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Perception of the speed of self-motion vs. object-motion: Another example of two modes of vision?[☆]

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ABSTRACT

We investigated the effect of reduced contrast on speed perception for two types of tasks: (a) the speed of a rotating image, an example of “object-motion,” and (b) speed of travel when viewing wide-screen videos recorded from inside a car, an example of “self-motion.” Both types of stimuli were presented over a range of spatial contrasts. The results showed that reduced contrast caused significant decreases of perceived speed for the rotating disk, replicating the well known Thompson Effect. Reduced contrast had inconsistent effects on perceived speed of self-motion, however, resulting in perception of faster self-motion at the lowest speed, slower self-motion at higher speeds, and no effect at intermediate speed. Although further research is needed, the differential effects of reduced contrast on perceived speed of object-motion vs. self-motion are consistent with evidence for two modes of vision.

1. Introduction

Among his diverse scientific contributions, Bruce Bridgeman had a long-standing interest in the functional distinction between two modes of vision: a *focal* mode for visual awareness and cognition, and an *ambient* mode for visual proprioception and guidance of action (Trevarthen, 1968; Bridgeman, 1991).[1] Bridgeman’s work showed that one can experience illusory misperception of an object’s location or motion, yet simultaneously point accurately toward the same object (Bridgeman, Lewis, Heit, & Nagle, 1979; Bridgeman, Kirch, & Sperling, 1981; Post, Welch, & Bridgeman, 2003). A similar type of illusion can be seen occasionally in natural conditions: When surrounded by wind-blown clouds, the moon appears to drift in the direction opposite to motion of the clouds. Based on the findings of Bridgeman and colleagues, one would predict that, while enjoying the sight of a “sailing” moon, an observer would still point accurately toward the position of the moon without sight of her hand. The fact that visual guidance of action (pointing) is unaffected by the perceived motion of the target (experience) added important evidence that focal and ambient visual processes involve functionally distinct neural systems (Held, 1968, 1970; Ingle, 1967; Schneider, 1967, 1969; Mishkin, Ungerleider, & Macko, 1983; Goodale & Milner, 1992).

In parallel with Bridgeman’s research, Leibowitz and colleagues were investigating the role of two modes of vision in driving. Like many complex tasks, driving involves both modes of vision: *focal* for seeing the roadway and objects of interest, and *ambient* for controlling the heading and speed of one’s vehicle (Leibowitz & Owens, 1977). Our interest was initially sparked by a widespread

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[☆] This research was conducted while Jingyi Gu and Rebecca D. Patterson were students at Franklin & Marshall College.

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[1] Nomenclature for the two modes of vision varies. Bridgeman framed the distinction as *cognitive* vs. *motor* (Bridgeman, 1991). We use the terms *focal* and *ambient* as originally proposed by Trevarthen (1968).

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behavioral problem in night driving. Despite serious limitations of night vision, most motorists routinely “overdrive” their headlights, travelling as fast at night as in daylight (Leibowitz, Owens, & Tyrrell, 1998; Herd, Agent, & Rizenbergs, 1980; de Bellis, Schulte-Mecklenbeck, Brucks, Herrmann, & Hertwig, 2018). This hazardous behavior is a major contributor to fatal crashes with low-visibility objects like dark-clad pedestrians (Owens & Sivak, 1996). We theorized that this dangerous behavior is unintentional, arguing that drivers are not aware of their visual limitations at night for two reasons: (i) controlling the vehicle requires no special effort at night because ambient vision evolved to operate efficiently in nocturnal as well as diurnal environments (Walls, 1942; Warrant, 2004), and (ii) the design of modern vehicles and road systems have compensated for degraded focal vision through use of lighting and reflective markings for important objects like instruments, other vehicles, highway signs, and lane delineators (Leibowitz & Owens, 1977; Leibowitz, Owens, & Post, 1982; Owens, 2003). Our *selective degradation hypothesis* was supported by later studies with night driving simulators, which showed that steering performance remains highly accurate in very dim light, even under scotopic conditions when the visual recognition abilities (e.g., acuity and contrast sensitivity) are very poor (Owens & Tyrrell, 1999; Brooks, Tyrrell, & Frank, 2005).

