Luminance-driven delays measured with the Pulfrich effect and the eye-movement correlogram

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Introduction

Changes in eye movement latencies with changes in stimulus parameters might be interpreted as a measure of sensory processing time; is this interpretation valid?

The Pulfrich effect is an example of a perceptual phenomenon traditionally explained by an early sensory delay.

In this project sensory delays resulting from luminance changes are estimated by: 1) psychophysical nulling of the Pulfrich effect; and 2) eye movement latencies estimated using a correlogram analysis.

The Pulfrich Pendulum

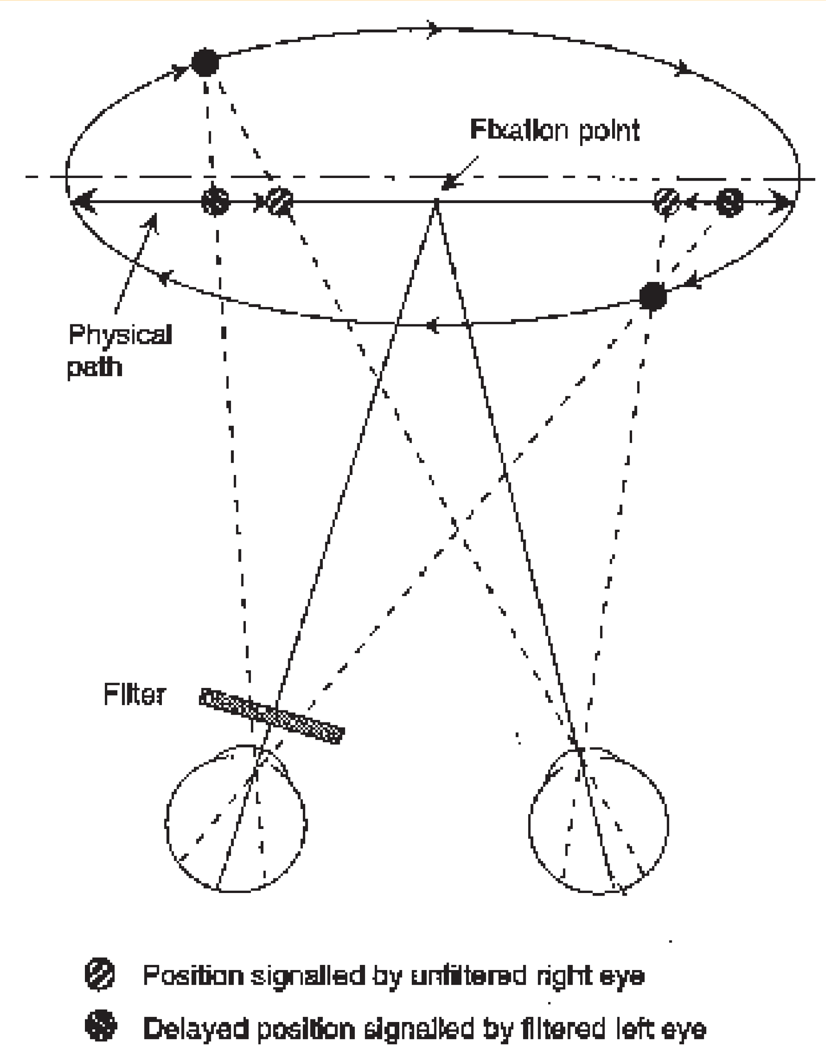


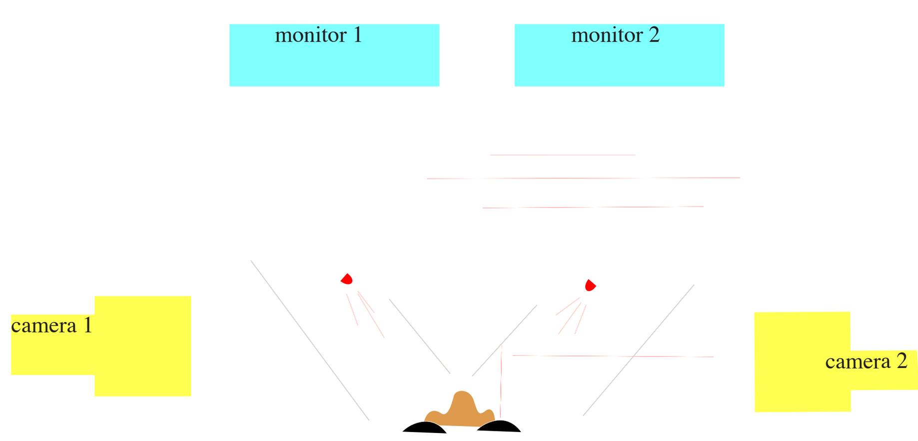
Figure from Howard and Rogers (1995), "Binocular Vision and Stereopsis," Oxford University Press, p. 536.

