Dark adaptation and the Pulfrich effect¹

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The Pulfrich effect (the illusory displacement of a moving stimulus when it is viewed with an optical filter over one eye) was measured repeatedly during a 20 min period following the initial filtering of the eye. For each of 10 filter densities, the Pulfrich effect always occurred immediately upon filtering the eye, but subsequently increased greatly during the adaptation period. The results indicate that the perceptual latency of the filtered eye is increased by two factors: the reduction in stimulus luminance due to the filter and progressive dark adaptation. Dark adaptation is apparently the more important of these two factors.

The phenomenal path of a moving object, viewed with a colored or neutral density filter over one eye, is displaced from its true path (Pulfrich, 1922). The size and direction of the displacements are usually accepted as evidence that perceptual latency in the filtered eye increases monotonically with the optical density of the filter employed (Lit, 1949; Ogle, 1962). This interpretation is consistent with the known inverse relation between the intensity of a visual stimulus and its perceptual latency (Pieron, 1952), and the slower speed of response of the dark-adapted eye (Granit, 1947). Electrophysiological work on visual evoked potentials supports both points (Vaughan & Costa, 1964). Normally, when the Pulfrich effect is measured repeatedly the two factors are confounded, so that either or both may be responsible for the phenomenon. It is sometimes assumed (e.g., Gregory, 1966) that the effect is simply due to differences in adaptation level in the two eyes, but Harker, Dodwell, and Behar (1967) have shown that it can be obtained when the eyes are equally adapted. Differential adaptation of the eyes can cause displacement, however, since it has been found that, when one eye is dark adapted and S then views the moving object (without filters), the Pulfrich effect occurs in a direction corresponding to greater latency in the dark-adapted eye (Engelking & Poos, 1924; Rock & Fox, 1949). In this case the effect attenuates quite rapidly, as the dark-adapted eye approaches the level of light adaptation of the other eye. However, progressive changes in the Pulfrich effect during the course of dark adaptation have not been studied previously.

The present study is intended to determine whether progressive changes in adaptation play an appreciable role in the Pulfrich effect. This is achieved by measuring, for each of a series of filters, the size of the effect at various times from the moment when one eye is initially filtered to the time when a steady state of adaptation has been reached.

METHOD

Subjects

Two of the authors (LGS and DL) served as Ss. Both possessed normal uncorrected vision.

Apparatus

The S viewed a moving pointer P, which was mounted on a turntable and crossed his line of sight from right to left every 1.8 sec, at a distance of 140 cm. P moved at 31.4 cm/sec. Between S and P a half-silvered mirror was mounted at 45 deg, so that when his head was placed in an adjustable headrest P was visible through the mirror. A movable pointer M was mounted so that its reflected image in the mirror lay just below the level of P; by moving M along a scale perpendicular to his line of sight, S could make its reflected image appear equidistant with P.

The S viewed the stimuli through 4-mm artificial pupils, to limit any effects due to change in pupil size and reduce the entry of extraneous stray light to the eyes. The pointers P and M were narrow upright cylinders, 2 cm high, 3 mm wide, painted white and illuminated to provide luminances of 120 mL and 46 mL, respectively, as measured at the eye. They were viewed against a background luminance of 6 mL in an otherwise dark room.

Procedure

Each S was given several hours of practice in viewing the Pulfrich effect before he was tested. At the start of each experimental session S viewed the stimuli through the artificial pupils for 10 min to achieve a steady pre-experimental level of light adaptation. Then, at time 0, a neutral density filter was dropped into place in front of S's left eye and he instantly adjusted the pointer M so that it appeared equidistant with the nearest point of the phenomenal path of the moving pointer P. If the initial setting could not be made within 2 or 3 sec to S's satisfaction, the filter was removed and the procedure repeated. The S then viewed the moving pointer P for 20 min, keeping the adjustable pointer M adjusted to the same apparent distance. Fixation was maintained on the pointer P. The position of M was recorded for the initial setting and at 1 min intervals thereafter.

For each of the two Ss used, 10 values of neutral density filter were employed, from 0.3 to 3.0 log units in steps of 0.3. Each value was used for 10 experimental sessions, the successive treatments for each S being arranged in a 10 by 10 Latin square. About 60 h of testing were required for each S.

