Magnitude of the Pulfrich Stereophenomenon as a Function of Target Thickness*

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When filters of unequal optical density are placed in front of the two eyes, a target which is actually oscillating in a frontoparallel plane appears nearer than it really is for one direction of stroke and farther than it really is for the return stroke (Pulfrich stereophenomenon). Measurements of the near and far displacements of an oscillating black vertical rod are obtained as functions of (a) target thickness, (b) target velocity, and (c) condition of unequal binocular retinal illuminance.

The experimental data show that variation in target thickness has no effect on the magnitude of the apparent near and far displacements. Variations in target velocity and in condition of unequal binocular retinal illuminance produce characteristic effects which are shown to be in good quantitative agreement with geometrical predictions based on the theory of the Pulfrich stereophenomenon. Discrepancies in the magnitude of the displacements at low target velocities are noted and discussed.

INTRODUCTION

THE stereoscopic effect with which the present experiment deals was first described and analyzed by Pulfrich[1] in 1922. A target which is oscillating at eye level in a frontoparallel plane appears to rotate out of its plane of oscillation when a neutral or colored filter is placed in front of one of the observer's eyes. The depth effect becomes noticeable at some threshold difference of binocular retinal illuminance and progressively increases as the difference of binocular retinal illuminance is increased. Pulfrich (following a suggestion by Fertsch) accounted for these depth displacements in terms of a difference in the hypothesized visual latent periods of the two eyes. The visual latent period of each eye was assumed to be a reciprocal function of the prevailing level of retinal illuminance. Thus, the eye covered with the filter presumably "signals" a position of the oscillating target that lags behind the position signaled by the uncovered eye. Hence, at any given moment, synchronous binocular signals are provided by pairs of noncorresponding retinal points in the two eyes, and the magnitude of the stereoeffect theoretically depends on the amount of the retinal disparity produced as a consequence of the difference in the visual latent periods of the two eyes.

A detailed analysis of the geometric relations involved in the Pulfrich stereophenomenon has been given in the previous reports.[2-4] Consider the case shown in Fig. 1 of a target that is oscillating in a frontoparallel plane with constant linear velocity V for the central portion of its stroke. The linear path of the target in its plane of oscillation is denoted by W_1W_2. The distance d of the plane of oscillation is measured from the midpoint of the line Z_LZ_R which joins the centers of rotation of the two eyes. As indicated, the filter is placed in front of the left eye. The point P_F' represents the far position in the vertical median plane at which the oscillating target, at point P_{LR}, is localized by the observer as the target moves from left to right. The point P_N' represents the near position of localization in the vertical median plane when the target, moving from right to left, has reached the point P_{RL}. The distance OP_F' designates the magnitude of the far displacement C_F. The distance OP_N' designates the magnitude of the near displacement C_N.

In accordance with the laws of binocular space discrimination, lines of sight from each eye are drawn through the two respective points of target localization, P_F' and P_N'. The intersection points of the lines of sight with the line W_1W_2 are designated by A and B, and these points theoretically mark the respective positions in the path of the oscillating target at which onset of stimulation occurred in each of the two eyes. Thus, when the target is moving from left to right and appears to be located at the far position P_F' towards which the eyes are converged, the onset of stimulation for the right eye occurs when the target (at P_{LR} in the diagram) is located at point B, and the onset of stimulation for the left eye, covered by the filter, occurs when

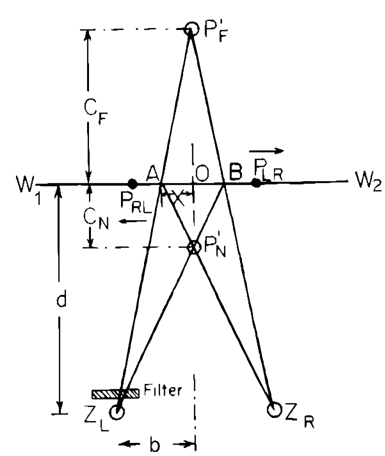

FIG. 1. Geometrical representation of the Pulfrich stereophenomenon indicating the stereoscopic space-image in the horizontal plane of fixation.