The **Pulfrich Effect** refers to illusory motion-in-depth which is seen when a target oscillating from side-to-side in the fronto-parallel plane is observed with a neutral density filter over one eye. The effect can be explained by the **visual-latency spatial-disparity hypothesis** (attributed by Pulfrich to Fertsch), in which the decreased luminance produced by the filter results in a delay; for the moving target, the delay results in a spatial disparity, producing a crossed or uncrossed binocular dispartiy depending on the direction of motion. A comprehensive review of the subject can be found in the recent book by Howard and Rogers (1995).

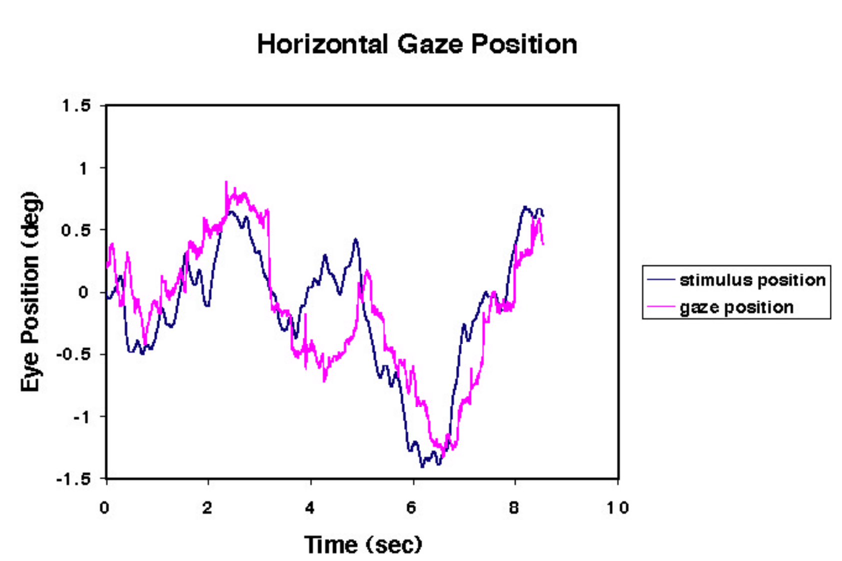
Psychophysical Methods

A dark Gaussian spot (100% contrast) was presented on backgrounds of different luminances, and moved horizontally with a sinusoidal trajectory at a temporal frequency of 1 Hz. Subjects viewed a pair of monitors displaying such stimuli through a mirror stereoscope. Subjects were instructed to judge the rotation in depth of the spot, and depress one button if the spot were seen to move to the right while in front, and another button if it were seen to move to the left while in front. The relative temporal phase of right- and left-eye trajectories was controlled by an up-down staircase. Psychometric functions were fit with cumulative normals, and the location of the inflection point was taken as the estimate of the interocular delay.

