mounted on the undersurface of a carriage which rides on horizontal tracks (*T*) located in a frontal 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 carriage rides on a horizontal metal track (*J*) located below eye level in the observer's 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 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.

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 diam 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 matched 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 frontal 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 ac ± 1.0%) is 2735 K. With the 2.5-mm artificial pupil in use, the retinal illuminance without filters is 14 359 trolands, or 4.16 log trolands. Screening units provide the observer with a horizontal rectangular field of view, $21.6^{\circ} \times 4.2^{\circ}$. 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[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 FC was 6.20 cm, and that for observer MM was 6.70 cm. At this fixation distance, the phoria for observer FC was $3^{\text{delta}}$ exophoria and that for observer MM was $1^{\text{delta}}$ 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 median plane until it appears to lie directly below the frontal 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, five pairs of equality settings (10 readings) were obtained at one retinal 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 retinal illuminance levels were presented in a counterbalanced order.

This procedure yielded for each observer a total of 20 equality readings for a given target velocity under a given level of retinal illuminance.

## 3. RESULTS

The results obtained from both observers are presented in Fig. 2. Each data point represents the average value of the constant errors of the two sets of 10 equality settings made by each observer under each of the specified conditions of target velocity and retinal illuminance, logE. 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, $\Delta R$ gives in each case the linear magnitude of the localization error. The depth difference is expressed in centimeters.

It can be readily seen from Fig. 2 that the direction of the localization errors (that is, the sign of $\Delta R$) is opposite for the two observers. Thus, for observer FC, the oscillating target is located at a distance consistently nearer than that of the actual plane of oscillation ($\Delta R$ is negative) whereas for observer MM the apparent plane of oscillation is consistently located beyond the actual plane of oscillation ($\Delta R$ is positive). For both observers, no appreciable localization error exists at the lowest target velocity. At the highest target velocity, the localization errors under the three retinal illuminance levels show an average value of –1.08 cm for observer FC and an average value of +1.19 cm for observer MM. Expressed in terms of equivalent stereoscopic parallax angles, $\eta_t$, the linear values of $|\Delta R|$ correspond to about 140 sec of arc for observer FC and about 164 sec of arc for observer MM (See Lit[8] for details concerning the method of computing the stereoscopic parallax angle $\eta_t$ given the magnitude of the linear depth-difference $\Delta R$).

The curves of Fig. 2 demonstrate that retinal illuminance level also has an effect on localization errors. For observer MM, the effect is slight: $\Delta R$ tends to increase at many target velocities as retinal illuminance level is increased. For observer FC, $|\Delta R|$ decreases markedly at all target velocities as retinal illuminance level is increased. Thus, for both observers, the oscillating target appears progressively displaced away from the eyes as retinal illuminance level is increased.

## 4. 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 level of photopic retinal illuminance: as the level of binocular retinal illuminance is increased, the oscillating target becomes localized at increasing distances from the observer.

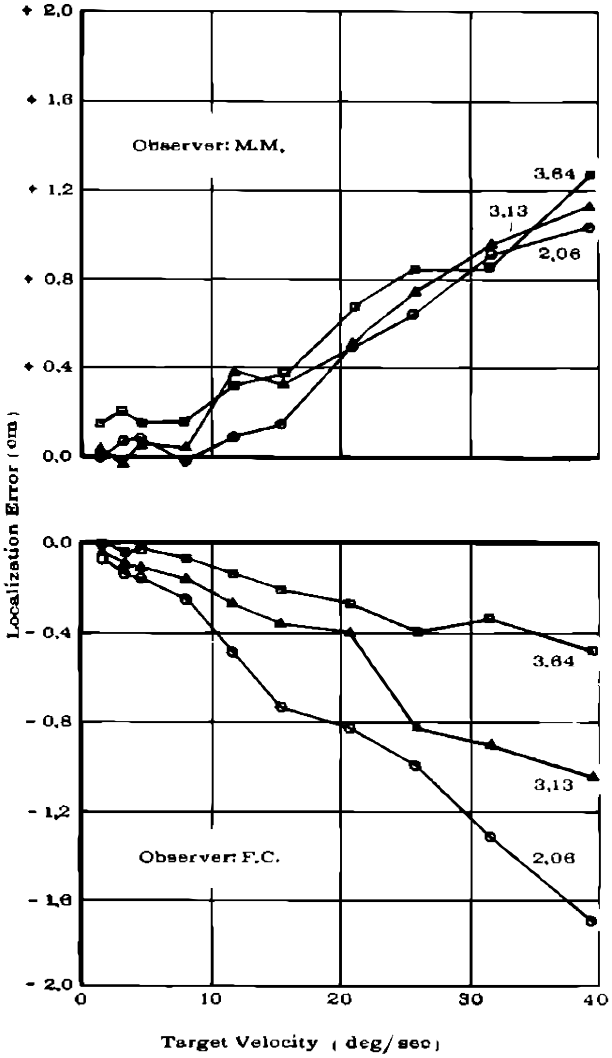

FIG. 2. Localization error (in cm) as a function of target velocity (in deg/sec). The number accompanying each curve represents the prevailing level of binocular retinal illuminance in log trolands.
Each point is based on the average value of the constant errors of two sets of 10 equality settings (20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

The data for observer FC 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.[8,9] 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 is made to oscillate with increasing velocity in the given frontal plane, the localization errors at all retinal illuminance levels become negative in sign and progressively increase in absolute magnitude, that is, the oscillating target appears 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 has an opposite effect on the localization of the stationary target than it does on the localization of the oscillating target. When the level of

---

[8] A. Lit, *J. Opt. Soc. Am.* **49**, 746 (1959).

[9] A. Lit, *J. Exptl. Psychol.* **58**, 476 (1959).

retinal illuminance is increased for the oscillating target, the target appears progressively displaced away from the observer's eyes. When the level is increased for the stationary target, it appears progressively displaced toward the observer. This new finding is important and requires additional experimental verification.

The two observers (FC and MM) used in the present study also served as observers in experiments on the Pulfrich stereophenomenon.[4,5] In the Pulfrich situation, the near and far displacernents 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 should 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) in the Pulfrich situation can be expected to depend on the sign of the localization error obtained under conditions of equal binocular retinal illuminance. Thus, when the localization error is negative (as in the present case for observer FC), 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 MM), 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 FC and MM on the Pulfrich stereophenomenon shows 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 remains between the magnitude of the corresponding near and far displacements (and of their corresponding computed near and far latency differences) even when the displacements are "corrected" for their respective localization errors, that is, even when the displacements are 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, remain virtually unchanged when the respective displacements are "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.[10] 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.

---

[10] K. N. Ogle, *Researches in Binocular Vision* (W. B. Saunders Company, Philadelphia, 1950).