New method of measuring visual-perceptual latency differences¹

A. M. PRESTRUDE² AND H. D. BAKER
FLORIDA STATE UNIVERSITY

Inequalities in binocular illumination (ΔI) result in unequal visual-perceptual latencies. The differences between latencies (Δt) have been assumed to be basic to the Pulfrich effect. A new method for measuring Δt s is described and compared with the Pulfrich pendulum procedure and three other methods. The values of the Δt - ΔI functions from this method are comparable to the results of previous studies providing additional support for the latency-difference hypothesis. The method also appears to have achieved a reduction in variability.

A swinging pendulum will appear to move in an elliptical path around its plane of actual movement when it is viewed binocularly and one eye of an observer (O) receives less light than the other, e.g., when a neutral density filter is placed in front of one eye. This phenomenon, the Pulfrich effect (Pulfrich, 1922) has been assumed to be due to a difference in the response latencies (Δt) of the O's eyes in which the darkened eye has an increased latency and consequently sees the moving pendulum farther behind in its path than does the undarkened eye. The resultant condition of disparity leads to the perception of movement in depth.

The characteristic apparent excursions of the pendulum from the frontal plane in the Pulfrich effect have been noted and described by Banister (1932), Crawford (1938), Diamond (1958), Harker and O'Neal (1967), Katz and Schwartz (1955), Lit (1949), Lythgoe (1938), Rock and Fox (1949), and Weale (1954b). However, of these only Banister (1932) and Lit (1949) calculated Δt s from the geometry of the procedure. Lit's definitive study (1949) not only verified that Δt was a direct function of the difference in retinal illumination (ΔI), but also established that Δt varied systematically with the background illumination (I) for any given filter density (ΔI). These relationships had been suggested previously by Lythgoe (1938).

Other methods have been employed to measure the Δt s induced by filters. A double-flash method in which the Os set two brief flashes of light of equal duration but unequal intensity to apparent simultaneity was used by Alpern (1954), Arden and Weale (1954), and Roufs (1963). Alpern (1954) used monocular presentation, Arden and Weale (1954) used binocular presentation, and Roufs (1963) compared monocular and haploscopic presentations and found no differences between them. May (1964) used an "eye-and-ear" method in which the Os were instructed to adjust

the temporal relations between visual and auditory stimuli as the intensity of the visual stimulus was varied. This method was compared by Roufs (1963) with a double-flash method and a reaction time measure.

All these methods produced comparable Δt - ΔI functions (see Table 1), but each can be criticized seriously. For example, the Pulfrich pendulum procedure requires a stereoscopic judgment which is subject to differences among Os in the location of the apparent path of the oscillating target (Lit, 1960) and the perceived path may depart considerably from an ellipse (Harker & O'Neal, 1967; Katz & Schwartz, 1955). The pendulum procedure even allows an alternative explanation of the Pulfrich effect in terms of saccadic suppression without any reference at all to latency and latency differences (Harker, 1967). The double-flash method depends on the perception of apparent movement (Arden & Weale, 1954; Roufs, 1963) and may be affected by flicker (Arden & Weale, 1954) and fluctuations in the O's state of adaptation (Alpern, 1954) especially when both stimuli are presented monocularly. Roufs (1963) said that the "eye-and-ear" and reaction time measures lacked precision. In the former it was difficult for Os to maintain a constant criterion while the latter was imprecise because of the intrusion of such false responses as errors of anticipation.

It seemed desirable to develop a reliable method for measuring the Δt s induced by neutral density filters that would be independent of the Pulfrich pendulum and apparent movement procedures and their associated problems of anomalous perceptions and fluctuating stimulus characteristics.

APPARATUS AND PROCEDURE

The apparatus consisted of right and left disks that rotated together in the same direction at a constant speed of 1 rev/sec. The disks were driven by a reversible Bodine synchronous motor and were linked by a timing chain. Each disk was viewed by the respective eye through a system of lenses and the two were fused into a single binocular image. The optical system also relaxed accommodation, maintained parallel lines of sight, and was adjustable for each O's interpupillary distance. Each disk had a central fixation and a rotating line segment. The left eye viewed a line segment rotating about the central fixation point and the right eye, a line segment 12½ deg out from the fixation point and

Table 1
Comparison With Previous Studies

Study	Method	Δt (msec)	ΔI	I	Error (msec)
Alpern (1954)	Double-flash	0-12	2.5 log units	930 ft-L	not given
Arden & Weale (1954)	Double-flash	0-30	2.5 log units	221 mL	.37-1.63 ³
Banister (1932)	Pendulum	2.4-21.2	0.46 log relative I	not given	not given
Lit (1949)	Oscillating pointer	0-27 ¹	---same as Alpern (1954)---	-----	not given
Lit (1949)		0-35 ²	---same as May (1964)---	-----	not given
May (1964)	"eye-and-ear"	10-62	4.0 log units	4 log Trolands	not given
Prestrude & Baker (1968)	Rotating disks	4.3-39.4	3.0 log units	1.8 log ft-L 2.4 log ft-L	0.6-1.4 ³
Roufs (1963)	Double-flash	0-26	1.5 log relative I	960 Trolands	2-8 ⁴
	"eye-and-ear"	20-55	3.5 log relative I	1470 Trolands	10-15 ⁴
	Reaction time	0-40	3.0 log relative I	960 Trolands	25 ⁵
Weale (1954a)	Oscillating pointer	not given	not given	not given	1 ³

¹ Reported by Alpern (1954).