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[2]A. Lit, Am. J. Psychol. 62, 1S9 — 181 (1949).
[3]A. Lit and A. Hyman, Am. J. Optom. 28, 564-580 (1951).
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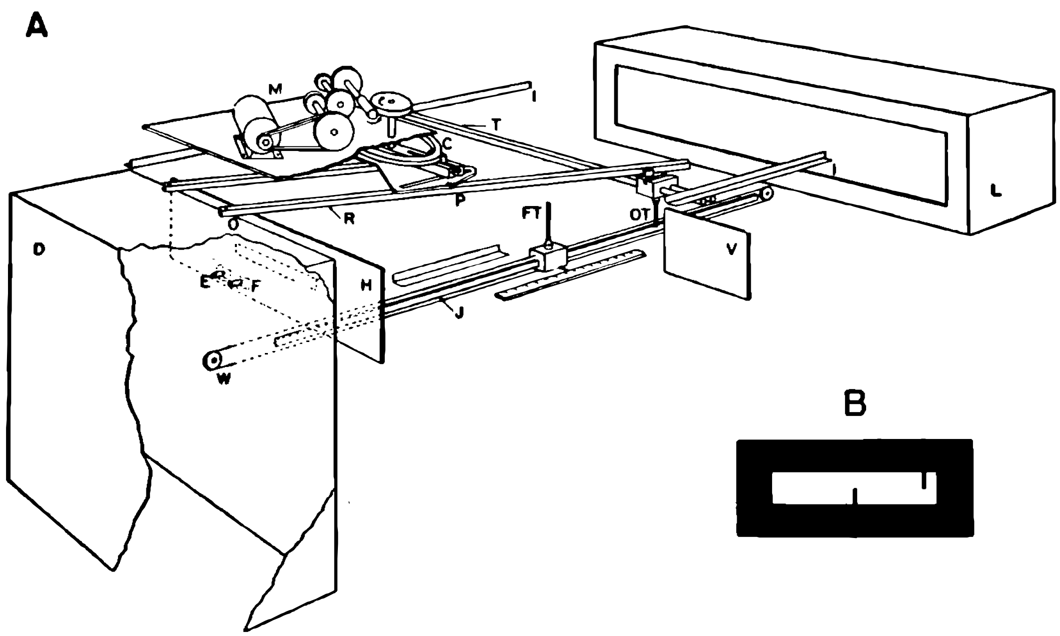

FIG. 2. Schematic representation of the apparatus and observer’s view of stimulus targets. (a) The observer is seated in a dark room (*D*) and binocularly observes the fixation target (*FT*) located in the lower visual field and the oscillating target (*OT*) located in the upper visual field through a pair of artificial pupils (*E*). Movement of the oscillating target in a 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 toward or away from his eyes by means of a pulley-wheel (*W*) located in the dark room. Background illumination is provided by a lightbox (*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) The upper rod is the oscillating target; the lower rod is the fixation target. (From Lit and Hyman.[3])

the target is located at point *A*, a bit farther behind in its path. The time taken for the target to move from *B* to P_{LR} represents the magnitude of the visual latent period of the right eye, and the time taken for the target to move from *A* to P_{LR} represents the slightly longer visual latent period of the left eye. Consequently, the time taken for the target to move from *A* to *B* represents the difference, Δt_F, in the visual latent periods of the two eyes, based on the far position of target localization, P_F’. It follows by the same reasoning that when the target is moving from right to left and appears to be located at the near position, P_N’, towards which the eyes are now converged, the time taken for the target to move from *B* to *A* represents the difference, Δt_N, in the visual latent periods of the two eyes, based on the near position of target localization, P_N’.

It can be readily seen from similar triangles in the diagram (Fig. 1) that for target localizations at PN’ and PF’, respectively:

$$X = bC_N/(d - C_N) \text{ and } X = bC_F/(d - C_F), \quad (1)$$

where X=1/2 the distance from A to B, and b=1/2 the distance between the centers of rotation of the two eyes.