Eye Movement Methods

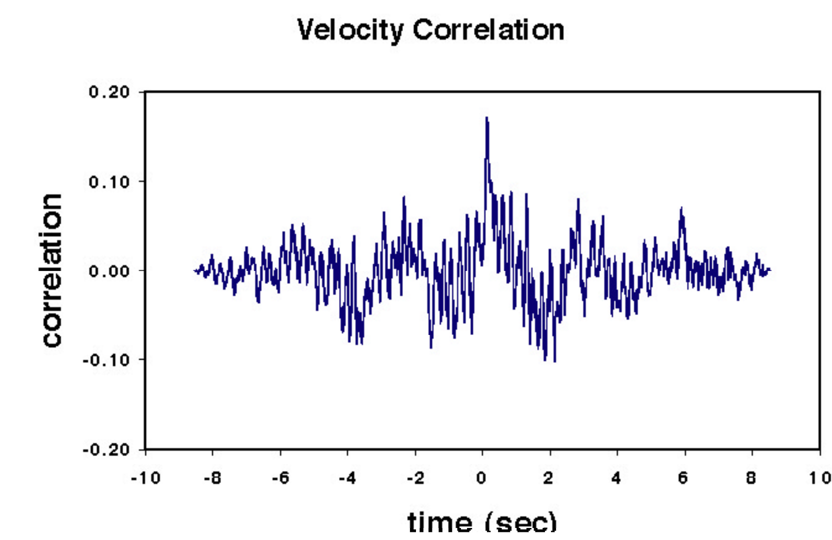


The mirror stereoscope was constructed using "cold" mirrors which reflect visible light but are transparent to near infrared. Behind these mirrors were placed a pair of video cameras fitted with infrared filters. A high-power infrared LED was used to illuminate each eye.

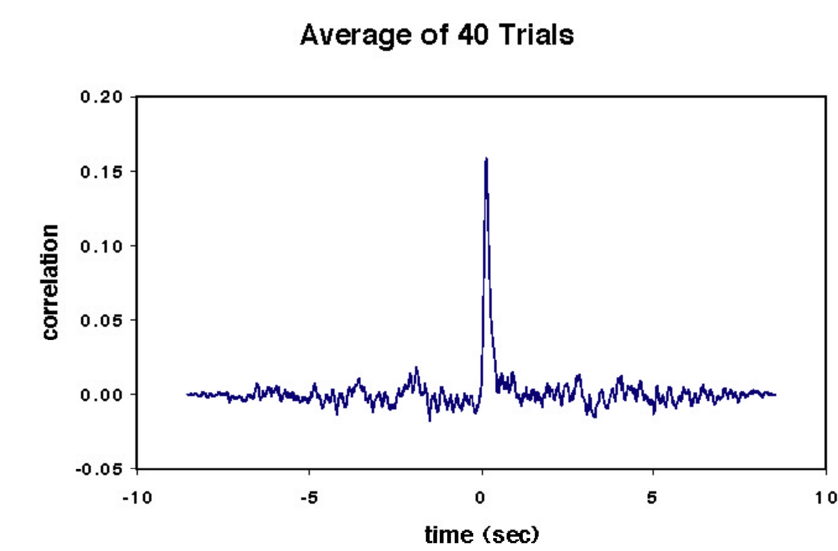


Subjects were instructed to track a small gaussian spot which moved randomly in two dimensions. Images of both eyes and the stimulus were captured and stored to an array of fast disks. These images were later analysed by software which localized the pupil margin and the first Purkinje image. The raw data were "calibrated" by finding the linear combination of the measurements which produced the closest agreement to the stimulus position.

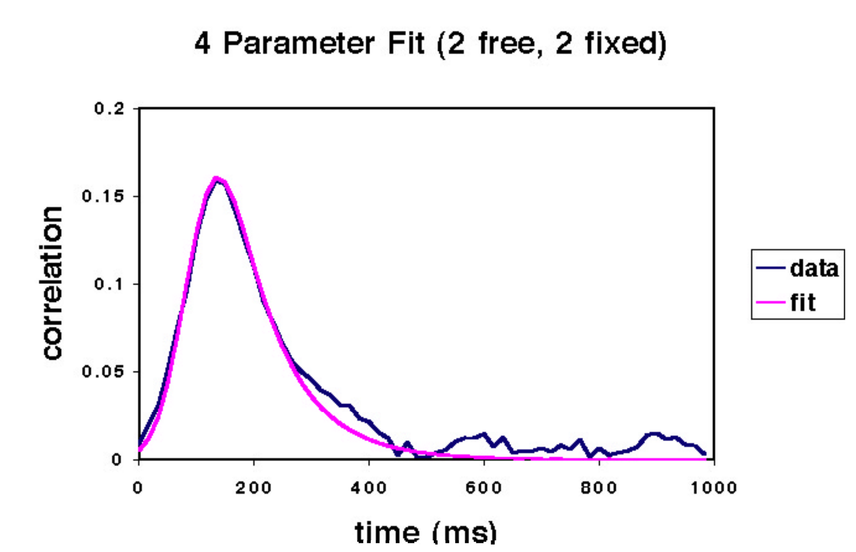
Correlogram Analysis



Stimulus and eye velocities were computed by simple differencing; the eye velocity was interpolated in the vicinity of saccades and blinks. The normalized cross correlation was computed between the stimulus velocity and the processed eye velocity in the horizontal and vertical dimension.

