Visual Latency Difference Determined by Two "Rotating" Pulfrich Techniques

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We tested the validity of Nickalls' formula for determining visual latency difference by using two rotating Pulfrich techniques: (A) varying viewing distance while keeping target angular velocity constant (33 rev/min) and (B) varying the target angular velocity while keeping the viewing distance constant (180 cm). The formula predicts that the latency differences estimated by the two techniques are equal with a given neutral density filter. Observers were asked to judge whether or not the rotating target (clockwise) appeared to move back-and-forth from side-to-side with a neutral density filter (OD = 0.7, 1.0, 1.3) in front of the right eye. The results with ten observers showed that the mean visual latency differences associated with each technique for a given filter were not significantly different. These results further validate the Nickalls' formula and, therefore, support the visual-latency hypothesis to account for the Pulfrich phenomenon.

Keywords: Pulfrich stereoeffect, rotating Pulfrich phenomenon, visual-latency hypothesis

Although the Pulfrich stereoeffect (Pulfrich, 1922) has been extensively investigated (for a review, see Howard & Rogers, 2002), there is still debate regarding its underlying cause. One manifestation of this stereoeffect is the "pendulum" illusion, in which a pendulum swinging horizontally in a fronto-parallel plane (i.e., at right-angles to the line of sight and at eye-level) and viewed binocularly with a neutral density filter in front of one eye, appears to move in an elliptical path (see Figure 1a). More recent investigations have been directed towards the "rotating" Pulfrich illusion (Nakamizo, Nawae, & Nickalls, 1998; Nickalls, 1986, 1996, 2000; Nickalls, Kazachkov, Vasylevska, & Kalinin, 2002) in which a vertical rod rotating in a horizontal circular path can, under certain circumstances, appear to move back-and-forth from side-to-side (see Figure 1b).

The Pulfrich stereoeffect is generally explained by an apparent spatial disparity due to a unilateral increase in visual latency associated with the decreased retinal image intensity in the filtered eye, as originally proposed by Fertsch (Pulfrich, 1922). Furthermore, an increased latency of visually evoked potentials is known to be associated with decreased retinal luminance (Tobimatsu, Celesia, & Cone, 1988). Other studies are summarized by Howard and Rogers (2002) and Nickalls (1996).

In the Pulfrich pendulum illusion with the left eye filtered, when the pendulum moves from left to right, the latency difference causes the equivalent of an uncrossed disparity, and the pendulum appears to be beyond its physical path. Conversely, when the pendulum moves from right to left, the latency difference causes the equivalent of a crossed disparity, and in this case, the pendulum appears

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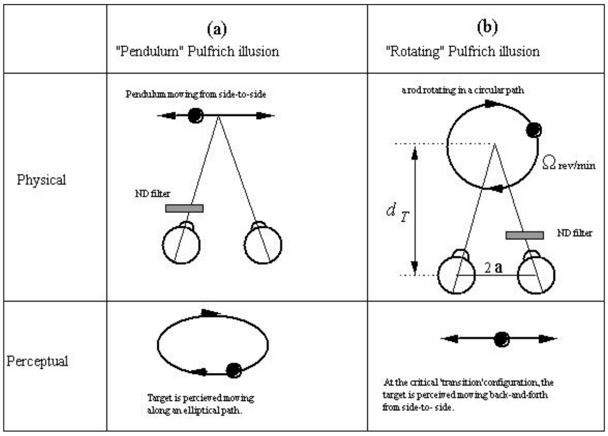

Figure 1. The "pendulum" and "rotating" Pulfrich illusions. In the pendulum Pulfrich illusion, when a pendulum swinging from side-by-side is viewed binocularly with a neutral density filter in front of one eye, the pendulum appears to move in an elliptical path. The rotating Pulfrich illusion arises when a vertical rod rotating clockwise on a horizontal turntable is viewed binocularly from the side with a neutral density filter in front of one eye. In this case, the apparent direction of rotation of the rod varies depending on the angular velocity, viewing distance, and the filter density. At some critical configuration ("transition"), the rod appears not to rotate but to move back-and-forth from side-to-side.

to be in front of its physical path (near the observer). Thus, the pendulum appears to rotate clockwise (as seen from above). As the magnitude of the disparity varies with the velocity of the pendulum and/or the density of the filter, the pendulum appears to rotate in an elliptical path (see Figure 1a and Howard & Rogers, 2002).