For an oscillating target moving with constant linear velocity V, the time taken for the target to pass through the distance X is given by the formula

$$t = X/V \quad (2)$$

The time taken for the target to move from *A* to *B* (or *B* to *A*) represents the difference, Δt, in the visual latent periods of the two eyes. Since $\Delta t = 2t$, we obtain from Eq. (2)

$$\Delta t = 2X/V . \quad (3)$$

By substituting for *X* the respective expressions given in Eq. (1), we finally obtain the following relationships between the experimentally determined near and far displacements (C_N and C_F) and the corresponding near and far latency differences (Δt_N and Δt_F):

$$\Delta t_N = \frac{2b}{V}\frac{C_N}{d - C_N}$$

and (4)

$$\Delta t_F = \frac{2b}{V}\frac{C_F}{d - C_F} .$$

It should be noted from purely geometric considerations that, for any constant difference of binocular retinal illuminance, the magnitude of the stereoscopic effect as measured by C_N and C_F should progressively increase as the linear velocity of the oscillating target is increased, but the corresponding calculated values of Δt_N and Δt_F should remain constant for all target velocities used.

The present experiment is a continuation of a research program[2-4] designed to obtain systematic data on some of the important stimulus variables that influence the magoitude of the Pulfrich effect. In the present experiment, the effect of variations in target thickness is studied over a wide range of target velocities and under several conditions of unequal binocular retinal illuminaoce.

APPARATUS AND PROCEDURE

A detailed description of the apparatus‡ is available n previous reports[3,4]. A schematic representation of it is given here [Fig. 2(a)].

The observer is seated in a dark room (*D*) and binocularly observes the fixation target (*FT*) and the oscillating target (*OT*) through a pair of circular artificial pupils (*E*) that are 2.5 mm in diam and adjustable for interpupillary separation. A filter box (*F*) is mounted on the outer wall in front of each eye so that the experimenter can control the retinal illuminance of each eye by combinations of neutral density ilters. The observer s head is kept immobilized by chin and forehead rests.

The oscillating target (*OT*) is a blackened steel rod hat is vertically suspended downward to eye level rom a Jacobs chuck in which it is retained. The chuck s centrally mounted on the undersurface of a supporting carriage which rides on horizontal tracks (*T*) oca,ted in a frontal plane at a distance of 100 cm from he observer's eyes. A cam-regulated mechanism[3] produces reciprocating linear velocity, with the central 90% of stroke at constant speed. The electrically driven gear train (*M*) shown was replaced by a Zero-Max Revco, Inc. Model 143) variable speed transmission device to allow adjustments of the linear velocity of he oscillating target over a wide range of 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 located below eye level. By means of a pulley-wheel (*W*) located in the darkroom, the observer can adjust the position of the fixation target along the calibrated metal track (*J*) in the observer's median plane in a direction either towards or away from his eyes. 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.

Uniform background illumination is provided by a lightbox (*L*). 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° x 4.2°. The view of the targets as seen by the observer is shown in Fig. 2(b).

‡ 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.

Two emmetropic graduate students with normal visual acuity and good binocular functioning served as paid observers. The observers were the same as those used in the previous experiment[4] and hence were highly trained in this type of depth-discrimination setting. 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.

In performing this type of depth 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 near and far paths of the upper oscillating target. The apparent near and far positions of the oscillating target are each localized first when the fixation rod is moved away, an again when it is moved towards the observer. In this way, multiple pairs of determinations of CN aod CF can be obtained under aoy given set of viewing conditions.

In the main experimental series, settings for the apparent near and far positions of the oscillating target were obtained from both observers at each of eight arget velocities, *V*: 2.59, 5.90, 8.16, 10.28, 13.76, 19.96, 35.56, and 68.17 cm/sec. For target movement n a frontoparallel plane located 100 cm from the observer's eyes, these values of linear velocity correspond to the following angular velocities: 1.49, 3.38, 4.68, 5.89, 7.88, 11.44, 20.37, 39.05 deg/sec. At each velocity, settings were obtained for stimulus rods of six different diameters: 0.031, 0.050, 0.080, 0.125, 0.230, and 0.460 in. In angular terms, these diameters correspond to the values 2.7, 4.4, 7.0, 10.9, 20.1, and 40.2 min of arc. In a given experimental session only one target thickness was used, and three pairs of settings (six readings each or C_N and C_F) were obtained for each of the eight target velocities, presented always in order of increasing ma.gnitude. A total of 12 experimental sessions was held for each observer. A counterbalanced order was introduced for target thickness. The condition of bioocular retinal illuminance, $\log(E_R/E_L)$, was kept constant at 1.07 by use of a neutral filter of optical density 2.10 placed in front of the left eye and a neutral filter of optical density 1.03 placed in front of the right eye. Thus, the retinal illuminance of the left eye ($\log E_L$) was 2.06 log trolands, and that of the right eye ($\log E_R$) was 3.13 log trolands.