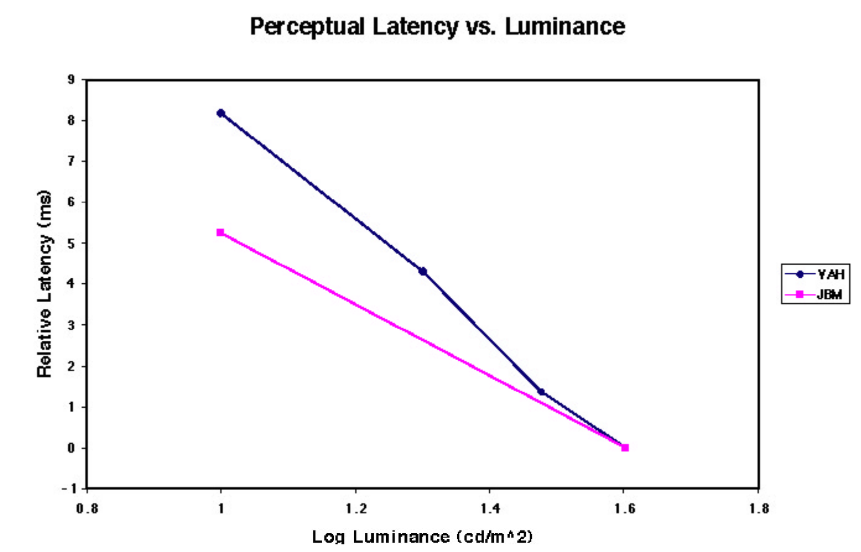


For a given eye and background luminance, a total of 40 presentations of 8.5 seconds duration were observed, and the resulting correlograms were averaged together. The random features wash out, while a sharp pulse at 150-200 milliseconds is revealed.



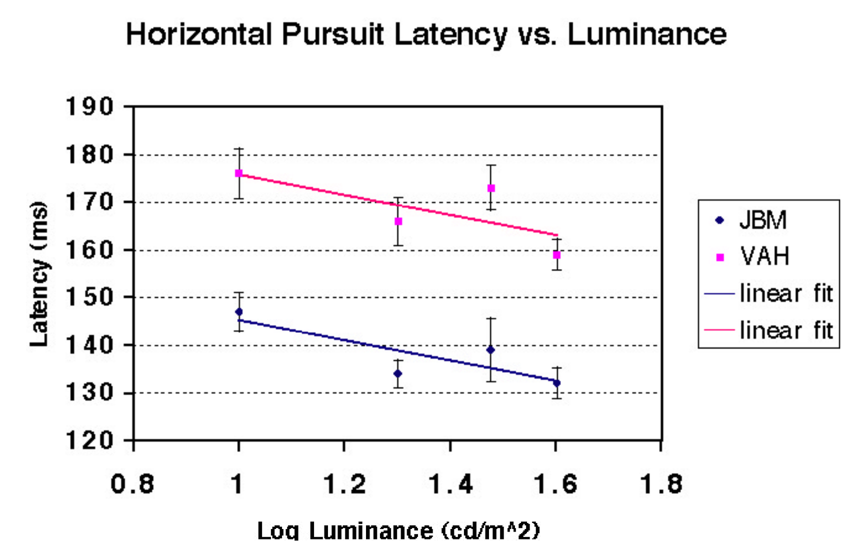
The correlograms are fit well by the convolution of a Gaussian with an exponential. Latencies (defined as the time of peak correlation value) are estimated from samples of the fit function.

