Eye movement and the Pulfrich effect

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The saccadic suppression theory of the Pulfrich effect proposes that the input from each eye is alternately suppressed during saccadic eye movements. This paper describes an empirical test of this theory by monitoring horizontal eye movements. The results show that the Pulfrich effect occurs whether the eyes fixate upon a stationary point, fixate upon the moving pendulum bob, or partially track the pendulum. The effect is present with both conjunctive and disjunctive eye movements. These data do not support the saccadic suppression theory, at least so far as macrosaccadic movement is concerned.

Under certain conditions a simple harmonic pendulum viewed binocularly appears to swing in an elliptical path rather than to and fro in a plane. This effect occurs when a filter is placed over one eye (the Pulfrich effect) or when an episcotister is used to occlude the view to each eye alternately (the Mach-Dvorak effect). The explanation put forward for the former effect by Pulfrich (1922), later expanded by Lit (1949) and Alpern (1968), is in terms of the theory of corresponding retinal points and variations in the latency of information transmission along the visual pathways. Placing a filter before one eye reduces retinal illuminance and increases visual latency. Thus, simultaneous excitation of the corresponding retinal points of unequally illuminated retinas results in simultaneous convergence at some central analyzer of impulses from disparate retinal areas, and this disparity is interpreted as a depth displacement of a moving object.

The Mach-Dvorak effect (Dvorak, 1872) is readily accounted for in terms of retinal disparity directly induced by alternately gating the input to each eye. Harker (1967) rediscovered this effect and suggested that a similar mechanism was responsible for the Pulfrich phenomenon, the gating being brought about by asymmetries in the duration of suppression of visual input occurring during saccadic movement of the eyes. Harker argued that as the period of saccadic suppression is a function of the intensity of target illumination, the presence of a filter before one eye provides the necessary conditions for differential saccadic suppression, resulting in a distortion in the seen path of a moving object.

The present paper reports an empirical test of Harker's explanation by monitoring eye movements while the S views a moving pendulum bob with and without a filter before one eye. The effect of instructions for "natural" viewing, fixation upon the pendulum bob, and fixation upon a stationary point while observing the moving pendulum bob is also described.

METHOD

Subjects

Four young adult Ss without readily detectable visual or neurological abnormalities served. Two were initially naive regarding the Pulfrich phenomenon but their results did not differ materially from those obtained from the other Ss.

Apparatus

Eye movement potentials (EOG) were monitored via Beckman Ag/Ag Cl surface electrodes used in conjunction with Offner paste. These potentials were amplified by a dc-coupled Offner RS dynograph, the output of which was also displayed on a Tektronix 502A dual-beam CRO and photographed on 35-mm film.

The S was seated in an electrically shielded darkroom with

his movements restricted by a chin rest and head holder. A frame held a sliding glass plate in front of his eyes, arranged so that when the slide was moved from side to side the S looked through plain glass with both eyes or through plain glass with the left eye while an Ilford neutral density filter (25% transmittance) covered the right eye. This was done to minimize changes in eye position compensating for the purely refractive effects of the filter. A microswitch signalled when the filter was slid in place before the eye.

The stimulus object was a pendulum bob made from a white cardboard disc 2.5 cm in diam. Light from a shaded tungsten bulb out of the direct view of the S shone upon the disc to give it an illuminance of 1 ft-L as measured by an SEI photometer. The pendulum bob was attached to a thin steel rod painted black and driven by a modified metronome movement having a period of approximately 1.5 sec. Viewing distance was 1.5 m and the arc of the pendulum subtended a horizontal visual angle of 20 deg. The pendulum background was painted matt black to maximize contrast. The metronome clicks actuated a voice-operated relay thereby operating the dynograph time marker and also provided a synchronizing pulse to trigger the horizontal sweep of the CRO.

EXPERIMENT 1

Method

After the skin had been cleaned with ether and lightly abraded with fine sandpaper a pair of electrodes were attached at the outer canthi of the right and left eyes. The potential between the electrodes was therefore the sum of the EOG potentials of each eye, and it was assumed that conjunctive and disjunctive changes in binocular eye movements would be readily detected as a result. An earthing electrode was also used, attached behind the right ear.