Control readings were obtained under two conditions. In the first (control condition 1), settings of M for apparent equidistance with P were made under conditions identical to an experimental session, except that no filters were employed, to test for stability of depth judgments over time. In control condition 2, S was given a 20-min preadaptation period using one of the filters (during which he viewed the stimuli, but with P stationary) followed immediately by a 20-min experimental session using that filter, during which readings were taken of the magnitude of the Pulfrich effect. This procedure was repeated for each filter value, to check that the magnitude of the Pulfrich effect had reached a true asymptote during the preadaptation period, and that S's settings of M thereafter were stable.

RESULTS

The Pulfrich effect here is measured as the difference in position of the pointer M under experimental conditions from its settings made under control condition 1. In Fig. 1 the settings of

Fig. 1. Mean settings of movable pointer M for apparent equidistance with moving pointer P, as a function of filter density and time after filtering. Filter densities (adjacent values pooled) are given on each adaptation curve. Also shown: settings made with no filter and after preadaptation (control conditions 1 and 2). Data are pooled for both Ss, and (for control condition 2) for all filter densities.

The mean size of the Pulfrich effect at time 0 is plotted against its magnitude after 20 min in Fig. 2, for each filter value and each S. These values represent the first and last points of the functions given in Fig. 1, and indicate, respectively, the size of the effect before and after dark adaptation has occurred. Also shown on Fig. 2 are the inferred latency differences which correspond to each level of the effect, calculated from the formula of Lit (1949).

Our results are consistent with the idea that the primary cause of the Pulfrich effect is a change in perceptual latency in one eye (Lit, 1949), and that latency increases progressively during dark adaptation. They are also consistent with the findings of Engelking

Fig. 2. Magnitude of the Pulfrich effect in centimeters before and after 20 min of dark adaptation "initial" and "final" settings) as a function of filter density, together with calculated latency differences.

	<u>Control Condition 1</u>	<u>Control Condition 2</u>
Mean setting for	139.84	124.62
all adaptation times	139.47	125.96
Standard deviation	0.15	1.16
(between adaptation times)	0.24	0.26

$p = 0.05$ level if a one-tailed test is used, and the relationship must therefore be considered tenuous.

Does a similar adaptational mechanism underlie the deterioration in pattern vision observed both in this experiment and with retinal image stabilization? The conditions differ in two obvious respects: Firstly, there is no stabilization of images upon the retina when the O inspects the inner surface of the eye cap. Secondly, while care is usually taken to ensure precise accommodation of the focus of the eye to the test figure in stabilized retinal image experiments, the eye caps used in this study are so close to the eye that the image is never sharply resolved, and the phenomenal appearance of a contour drawn upon the cap is of a blurred edge shading gradually into the background. This reduces the effect of small eye movements as the rate of change of luminance is less across a blurred contour than it is across a sharp one. There are also data from Enoch (1958) and Thomas and Kovar (1965) showing that perceived figure-ground contrast is reduced as the sharpness of the boundary separating figure from ground is decreased.

The results of this experiment can thus be accounted for in terms of lateral inhibitory interactions such as those observed in *Limulus* (Ratliff et al, 1963) and suggested for human vision (von Békésy, 1960). As the differentials in excitation between adjacent neural elements in the region of a diffuse contour would be small and relatively little change would occur as a result of micro-nystagmus the model would predict that after a time adaptation would be complete and all units would reach a uniform level of activity resulting in a loss of response to contour, as is the case in this experiment. As this adaptation takes time to occur it would also be expected that figure-ground differentials would be better maintained at low flicker frequencies. This prediction is sustained by the results of this experiment and also by Bittini et al (1960) who reported enhanced contrast of indefinitely contoured objects with intermittent illumination. An additional factor that would aid contour perception under flickering light is the reported increase in saccade rate induced at flicker frequencies in the region of 1 to 3 cps (West & Boyce, 1968). Independent of the correctness of this explanation, the data clearly show that even large diffusely contoured figures on a ground of uniform brightness and texture can be perceptually unstable.

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NOTE

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