The rotating Pulfrich illusion can also be explained successfully by the latency hypothesis. That is, the disparity created by the visual latency difference due to the filter, is cancelled out by the binocular retinal disparity (equal magnitude but opposite direction) produced by the rod rotating in a circular path with a particular velocity and at a particular viewing distance. As a consequence of this cancellation, the rod appears to move only from side-to-side in spite of the circular path of the rod (see Figure 1b).

The method for determining visual latency difference used in the present study, is essentially one of the four "nulling" methods, which have been described (Nakamizo & Kondo, 1985; Nickalls, 1986; Pulfrich, 1922; Rogers & Anstis, 1972). Pulfrich (1922) appears to have been the first to observe that the apparent direction of rotation of a vertical rod mounted eccentrically on a horizontal turntable depends on the angular velocity of the turntable, reversing at some critical combination of angular velocity, filter, viewing distance and so on. Detection of this critical configuration (the "transition" null-point) is the basis of the present experiment.

Rogers and Anstis (1972) also used the null method to measure the magnitude of the Pulfrich effect. In their experiments the phase difference between two sinusoidal target motions dichoptically to the two eyes, was varied in order to cancel a filter-induced phase lag. Nakamizo and Kondo (1985) also used a null method to estimate apparent depth due to the Pulfrich effect, in which the apparent depth was cancelled by adjusting the extent of the physical depth of the target moving in an elliptical path in the horizontal plane.

Nickalls (1986) determined visual latency difference using the rotating Pulfrich illusion, by measuring the critical viewing distance at the "transition" null-point (when the rotating target appears to move only from side-to-side) for a given target angular velocity and filter density, using Equation (1),

$$\Delta t = \left(\frac{1}{3\Omega}\right) \tan^{-1}\left(\frac{a}{dT}\right) \tag{1}$$

where Ω is angular velocity (rev/min) of the target, a is the half of the interocular distance, and dT is the viewing distance (cm) at which the "transition" null-point is perceived (for derivation, see Nickalls, 1986, 1996). Equation (1) ought also to be equally valid if the "transition" null-point is identified using an alternative method, whereby the angular velocity is varied while keeping the viewing distance constant.

This study was therefore designed to test the validity of equation (1) by comparing the visual latency difference measured using these two techniques, namely (a) varying the viewing distance while keeping the angular velocity constant (technique A), or (b) varying the angular velocity while keeping the viewing distance constant (technique B). If Equation (1) is valid, the visual latency difference measured using the technique A should be equal to that measured using the technique B when a neutral-density filter having the same optical density is used. This prediction is examined in the present experiment.

Method

Stimulus and Apparatus

The stimulus was a black vertical rod (1.6 mm in diameter) mounted 11.9 cm from the centre of a horizontal clockwise rotating turntable, and was clearly visible against a white background. A front panel having a 5.0 cm high and 33.5 cm wide horizontal aperture screened out the turntable and the ends of the rod. The mean luminance of the front panel and the background screen over the full range of viewing distance was approximately 92 cd/m^2

and 108 cd/m[2], respectively. The turntable was mounted on a trolley, which ran backwards and forwards on a straight 3.0 m track. The observer was positioned at one end of the track. In technique A, the angular velocity was maintained constant, and experimenter varied the position of the trolley, and hence the viewing distance, by turning a small handle. In technique B, the viewing distance was constant, and the experimenter varied the angular velocity of the turntable by turning a dial.

Filters

Three different Wratten neutral-density filters (Kodak) were used, having optical densities (OD) of 0.7, 1.0, and 1.3. During each trial one of these filters was placed in front of the right eye of the observers.

Procedure

The height of the chin-forehead holder was adjusted so that the midpoint of the target was at level with the subject's eye. The subjects fixated the rotating target binocularly, and adjusted either the viewing distance (technique A) or angular velocity (technique B), in order to locate the "transition" state, when the target appeared to move horizontally back-and-forth from side-to-side along a smooth path.

In technique A, the angular velocity was constant (33 rpm), and the "transition" viewing distance was measured. The experimenter moved the turntable trolley in 5 cm steps, either from a location close to the subject and moving away (ascending trials), or from a distant point moving towards the subject (descending trials). Once the "transition" point was identified the experimenter measured the "transition" viewing distance (from the center of rotation to the subject's eyes).

In technique B, the viewing distance (from the center of rotation to the subject's eyes) was constant (180 cm). The experimenter varied the angular velocity of the turntable in two rev/min steps, either increasing from 20 to 60 rev/min (ascending trials), or decreasing from 60 to 20 rev/min (descending trials), until the "transition" endpoint was identified.

Each subject underwent three sessions for each technique, using a different filter for each session. The order of the sessions was randomized. Each session consisted of alternate ascending and descending trials; three ascending and three descending.