In the auxiliary experimental series, settings were obtained from only one of the observers (M.M.) for three additional conditions of unequal binocular retinal illuminance, $\log(E_R/E_L)$: 0.12, 0.58, and 1.58. The retinal illuminance of the left eye ($\log E_L$) was held constant at 2.06 log trolands while the retinal illuminance of the right eye ($\log E_R$) was successively increased to values of 2.18, 2.64, and 3.64 log trolands. A total of 12 auxiliary experimental sessions was held.

TABLE I. Depth displacements obtained under a given condition of unequal binocular retinal illuminance for six target thicknesses (diameters) and eight target velocities. The retinal illuminance of the left eye is 2.06 log trolands and that of the right eye is 3.13 log trolands. *CN* and *CF* refer, respectively, to the near and far displacements of a target oscillating at the specified linear velocities in a frontoparallel plane located 100 cm from the observer's eyes. Each entry for the two observers (F.C. and M.M.) is based on the mean of 12 settings.

Target velocity (cm/sec)	Observer	0.031 in. C_N (cm)	0.031 in. C_F (cm)	0.050 in. C_N (cm)	0.050 in. C_F (cm)	0.080 in. C_N (cm)	0.080 in. C_F (cm)	0.125 in. C_N (cm)	0.125 in. C_F (cm)	0.230 in. C_N (cm)	0.230 in. C_F (cm)	0.460 in. C_N (cm)	0.460 in. C_F (cm)
2.59	F.C.	0.71	0.47	0.56	0.67	0.64	0.54	0.69	0.57	0.67	0.68	0.52	0.69
	M.M.	0.73	0.68	0.75	0.58	0.72	0.72	0.80	0.76	0.74	0.82	0.74	0.89
5.90	F.C.	1.29	1.01	1.29	1.15	1.30	1.03	1.37	1.17	1.45	1.15	1.34	1.18
	M.M.	1.27	1.22	1.35	1.23	1.26	1.31	1.42	1.49	1.36	1.42	1.49	1.60
8.16	F.C.	1.81	1.22	1.74	1.45	1.77	1.22	1.67	1.36	1.73	1.36	1.70	1.43
	M.M.	1.78	1.66	1.81	1.69	1.64	1.65	1.71	1.67	1.80	1.88	1.76	2.01
10.28	F.C.	2.30	1.58	2.08	1.63	2.13	1.53	2.08	1.52	2.03	1.54	2.31	1.71
	M.M.	2.09	2.01	2.12	1.73	2.12	1.94	2.06	2.01	2.36	2.07	2.31	2.43
13.76	F.C.	2.76	1.88	2.58	1.99	2.68	1.96	2.55	1.84	2.66	1.96	2.69	2.26
	M.M.	3.02	2.49	2.71	2.18	2.46	2.38	2.46	2.37	2.79	2.76	2.88	2.98
19.96	F.C.	4.05	2.40	3.79	2.54	3.74	2.34	3.48	2.55	3.73	2.46	3.47	2.55
	M.M.	3.99	3.59	3.69	3.15	3.49	3.46	3.25	3.03	3.35	3.24	3.81	4.16
35.56	F.C.	6.46	3.37	5.98	4.01	5.79	3.74	5.43	3.68	5.45	3.55	5.70	3.65
	M.M.	5.17	5.32	5.37	6.17	5.07	6.07	4.62	5.35	4.65	6.13	5.07	5.93
68.17	F.C.	11.26	3.67	9.57	6.72	10.21	7.40	9.19	6.29	8.99	6.62	9.42	6.27
	M.M.	6.45	9.08	6.65	11.21	6.50	12.19	5.93	10.09	5.43	12.38	5.75	12.39

In any given session, settings were obtained at each of the eight target velocities used in the main experimental series. For the 6rst group of six auxiliary sessions target thickness was kept constant at 2.7 min of arc; for the second group of six auxiliary sessions target thickness was kept constant at 40.2 min of arc. The three conditions of unequal binocular retinal illuminance were presented in a counterbalanced order in each of the two groups of six auxiliary sessions.