Following a period spent calibrating the EOG and adapting the S to the dimly-lit room, the experiment proper began. The S was asked to observe the pendulum bob and on command operate a handle which moved the filter over or away from his eye. He was asked to report verbally when the Pulfrich effect occurred and when it ceased. Continuous EOG recording was made on the Dynograph paper and samples of the EOG potentials photographed on single frames of 35-mm film.

Results

All Ss reported a pronounced Pulfrich effect under the filter (F) condition, and never reported the effect under clear (C) conditions. The latency of the effect following the beginning of the F condition was approximately 2.0 sec and was consistent over Ss. All Ss showed a relatively smooth sinusoidal EOG under both the F and C conditions. The pattern showed a transient disturbance as the conditions were changed but stabilized rapidly. A typical section of record is shown in Fig. 1.

Measurements were taken of the peak-to-peak amplitude and the period of the Dynograph trace under the F and C conditions and the data submitted to simple analysis of variance. No significant difference was found between conditions for any S, the F ratios being, in fact, so low ($F < 1$; $df = 2/32$) that the variance observed could be mainly attributed to instrument and measurement errors.

The form of the traces under the F and C conditions was compared by superimposing the projected images from the 35-mm film record. No obvious difference could be detected

Fig. 1. Dynograph record of EOG potential summed across both eyes while viewing pendulum under "natural" instructions. E_I displays the EOG under clear viewing (C), latency (L), and Pulfrich (F) conditions. E_{II} shows the transition from F to C conditions. P_I and P_{II} are event marks recording each end of the pendulum swing.

by simple visual inspection. We regret that we lack a computer of averaged transients needed to make a more detailed analysis of the EOG waveforms.

EXPERIMENT 2

As there was no evidence of any significant difference in the EOG under the F and C conditions in Experiment 1, the next step was to repeat the procedure and investigate the effect of instructions upon the eye movement patterns, and, hopefully, upon the observed magnitude of the Pulfrich effect.

Method

The same four Ss were used, and they were instructed to either fixate upon the pendulum bob and actively follow it with their eyes, or alternatively to fixate upon a 1-cm red spot placed immediately behind the center point of the pendulum path. The instructions were alternated a number of times in each session with rest periods of "natural" viewing. The Ss were also asked to report on the magnitude of the effect and any change in the apparent path of pendulum in either the F or C conditions.

Results and Discussion

The Ss reported the full and normal Pulfrich effect under the F condition both with instructions to fixate upon the moving bob and instructions to fixate on the red spot. There is, of course, a criterion problem here as one is relying completely upon the Ss' verbal reports. Nevertheless, the Ss could by this time have been considered well practiced, and there is no obvious demand feature in the experiment to bias their responses. Moreover, each S could directly observe the effect as he changed from fixating on a fixed point to fixating the moving pendulum without delay or change of head position.

Inspection of the dynograph records showed that under the instruction to actively track the moving bob the eye movements were of greater amplitude and approximated the 20-deg arc of the pendulum, although the traces were generally less smoothly sinusoidal than they were with free viewing due to a tendency to over- and undershoot from time to time. (See Fig. 2). The amplitude and period of the traces under the F and C conditions were again measured and submitted to simple analysis of variance. Again, F ratios obtained were insignificant ($p > .1$).

The EOG records under the fixation instructions again

Fig. 2. Dynograph record of EOG summed across both eyes while viewing with instructions to fixate upon the swinging pendulum bob and actively track its movement. E_I , E_{II} , etc. as in Fig. 1.

showed little to support an eye movement account of the Pulfrich phenomenon. While Ss differed in their ability to maintain fixation for any length of time, all managed to hold fixation to within a fraction of a degree for several seconds under the F and C conditions. Figure 3 shows a section of record under the fixation instruction. Figures 1-3 are taken from the record of the same S. There seemed no point in measuring records like that shown in Fig. 3 and analyzing them statistically.