Subjects

Ten subjects (5 male) participated in the experiment, all having normal or corrected-to-normal visual acuity and also normal stereo acuity confirmed by Randot stereotest. The age range was 18 to 22 years. All subjects were naive as to the purpose of the experiment. Half the subjects experienced technique A followed by technique B, while the other half experienced the reversed order.

Results

Three sets of analyses were performed. The first and second sets examined the effects of the density of the filter and the type of trials (ascending or descending), the ascending or descending, on the critical viewing distance and the critical angular velocity, respectively. The third set examined the effects of the density of filter and the two techniques on the measured visual latency difference.

A two-way (3 densities × 2 types of trials) repeated measures analysis of variance was performed on the mean critical viewing distance averaged over the three trials for each subcondition and for each subject. The interaction effect was not statistically significant [$F(2, 18) = 2.921$]. The effect of filter density was highly significant [$F(2, 18) = 39117$, $p < .001$], but the effect of the type of trials was not significant [$F(1, 9) = 2.148$]. Figure 2 presents the means of the critical viewing distance, at which the stimulus appeared to move only from side-to-side, averaged over the 10 subjects and plotted as a function of filter density. The error bars in the figure are standard deviations. The non-significant interaction is depicted in the figure by

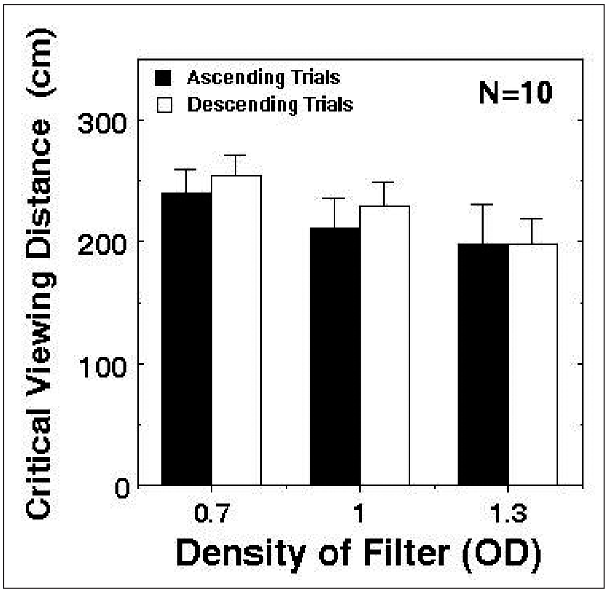

Figure 2. Mean critical viewing distance ($N = 10$) as a function of filter density, separately for the trial type. The small vertical bars are standard deviations.

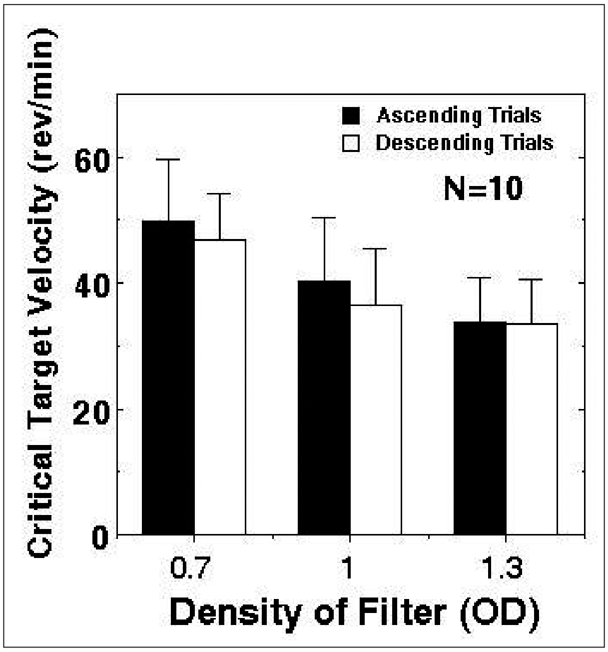

Figure 3. Mean critical angular velocity of the target as a function of filter density, separately for the trial type.

the almost equal decreases of the black and white bars as a function of filter density. The significant effect of the filter density is depicted in the figure by the change in the length of the bars as the density increases.