RESULTS

The results of the main experimental series for both observers are presented in Table I. Each entry of C_N and C_F represents the mean value (in centimeters) of the two sets of six readings obtained at each target velocity for each of the specified target diam.

Table I shows that, for any given target velocity, C_N and C_F remain essentially constant as target thickness is increased. Moreover, for each target thickness, C_N and C_F progressively increase as the velocity of the oscillating target is increased. It is also to be noted that the relationship between the respective magnitudes of C_N and C_F differs for the two observers: for observer F.C., the value of C_N is consistently larger than the corresponding value of C_F under each of the conditions of viewing; for observer M.M., the values of C_N are consistently smaller than those of C_F.

When the values of Δt_N and Δt_F, which correspond to each of the depth displacements in Table I, were computed from Eq. (4), the data (not shown here) demonstrate that, for any given target velocity, latency difference is independent of target thickness. It was observed, however, that latency difference is not completely independent of target velocity: for any given target thickness, the values of Δt_N and Δt rise rapidly as target velocity is reduced to low values.

The results of the auxiliary experimental series for observer M.M. are presented in Table Il. Each entry of C_N and C_F is based on the mean value (in centimeters) of the two sets of six readings obtained for the

TABLE II. Depth displacements obtained under three conditions of unequal binocular retinal illuminance, $\log(E_R/E_L)$, for two target thicknesses (diam) and eight target velocities. The retinal illuminance of the left eye, $\log E_L$, is kept constant at 2.06 log trolands. C_N and C_F refer, respectively, to the near and far displacements of a target oscillating in a frontoparallel plane located 100 cm from the observer's eyes. Each entry is based on the mean of 12 settings obtained from observer M.M.

Target velocity (cm/sec)	**Target thickness = 0.031 in.**						**Target thickness =0.460 in.**					
	$\mathrm{Log}(E_R/E_L)$=0.12		$\mathrm{Log}(E_R/E_L)$=0.58		$\mathrm{Log}(E_L/E_R)$=1.58		$\mathrm{Log}(E_L/E_R)$=0.12		$\mathrm{Log}(E_R/E_L)$=0.58		$\mathrm{Log}(E_R/E_L)$=1.58	
	C_N (cm)	C_F (cm)	C_N (cm)	C_F (cm)	C_N (cm)	C_F (cm)	C_N (cm)	C_F (cm)	C_N (cm)	C_F (cm)	C_N (cm)	C_F (cm)
2.59	0.26	0.22	0.46	0.46	0.93	0.82	0.37	0.41	0.62	0.66	0.81	0.93
5.90	0.56	0.39	0.77	0.93	1.66	1.77	0.59	0.62	0.95	0.9i	1.68	1.80
8.16	0.63	0.63	1.15	1.10	2.05	2.36	0.86	0.59	1.24	1.22	2.29	2.33
10.28	0.71	0.79	1.50	1.55	2.63	2.8i	0.96	0.83	1.57	1.45	2.74	2.64
13.76	0.79	0.71	2.10	1.82	3.42	3.46	1.07	0.91	1.76	1.56	3.38	3.64
19.96	0.76	0.83	2.50	2.10	4.61	4.71	0.97	1.22	2.28	2.47	4.34	4.88
35.56	0.78	1.51	3.67	3.52	6.96	9.15	0.75	1.47	2.48	3.34	5.67	7.61
68.17	−0.28[a]	3.05	2.70	7.03	8.46	13.58	−0.31[a]	3.88	1.73	6.14	5.13	14.37

[a]The negative sign is used to indicate that the localized near position of the oscillating target lies farther from the observer than does the actual plane of oscillation.

TABLE III. Average latency difference (Δt) as a function of target thickness (diam) and target velocity. Each entry represents the average of the near and far latency differences (Δt_N and Δt_F) computed from Eq. (4) for each set of values of the near and far displacements (C_N and C_F) obtained from observer M.M. The retinal illuminance of the left eye, logE_L, is kept constant at 2.06 log trolands. The latency differences are given in msec.

