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A moving cast shadow diminishes the Pulfrich phenomenon

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Abstract. It is demonstrated that the presence of a moving cast shadow diminishes the Pulfrich phenomenon. This complements previous work by Kersten, Knill, Mamassian, and Bülthoff [1996 *Nature (London)* **379** 31] indicating that visible cast shadows can override monocularly based cues to the perceived trajectory of a moving object. The present finding with the Pulfrich phenomenon indicates the effectiveness of shadows for overriding binocularly based cues to the perceived trajectory of a moving object.

1 Introduction

The Pulfrich phenomenon (Pulfrich 1922) is a visual illusion that occurs while viewing a pendulum binocularly with a neutral density filter over one eye. Observers experience the pendulum moving through an elliptical orbit rather than along its true flat trajectory. The phenomenon thus involves a misperception of the trajectory of a moving object that results from a luminance mismatch in the information presented to the two eyes [see Morgan and Thompson (1976) for a review of the classic explanation and history of the effect[1]].

Recent work has provided compelling evidence that moving cast shadows also affect the perceived trajectory of a moving object (Kersten et al 1996, 1997). Kersten et al found that observers perceived distorted object motion when the trajectory of the object's cast shadow was altered.[2] They used high-quality computer graphics to synthesize a ball moving at constant speed and height in a diagonal trajectory across a simulated checkerboard floor. Next, they added a variety of moving cast shadows that were either consistent or inconsistent with a stable light source and the 'true' synthesized motion of the ball. The 'inconsistent' shadows were designed to be consistent with an object moving along a variety of 'other' trajectories, including various kinds of bouncing balls, and balls that changed height while moving across the checkerboard. Adjusting *only* the motion of the cast shadow proved sufficient to perceptually induce dramatically different apparent trajectories of object motion. These 'distorted' object trajectories were consistent with the information provided by the cast shadow (Kersten et al 1997). They concluded that the information provided by the motion of an object's cast shadow is strong enough to override perceptual bias, such as the assumption of object size constancy and the assumption of a general viewpoint. These results suggest the importance of some relatively global scene-based analyses linking the motion of objects and shadows for interpreting local object motion trajectories.

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[1] See also Morgan (1975) for a somewhat different perspective on the cause of the illusion.

[2] The interested reader can find excellent computer demonstrations of these phenomena on-line. Sample digital movie examples of the demonstrations of Kersten and colleagues can be obtained at http://www.nature.com/Magazine/Archives/SuppInfo/kersten/figure1.mov or the annual CD-ROM distributed with issue 12 of *Perception*. See also pages under http://vision.psych.umn.edu/www/kersten-lab/kersten-lab.html for some very recent computer graphic simulations of the interaction between shadows and stereoscopic disparity.

We noticed during a classroom demonstration that the accidental presence of a cast shadow seemed to diminish the Pulfrich effect for many observers. This was interesting in light of the findings of Kersten et al (1996, 1997), indicating that shadows can override a host of monocularly based cues to object motion trajectories. A similar finding with the Pulfrich phenomenon would extend these results to indicate the effect of shadows on the interpretation of binocularly based cues to the motion trajectory of a moving object.

2 Demonstration

We confirmed our classroom observation formally with an experiment in which we compared shadow and no-shadow illumination conditions. With a neutral density filter over one eye, ten observers viewed 20 trials each of a pendulum moving with and without a cast shadow. We kept viewing distance and overall illumination conditions similar for both the shadow and no-shadow conditions. Observers responded "elliptical" or "flat" to the motion of the pendulum on each trial. The presence of the shadow diminished the proportion of elliptical judgments significantly, $F_{1,9} = 27.29$, $p < 0.01$ (see also figure 1).

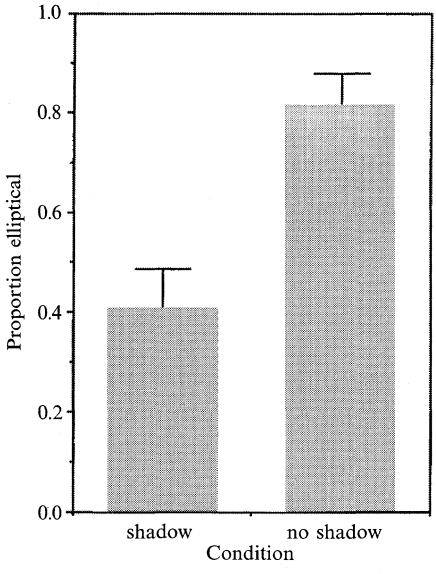

Figure 1. Proportion of 'elliptical' judgments as a function of the shadow and no-shadow conditions.

3 Discussion

The presence of a moving cast shadow diminished the tendency of observers to experience the Pulfrich effect, indicating that the shadow information was weighted strongly enough perceptually to override contradictory stereoscopic information. Perhaps the most interesting aspect of a cast shadow as a cue to an object motion trajectory is the relatively global scene-based nature of the information it provides. Clearly, to make use of the information the cast shadow provides, the motion of the object and of the shadow must be linked perceptually, and the contradictions between these two trajectories must be resolved. In the computer-graphics demonstrations of Kersten et al (1997), the object and the shadow motions are both specified in the context of a host of rich monocular scene cues. The basis of object motion in the Pulfrich phenomenon, on the other hand, is primarily stereoscopic in nature[3] and contradicts the

[3] It is worth noting that Thompson and Wood (1993) have demonstrated that stereoblind observers (ie observers who experience no interocular motion aftereffect and cannot fuse random-dot stereograms) still experience the Pulfrich phenomenon. They conclude that stereoblind observers, so defined, must retain some residual binocular depth mechanism, and speculate that such residual abilities may be based on the lower-resolution magnocellular pathway.

other available scene cues. As such, the present data indicate that, in addition to the effects cast shadows seem to have on perceptual bias and global viewpoint assumptions (Kersten et al 1997), they would also appear to affect the interpretation of more local stereoscopic cues to object motion.

In summary, we believe that the present findings complement those of Kersten et al (1996, 1997) by adding stereoscopic information to the list of cues that the motion of a cast shadow can override. The present study is useful also in that it provides a simple 'low tech' demonstration of the importance of the role of moving cast shadows in the determination of an object-motion percept. This shadow condition may be tacked on easily to standard classroom demonstrations of the Pulfrich phenomenon. We have found that an overhead projector light is easily adapted to the task of projecting a shadow behind a moving pendulum.

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