The present study extended investigation of two modes of vision in driving, focusing now on drivers’ perception of their speed in foggy daylight conditions. The central question was whether perception of the speed of self-motion is affected by reduced contrast in the same way as perception of the speed of moving objects. In the late 1970s, Thompson (1976, 1982) reported that the apparent velocity of drifting sinusoidal gratings decreased when spatial contrast is reduced. This illusion was replicated with a wide variety of more complex stimuli, including rotating gratings and dot patterns (Campbell & Maffei, 1981), blocks behind bars (Anstis, 2003), and motion-in-depth (Blakemore & Snowden, 1999; Brooks, 2001).

The strength and generality of the “Thompson Effect” raised concern that drivers misperceive their speed when visibility is poor. If reduced contrast affects perception of self-motion in the same way it affects the perception of object-motion, then in foggy conditions drivers would perceive their speed as slower than reality and, consequently, travel faster than they realize. This hypothesis was supported by a study of perceived speed that used a desktop driving simulator (Snowden, Stimson, and Ruddle, 1998). Their results indicated that perceived speed was slower with reduced contrast for both verbal estimates and speed matching tasks, suggesting that the Thompson Effect occurs for perception of self-motion when driving. This inference is questionable, however, because it is not clear whether the participants actually experienced self-motion. It is possible they perceived the display as a streaming pattern, perhaps like a video game, and their responses reflected perception of a complex form of object-motion. Similar findings from later studies are faced with the same question (e.g., Horswill & Plooy, 2008): Did their participants actually experience self-motion? It seems unlikely that they did because visual perception of self-motion generally requires wide-field stimulation of peripheral vision with relatively long viewing durations (Dichgans & Brandt, 1978; Palmisano, Allison, Schira, & Barry, 2015).

Unlike the findings with narrow-field simulators, a subsequent study of real-world driving found no evidence that perception of self-motion is affected by reduced contrast (Owens, Wood, and Carberry, 2010). Participants drove a car on a closed road course that included multiple hills, curves, intersections, road signs, and standard pavement markings. Three levels of “fog” were simulated by attaching diffusing filters to the test vehicle’s windows. Without view of the speedometer, participants completed three tasks with each contrast level: (i) verbal estimates of their speed, (ii) adjustments to match target speeds ranging from 25 to 70 km/h (15.5–43.5 mph), and (iii) responses to mark the “last possible” moment they could stop to avoid collision with a (simulated) wallaby, again over the same range of speeds.[2] Reduced contrast had no significant effect on verbal estimates of speed, although an interaction showed that, in the lowest contrast condition, drivers reported slower self-motion at the lowest speed (25 km/h), and they reported faster self-motion at higher speeds (60 and 70 km/h). Adjustments of speed to match target levels were consistently slower at all speeds under low contrast conditions, indicating that drivers overestimated their actual speed, which is opposite the effect of reduced contrast on perception of object-motion. Finally, contrast had no effect on participants’ estimates of minimum stopping distance. Taken together, all three measures of perceived speed when driving on a real road indicated that reduced contrast has little or no effect on drivers’ perception and control of their speed when driving.

We interpreted these findings as evidence that the effect of reduced contrast may be limited to perception of object-motion (a *focal* function), whereas it does not occur for perception of self-motion (an *ambient* function). This interpretation is consistent with earlier evidence that reduction of luminance to scotopic levels selectively affects focal vision (e.g., object recognition), while having little or no effect on the accuracy of steering in wide-screen night driving simulators (Owens & Tyrrell, 1999; Brooks, 2005; Brooks, et al., 2005). An earlier study by Leibowitz, Schupert, & Dichgans, (1979) had also found that reducing luminance to scotopic levels had not effect on visually-induced feelings of self motion (i.e., *vection*). Thus, similar to Bridgeman’s findings, results for vection, for steering in low light, and for perceiving speed when driving with low contrast all indicated that ambient vision operates accurately under conditions that impair focal vision.

Our interpretation of the road test could be questioned, however, due to an important methodological concern: Driving in the real world provides redundant information from multiple sensory modalities, including auditory, vestibular, proprioceptive, and efferent systems, as well as vision. Therefore, it is possible that the visual illusion occurred when driving with simulated fog, but it was overridden by concomitant non-visual information. It seemed that research using more tightly controlled conditions could be useful to ascertain the effect of reduced contrast on the *visual* perception of self-motion when driving.

The present study moved back to the lab to test the effect of reduced contrast on perception of the speed of self-motion when only visual information is available. First, we conducted an experiment to determine whether participants can estimate the speed of travel

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[2] Estimated minimum stopping distance provides an indirect measure of perceived speed; stopping distance increases as a function of kinetic energy, which is proportional to the square of speed (i.e., velocity^2).