Target velocity (cm/sec) (Δt)[a]	Target thickness (in.)	Log(E_R/E_L) =0.12 (Δt)[a]	Log(E_R/E_L) =0.58 (Δt)[a]	Log(E_R/E_L) =1.07 (Δt)[b]	Log(E_R/E_L) =1.58
2.59	0.031	6.24	11.75	18.17	22.57
	0.125	9.21	15.75	20.22	27.11
	0.460	10.05	16.59	20.94	22.44
5.90	0.031	5.41	9.63	14.11	19.41
	0.125	4.87	10.16	16.51	21.91
	0.460	6.89	10.57	17.50	19.76
8.16	0.031	5.16	9.25	14.13	17.55
	0.125	4.00	9.47	13.88	18.22
	0.460	5.97	10.10	15.44	18.99
10.28	0.031	4.88	9.95	13.40	17.69
	0.125	3.88	8.98	13.28	17.15
	0.460	5.81	9.84	15.43	17.54
13.76	0.031	3.65	9.52	13.51	16.72
	0.125	3.92	8.42	11.79	16.26
	0.460	4.84	8.02	14.25	17.08
19.96	0.031	2.68	7.76	12.79	15.66
	0.125	3.16	8.00	10.57	14.49
	0.460	3.66	7.97	13.35	15.42
35.56	0.031	2.36	6.80	9.89	14.95
	0.125	2.89	6.14	9.35	13.45
	0.460	2.08	5.44	10.31	12.33
68.17	0.031	1.32	4.60	7.48	10.40
	0.125	2.96	6.72	7.60	11.79
	0.460	2.13	3.72	8.42	8.84

[a] The values listed in these columns for target thicknesses 0.031 and 0.460 were computed from the data given in Table II of this report; the values reported for target thickness 0.125 were computed from the data given in Table I of a previous report.[4]
[b] All values listed in this column were computed from the data given in Table I of this report.

largest and smallest target thicknesses at each target velocity under the three additional conditions of unequal binocular retinal illuminance. These data show that C_N and C_F are uninfluenced by target thickness for all specified. target velocities and conditions of unequal binocular retinal illuminance. However, the values of C_N and C_F increase progressively as target velocity is increased for each condition of unequal binocular retinal illuminance. Also, for any given target velocity, the values of C_N and C_F progressively increase as the amount of the unequal binocular retinal illuminance is increased.

Table III summarizes the results of the present experiment and those of a previous experiment[4] for observer M.M. Each entry of $\langle\Delta t\rangle$ is based on the average of the near and far latency differences (Δt_N and Δt_F) computed from Eq. (4) for each of the respective sets of near and far displacements (C_N and C_F) obtained for the given target thickness at each velocity.

Inspection of Table III further demonstrates that target thickness has no systematic effect on the magnitude of $\langle\Delta t\rangle$. Accordingly, the vaIues of $\langle\Delta t\rangle$ for the three thicknesses have been combined in the data of Fig. *3* and Fig. 4. In Fig. 3, the combined average latency difference is plotted as a function of target velocity, with condition of binocular retinal illuminance serving as parameter. In Fig. 4, the combined average latency difference is plotted as a function of difference of binocular retinal illuminance, log(E_R/E_L), with target velocity serving as parameter. It is clear (from Fig. 3) that latency difference is not completely independent of target velocity, particularly for large values of log(E_R/E_L). In each case, the values of $\langle\Delta t\rangle$ tend to increase rapidly at low target velocities. It can be readily seen (from Fig. 4) that latency difference varies

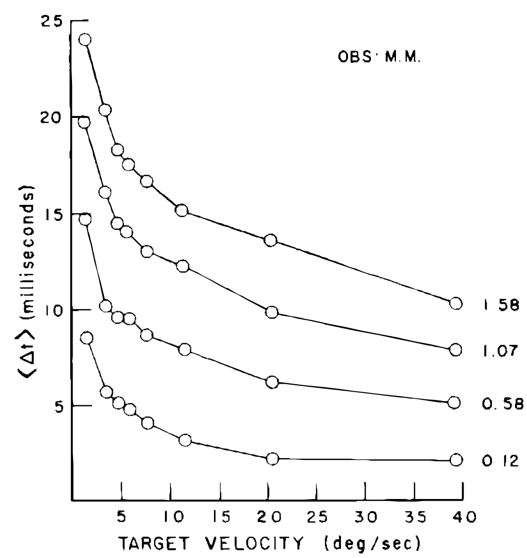

FIG. 3. Average latency difference as a function of target velocity. The number accompanying each curve represents the magnitude of the difference in binocular retinal illuminance, log(E_R/E_L), where the retinal illuminance of the left eye, logE_L,is kept constant at 2.06 log trolands.