Psychophysical Results

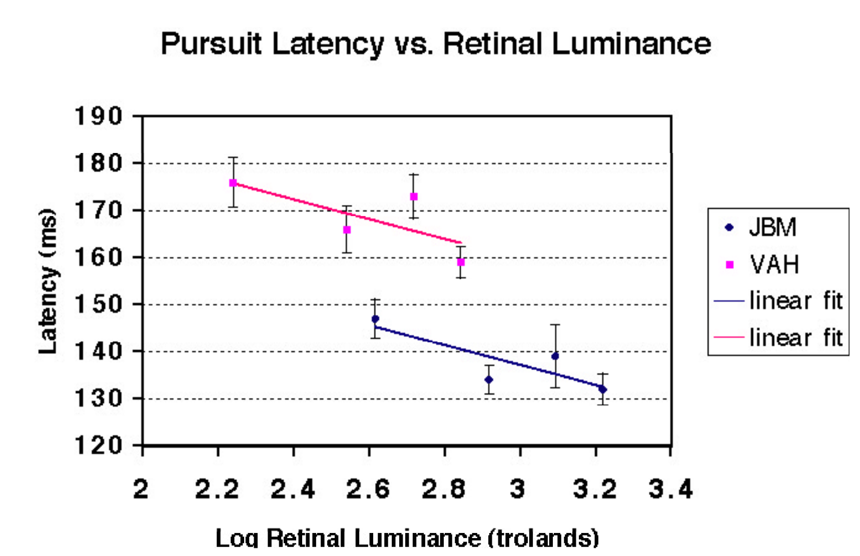


Given a set of relative delays between various pairs of luminances, the singular value decomposition is used to obtain a least squares estimate of delay as a function of luminance. The delay at the highest luminance is arbitrarily anchored at 0.

Eye Movement Results

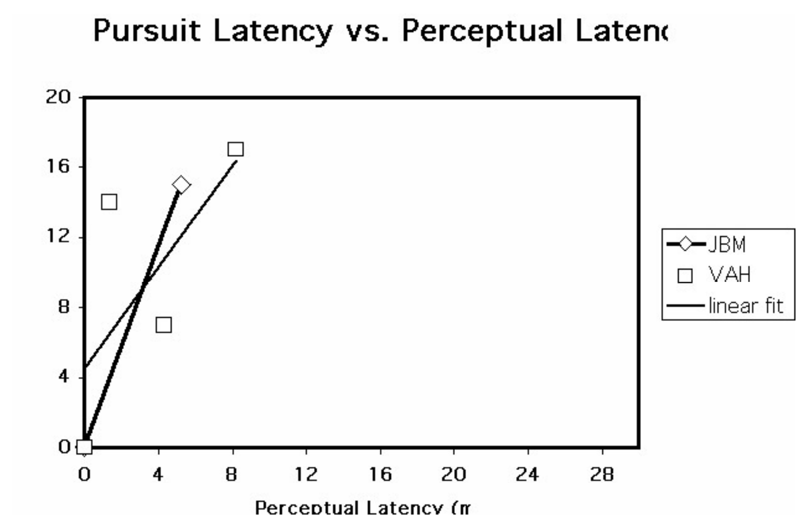


For a given luminance, the latency is estimated as the location of the peak of the fit to the correlogram. Each point in this plot is the average of 4 estimates (left and right eyes, under conditions of left- and right-eye stimulation.)



Correcting for subjects' pupil sizes brings the results slightly closer together.

Summary



Visual latency, measured by both eye movements and perceptual judgments, increases with decreasing luminance. The eye-movement effect has approximately twice the magnitude as the psychophysically measured perceptual effect.

It should be noted that the differences in eye-movement latency reported here are less than or equal to the temporal sampling period (1/60 second) of of the video eye-movement recording system. The fact that consistent results are obtained by interpolating smooth functions fit to the data is a tribute to the sensitivity of the method. Nevertheless, the result needs to be replicated with a higher frame rate system, and/or for larger luminance differences, both of which should result in a higher signal-to-noise ratio.

Conclusions

The present results do not confirm the idea that stimulus-driven differences in eye movement latencies can be strictly attributed to sensory processing delays, because the luminance dependency does not match that obtained psychophysically. These results suggest another interpretation in which weaker signals are propagated more slowly, with the overall delay depending on the particular pathway(s) involved.