² Reported by May (1964).

³ Standard error.

⁴ 95% confidence interval.

⁵ Standard deviation.

continuous with the left-eye segment when they were fused binocularly (see Fig. 1).

When a Wratten neutral density filter was placed in front of one eye of an O, the response latency of that eye was increased and the corresponding line segment appeared to be retarded, i.e., the binocularly fused lines appeared discontinuous (see Fig. 1). It then had to be advanced to regain its original position from the apparent retarded position. The amount of advancement measured, on a calibrated scale, the Δt due to each filter.

The method of advancement was provided by a Dove prism in the right visual axis which could be rotated in a Teflon bearing to advance or retard the right target segment until it matched the left target segment. Attached to this prism was a pointer which served as the lever by which the Os rotated the prism and which read Δt from the scale which was calibrated in 100ths of a second. Figure 2 shows the arrangement of the apparatus that can be considered to be analogous to a clock. Both target disks were directly linked in a 1:1 ratio and moved with the same angular velocity (3.6 deg./0.1 sec). If one target was perceived as lagging behind the other, the number of degrees through which the lagging target had to be shifted in order to match the other could be converted to units of time.

A method-of-adjustment procedure was employed in which three Os made several settings at background intensity (I) levels of 2.8 log ft-L and 1.4 log ft-L. Wratten neutral density filters of 0.9, 2.0, and 3.0 log units were placed singly in front of each O's right or left eye to produce one of three levels of ΔI . After an adequate period of dark adaptation, each O made his settings. Each O received all combinations of filter density, filter location, and direction of rotation (12 in all) in a counterbalanced order. All Os were tested for adequate acuity and binocular fusion with the Armed Forces Vision Tester (Sloane, 1958). Each O was instructed in the use of the apparatus and then given 10 practice trials after which he made 50 settings, 25 for each direction of rotation, without filters ($\Delta I = 0$) in order to establish his individual zero point. After this, the test settings were made.

RESULTS

The results are presented in Fig. 3. For each ΔI at the two levels of I the mean Δt and its variability are indicated. The crossbars indicate ± 3 standard errors (SE) for each datum point. Each datum point at 2.8 log ft-L is the mean of 60 settings and each datum point at 1.4 log ft-L is the mean of 180 settings. For the condition of equal luminance to both eyes ($\Delta I = 0$), the SE at both levels of I was 0.5 msec.

DISCUSSION

As Fig. 3 indicates, Δt is a direct function of ΔI . As the level of illumination increases, equivalent ΔI s do give decreasing Δt s as previously suggested by Lythgoe (1938) and subsequently reported by Lit (1949).

The values of Δt reported here are consonant with those reported previously (see Table 1). The results, therefore, can be considered to give added support to the latency difference hypothesis.

Reference to Table 1 shows that the method described here represents an improvement in reliability over those earlier studies which reported the variability of their measures. The improved reliability is probably because the present procedure more adequately controlled those conditions that would allow anomalous perceptions, e.g., the "egg-shaped" (Harker & O'Neal, 1967) or "figure-eight" (Katz & Schwartz, 1955) apparent paths of the pendulum in the Pulfrich procedure. The variability, though low, does increase with ΔI and decreases with I . Neither result should be unexpected.

Since saccadic movements were limited in the present experimental arrangement, and were of different types from the saccades in the Pulfrich effect, the saccadic suppression hypothesis (Harker, 1967) now appears to be questionable.

The success of the apparatus has led to its use for several visual studies. Currently, Δt s are being measured over a wider range of

Fig. 1. Appearance of the targets. "a" left target, "b" right target, "c" fused image without filter, "d" fused image with a filter in front of O's left eye, targets rotating to the right, and "e" fused image with a filter in front of O's right eye, targets rotating to the right.

Fig. 2. Principle components of the apparatus. L_1 —eyepiece lenses, P_1 —prisms of eyepiece assemblies (note that the lens and prism form single units which are adjustable for each O's interpupillary distance). FB—filter boxes, L_2 —imaging lenses, FDP—fixed Dove prism, ADP—adjustable Dove prism, T_1 —left target, and T_2 —right target.

Fig. 3. Δt as a function of ΔI at two levels of I . Crossbars at each datum point indicate ± 3 SE.

ΔI and I , including the unexplored scotopic range. The apparatus may also prove useful in studying the course of dark-adaptation, which involves an interesting anomaly. Rock and Fox (1949) reported that in the Pulfrich effect, dark-adapting one eye has the same effect as darkening it with a filter, although the field actually appears brighter in that eye. Similarly, light-adapting one eye (Baker & Prestrude, 1967) or providing a constant glare source to one eye (Diamond, 1958; Lythgoe, 1938) causes the phenomenon to reverse, i.e., decreases that eye's latency although the field pattern appears dimmer to it.

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NOTES

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2. Address: Department of Psychology, Florida State University, Tallahassee, Florida 32306.

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