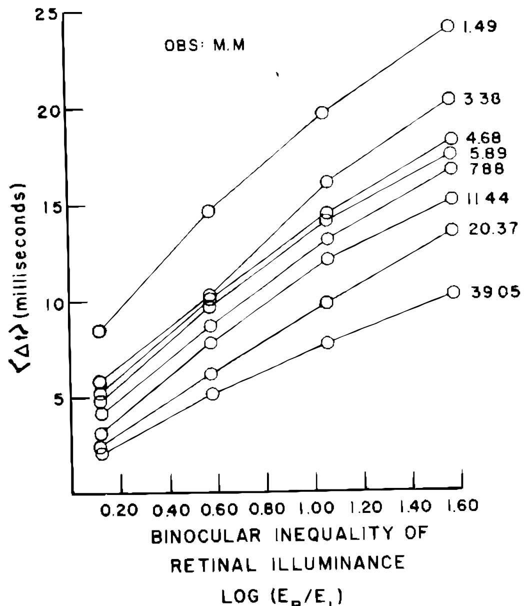

FIG. 4. Average latency difference as a function of differences in binocular retinal illuminance. The number accompanying each curve represents the prevailing target velocity in deg/sec.

systematically with difference in binocular retinal illuminance: for each of the given target velocities, $\langle \Delta t \rangle$ progressively increases as $\log(E_R/E_L)$ is increased.

DISCUSSION

Relatively little systematic work has been done to study the effects of target size on depth displacements, CN and C F. Engelking and Poos5 have obtained some data for white oscillating targets viewed against a black background. Their results showed that, to produce a depth displacement of a given constant magnitude, the inequality of binocular retinal illuminance had to be progressively increased as the width of the white oscillating target was increased. This finding implies that, for a given difference of binocular retinal illuminance, depth displacement is inversely related to target thickness.

In contrast, the results of the present experiment clearly indicate that target thickness has no systematic effect on the magnitude of the stereophenomenon when black oscillating rods are viewed against a white background. This holds over a wide range of target velocities for each of the conditions of unequal binocular retinal illuminance used. To account for the difference between the results of the present experiment and those reported by Engelking and Poos, additional data on the effects of target size are required for white targets on a black background and for black targets on a white background, each obtained under comparable experimental conditions.

[5] E. Engelking and F. Poos, *Arch. Ophthalmol,* 114, 340-379 (1924).

The present data on the effects of target velocity are in good quantitative agreement with predictions based on the geometric theory of the Pulfrich effect. They conhrm the results of an earlier experiment[4] on the same two observers: for a given difference of binocular retinal illuminance, displacements C_N and C_F progressively increase as target velocity is increased, but the corresponding average latency differences, $\langle \Delta t \rangle$, remain essentially constant for all velocities. In both studies, however, discrepancies are noted to occur primarily at low target velocities and for large differences of binocular retinal illuminance. That is, the experimental curves which relate latency difference and target velocity (Fig. 3) show a characteristic upturn at low target velocities, particularly for the curves representing large values of $\log(E_R/E_L)$. The upturn of the experimental curves noted in each of the two experiments reflects the fact that, as target velocity was progressively decreased for the given difference of binocular retinal illuminance, C_N and C_F remained systematically lightly larger than t.he respective theoretical values required by Eq. (4) to yield a given constant $\langle \Delta t \rangle$ for all target velocities. A similar effect for slowly moving targets occurs (see discussion in Lit) in the so-called sensation- time *(Empfindungszeit)* experiments of Frohlich.[6]

It should be emphasized that the data of the present experiment show that the magnitude of the upturn in the curves relating latency diiference and target velocity is not affected by the thickness of the oscillating