EXPERIMENT 3

If the underlying mechanism of the Pulfrich effect involves some sort of alternating gating in each half of the visual pathway, the results of Experiments 1 and 2 indicate that suppression of vision during macrosaccades can hardly be invoked as the mechanism involved. But the technique used in the first two experiments summed the EOG of the two eyes and there remained the faint possibility that changes in the movements of each eye were taking place, but in such a way that they were cancelled out in the combined record. Therefore, all the procedures reported above were repeated using one S with pairs of electrodes mounted at the inner and outer canthi of each eye giving the EOG from each eye independently. The earth electrode was again attached behind the right ear.

Fig. 3. Dynograph record of EOG summed across both eyes with instructions to fixate upon a static point directly behind center of the swing of the pendulum bob. E_I , E_{II} , etc. as in Fig. 1.

Fig. 4. CRO record of EOG from left (upper trace) and right eyes, respectively, with a filter (25% transmittance) occluding the right eye. S under "natural" viewing instruction and reporting full Pulfrich effect. The polarity of the upper trace is inverted giving a false impression of disjunctive movement. CRO calibration: Vertical reads 10 deg eye movement per major scale division, horizontal timebase is 0.1 sec per major scale division.

Results and Discussion

Figure 4 shows a sample of the CRO record under conditions of naturalistic viewing with the filter in place and the S reporting the Pulfrich effect. The apparently disjunctive movement in Fig. 4 is simply due to the polarity of the input to the upper beam being inadvertently reversed. Fig. 4 shows that in spite of the presence of noise in the trace from the left (no filter) eye the smooth coordination of movement of each eye is obvious. The spike on the lower trace is an artifact from the synchronizing pulse. Again, statistical analyses performed upon these records showed no difference in the EOG

Fig. 5. CRO record of EOG from left (upper trace) and right eye with filter (25% transmittance) occluding the right eye and S instructed to fixate upon a static point behind the center of the pendulum swing. S shows disjunctive eye movements, but reports full and normal Pulfrich effect. CRO calibration: 5-deg eye movement per major vertical division; time base: 0.1 sec per division.

peak-to-peak amplitudes between eyes or between the F and C conditions.

Perhaps the most remarkable demonstration of the independence of the Pulfrich effect from gross eye movements is shown in Fig. 5, where, under instructions to fixate, the right eye is maintaining fixation while the left is making sporadic tracking movements. Under the F condition the S reported the usual Pulfrich effect. This result was not due to an apparatus error as normal EOG traces were obtained when the S was instructed to adopt free eye movement. The disjunctive eye movement pattern occurred towards the end of a recording session lasting several hours and has not been observed since.

SUMMARY AND CONCLUSION

An empirical test of the saccadic suppression explanation of the Pulfrich effect was carried out measuring horizontal eye movements by electro-oculography. It was found that the Pulfrich stereo effect is substantially independent of gross eye movement, and the effect occurs whether the S is following the moving pendulum with his eyes or fixating on a fixed point while observing the pendulum. One S reported the effect even when making disjunctive eye movements.

We can conclude that if an explanation of the Pulfrich effect in terms of gating information from each eye is to be sustained, suppression of vision during macrosaccadic eye movement cannot be invoked as the basic mechanism. It is possible, but unlikely, that suppression during microsaccades is involved, as the Pulfrich effect is equally apparent under conditions of both fixation and active tracking, and microsaccades are suppressed throughout most of a macrosaccadic movement.

We find no evidence of change in the pattern of horizontal movement of the eyes between normal viewing of a swinging pendulum and viewing with a neutral density filter before one eye, at least with the methods at our disposal. Computer averaging might reveal such a change, but it would certainly be minor and not sufficient to account for the observed magnitude of the Pulfrich effect.

In conclusion, these data do not support Harker's (1967) saccadic suppression explanation of the Pulfrich stereophenomenon. If differential suppression of input from each retina is involved in the effect, some other gating mechanism must be postulated to account for it.

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NOTES

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2. This research was carried out with the junior authors under the direct supervision of the senior author as part requirement for the degree of Bachelor of Arts at the University of Otago.

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