A two-way (3 densities × 2 types of trials) repeated measures analysis of variance was performed on the mean critical target angular velocity averaged over the three trials for each subcondition and for each subject. The interaction effect was not significant [$F(2, 18) = 0.918$]. The effect of filter density was highly significant [$F(2, 18) = 27.692$, $p < .001$], but the effect of the types of trials was not significant [$F(1, 9) = 2.889$]. Figure 3 presents the means of the critical angular velocity, at which the stimulus appeared to move only from side-to-side, averaged over the 10 subjects and plotted as a function of filter density. The error bars in the figure are standard deviations. The non-significant interaction is depicted in the figure by the almost equal decreases of the black and white bars as a function of filter density. The significant effect of filter density is depicted in the figure by the change in the length of the bars as filter density increases.

The visual latency difference for each technique was calculated using Equation (1). The numeric data is shown in Table 1, separately for each subject. A two-way (3 densities × techniques) repeated measure analysis of variance was performed on the mean latency difference averaged over the three ascending and three descending trials for each subcondition and for each subject. The interaction effect was significant [$F(2, 18) = 4.236$, $p < .05$], but the value of omega squared indicates that it accounted for only 2.5 % of the variance. The influence of filter density was also significant [$F(2, 2) = 44.033$, $p < .01$], accounting for 37.3 % of the variance. The influence of technique (A, B) was not significant [$F(1, 9) = 2.975$]. Figure 4 shows the mean latency differences plotted as a function of filter density, separately for each technique. The significant effect of filter density is depicted in the figure by the change in the length of the bars as filter density increases. The non-significant effect of the technique is depicted in the figure by the almost equal increase of the black and white bars as a function of filter density.

Discussion

The results show (1) the mean visual latency differences associated with each technique for a given filter were not significantly different, and (2) the mean latency differences obtained with each technique increased similarly with optical density. Furthermore, the results using technique A yield absolute values which are in close agreement with (a) a study of similar method, illumination, filter, and angular velocity (Nickalls, 1996), and (b) equivalent studies by Prestrude and Baker (1968), and Standing, Dodwell, and Lang (1968) using alternative techniques.

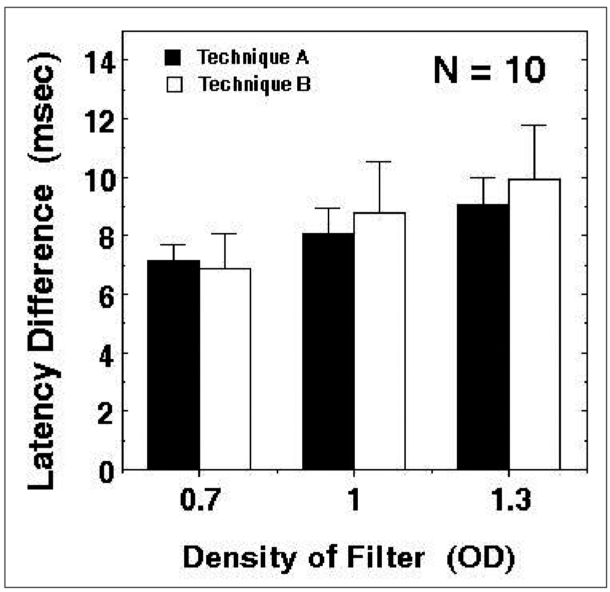

Figure 4. Mean latency difference for each technique as a function of filter density.

Table 1
Mean visual latency difference for each subject as a function of filter density and technique

		Technique A			Technique B		
	IPD	OD			OD		
Sub.	mm	0.7	1.0	1.3	0.7	1.0	1.3
Y.M.	65	7.35	9.66	10.18	8.21	8.82	11.85
S.U.	58	6.74	7.46	8.45	5.47	8.89	7.77
M.T.	59	6.54	7.12	8.28	5.49	5.49	6.65
K.I.	58	6.31	6.77	7.64	5.35	5.72	7.77
N.H.	59	7.29	7.29	8.10	9.17	10.74	10.44
H.K.	60	8.10	8.68	9.84	8.12	10.25	11.46
E.M.	62	8.04	8.51	10.88	6.68	9.98	12.13
T.N.	64	7.18	8.74	9.14	6.68	8.76	9.16
K.K.	57	6.89	8.74	9.49	7.17	10.65	10.50
H.T.	66	7.41	7.64	8.45	6.35	8.74	11.81
mean		7.19	8.06	9.05	6.69	8.80	9.95
SD		.49	.89	.94	1.99	1.78	1.91

These results further validate not only the visual-latency explanation of the rotating Pulfrich technique (Howard & Rogers, 2002; Nickalls, 1986, 1996), described in the introduction, but also the Nickalls' formula (Equation 1) for determining the latency difference directly. Since the geometry of the rotating Pulfrich effect requires a constant time delay, these findings are consistent with and lend support for the visual-latency hypothesis for the Pulfrich phenomenon.

Author Note

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