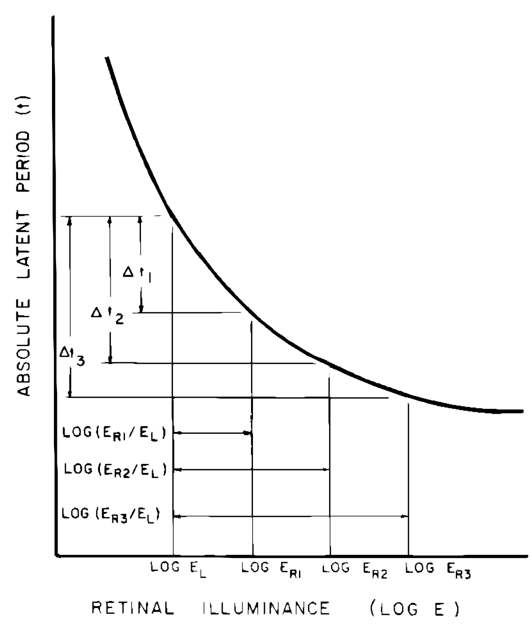

FIG. 5. The hypothesized absolute visual latent period (t) as a function of retinal illuminance ($\log E$). The curve represents an assumed relationship proposed to account for the experimental fact that, for the given constant retinal illuminance of the left eye ($\log E_L$). latency difference (Δt) increases progressively as the difference in binocular retinal illuminance [$\log(E_R/E_L)$] is increased.

[6] F. W. Frohlich, *Z. Sinnesphysiol*. 55, 1 - 46 (1923).

target. Thus, target thickness has no systematic influence on any binocular spatial localization effects that can be possibly produced by variations in target velocity, that is, target thickness produces no depth effects that arise from variations in binocular retinal illuminance (adaptation) associated with the variations in stimulus duration (target velocity). To establish the basis of the upturn occurring at low velocities for all target thicknesses in terms of binocular spatial localization effects that result from variations in target velocity (binocular adaptation) would require additional experiments in which a *luminous* oscillating target is viewed against a white background. The conditions of retinal illuminance prevailing in the present experiment (where target velocity is varied under a given condition of unequal binocular retinal illuminance) can be simulated in the proposed studies by having the difference in background illuminance for the two eyes held constant while the difference in binocular retinal illuminance for the oscillating target is systematically varied. The proposed experiments would at least provide important additional information concerning possible effects of binocular differences of target-backgrouod contrast on the rnagnitude of the Pulfrich stereophenomenon. The results would have important and direct theoretical implications.

The present experiment also provides systematic data on the effects of unequal binocular retinal illuminance. The data for observer M.M. clearly confirm the results obtained in an earlier experiment[2] on other observers: for a given target velocity, the near and far depth displacements and their corresponding computed latency differences progressively increase to approach a final limiting value as $\log(E_R/E_L)$ is increased. These results have been accounted for[2,4] in terms of an hypothesized absolute visual latent period (t) whose magnitude is presumed to be inversely related to retinal illuminance ($\log E$). The relationship is shown schematically in Fig. *5*. $\log E_L$ represents the constant retinal illuminance of the left eye, and $\log E_{R1}$, $\log E_{R2}$, and $\log E_{R3}$ represent three increasing values of retinal illuminance produced in the right eye. It can be seen from Fig. *5* that the difference in absolute latency (Δt) monotonically increases as the difference in binocular retinal illuminance [$\log(E_R/E_L)$] is increased. Theoretically, the rate of increase depends specifically on the magnitude of the constant retinal illuminance selected for the left eye.

It is to be noted in Fig. 4 that the curves relating $\langle \Delta t \rangle$ and $\log(E_R/E_L)$ do not overlap, but take positions on the ordinate axis that vary systematically in height with target velocity: the lower the target velocity, the higher is the displacement of the given curve. Target velocity also influences the shape of the experimental curves in Fig. 4: the curves which represent the lowest target velocities show the greatest rise in $\langle \Delta t \rangle$ values as $\log(E_R/E_L)$ is increased. This effect reflects the lack of parallelism in the latency difference *vs* target velocity curves of Fig. *3*. The complicating effects of target velocity on latency difference must, of course, be taken into account in any attempt to derive an empirical equation that relates absolute visual latent period (t) and level of retinal illuminance ($\log E$).