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Performance and presence with head-movement produced motion parallax in simulated driving

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ABSTRACT

Driving simulator studies can reveal relevant and valid aspects of driving behavior, but underestimation of distance and speed can negatively affect the driver's performance, such as in performance of overtaking. One possible explanation for the underestimation of distance and speed is that two-dimensional projection of the visual scene disrupts the monocular-based illusory depth because of conflicting binocular and monocular information of depth. A possible solution might involve the strengthening of the monocular information so that the binocular information becomes less potent. In the present study, we used an advanced high-fidelity driving simulator to investigate whether adding the visual depth information of motion parallax from head movement affects sense of presence, judgment of distance and speed, and performance measures coupled with overtaking. The simulations included two types of driving scenario in which one was urban and the other was rural. The main results show no effect of this head-movement produced motion parallax on sense of presence, head movement, time to collision, distance judgment, or speed judgment. However, the results show an effect on lateral positioning. When initiating the overtaking maneuver there is a lateral positioning farther away from the road center as effect of the motion parallax in both types of scenario, which can be interpreted as indicating use of naturally occurring information that change behavior at overtaking. Nevertheless, only showing tendencies of effects, absent is any clear additional impact of this motion parallax in the simulated driving.

1. Introduction

Although driving simulation, among other things, is used for studying driver perception and performance for road and traffic safety purposes, it is evident that the simulation is not directly interchangeable with authentic driving. It might even be described as something of a weak imitation of reality, which partly emphasizes that the imitation in essence is based on perceptual simplification or conflict (c.f., Baumberger, Delorme, Bergeron, Paquette, & Flückiger, 2007). Conversely, at least with high-fidelity driving simulators, the simulation is certainly considered compelling, effective, and useful, with the overarching conclusion that driving simulator studies can reveal relevant and valid aspects of driving behavior (e.g., Bella, 2008; Godley, Triggs, & Fildes, 2002; Hallvig et al., 2013; Lee, Cameron, & Lee, 2003; Ng Boyle & Lee, 2010; Wang et al., 2010). The

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simulation not only facilitates manipulation of events and measurement of performance but also provides a safe environment, all of which are crucial for experimental research. Driving simulators are therefore frequently used to study various traffic scenarios including more or less critical circumstances (e.g., Anund, Kecklund, Vadeby, Hjälmdahl, & Åkerstedt, 2008; Caird & Hancock, 1994; Jamson, Lai, & Jamson, 2010; Kircher & Ahlström, 2012; Thorslund, Peters, Lidestam, & Lyxell, 2013; Underwood, Crundall, & Chapman, 2011). On the other hand, because the simulation is not directly interchangeable with authentic driving there is considerable effort invested in developing the simulators. For example, distance and driving speed tend to be underestimated (Baumberger, Flückiger, Paquette, Bergeron, & Delorme, 2005; Boer, Girshick, Yamamura, & Kuge, 2000), which may have negative impact on validity aspects in that it can significantly influence the performance of braking, obstacle avoidance, overtaking, and safe following distance (Kemeny & Panerai, 2003). Although occasionally achieved (e.g., Bella, 2008), it can be considered not necessary to have an essentially exact match between driver performance in the simulator and in the real world (Törnros, 1998). Still, an improved realism in the experience of distance and speed can be of key importance, for example, in studies of driver assistance systems in which estimates of performance are more accuracy dependent. The overall aim to improve driving simulators therefore seems justified.

The view of the virtual driving environment normally is presented with a two-dimensional (2D) projection of the visual scene. Although this means a natural lack of depth information compared with that conveyed by a real environment, the induced illusory depth is enough for creating a good sense of immersion and driving. Adding visual cues or information available to the observer, however, can increase the information consistency and the accuracy with which judgments of depth are made (Cutting & Vishton, 1995). With the lion's share of driving simulators utilizing 2D projection, one relevant question is what monocular information is left to add. The illusion of depth is primarily based on the monocular information of object occlusion, linear perspective, relative size of familiar objects, and relative motions of objects and texture patches. The relative motions – motion parallax – are a function of object locations at varying distance from a moving point of observation (or moving objects relative observer). A further specification is that when an observer translates laterally, the relative motion of objects located nearer than the point of gaze is in the opposite direction to the observer movement and objects farther away move with the observer direction of movement (e.g., Miles, 1998). The motion perspective (Gibson, 1950), or motion parallax, is most at use within 1.5 to about 30 m from the observer but may change if the observer is in motion (Cutting, 1997). Whereas motion parallax of objects and textures already is capitalized on in driving simulators, motion parallax of head movement is not (Andersson Hultgren, Blissing, & Jansson, 2012; Kemeny & Panerai, 2003). Motion parallax of head movement concerns information about depth available when the observer moves the head because objects farther away will shift less in the visual field than closer ones. Produced by either head movement or object motions these perspective transformations are sufficient to establish an unambiguous impression of relative depth independent of other perceptual information of distance and depth (Rogers & Graham, 1979). It has also been estimated that infants are sensitive to unambiguous depth from motion parallax by the age of about 14–16 weeks, and one hypothesis is that motion parallax develops before stereopsis and may be the foundation for depth processing in the middle temporal (MT) cortical area (Nawrot & Mayo, 2009). MT is one of several cortical areas attributed to the neuronal processing of visual motion (e.g., Duffy & Wurtz, 1993; Wurtz, Duffy, & Roy, 1993). Interestingly, head movement can significantly contribute to the accuracy of distance perception in the presence of optic flow information (Peh, Panerai, Droulez, Cornilleau-Peres, & Cheong, 2002). However, motion parallax from head movement is effective at relatively close distances, and it remains to be further scrutinized whether it can affect perception of simulated more distant events and relevant aspects of driving performance (Andersson Hultgren et al., 2012; Kemeny & Panerai, 2003).

It is important to stress that the mere presentation of a visual scene from a moving point of observation, simulating an activity such as car driving or aircraft flying (with visible ground), is in itself a powerful simulation of self-motion that can effectively produce sense of motion and spatial orientation in the viewer. But there is more to it because this coherent visual motion of optic flow (Gibson, 1950; Lee, 1980) is capable of dominating sensory signals from the other senses to elicit involuntary triggered body movement (e.g., Lee & Lishman, 1975). In other words, visual motion can elicit not only perceived change of body position, but also non-intentional body movement based on unconscious processing. Positron emission tomography of humans also has indicated evoked activity in a network of various cortical areas as result of optic flow or coherent motion over a large area of the visual field (Beer, Blakemore, Previc, & Liotti, 2002; Peuskens, Sunaert, Dupont, van Hecke, & Orban, 2001; Previc, Liotti, Blakemore, Beer, & Fox, 2000). For example, the results in Peuskens et al. (2001) showed stronger dorsal premotor activity in judgment of heading from optic flow than in a control task, which may represent a visuomotor connection automatically transforming the visual information of heading into motor schemes. This conceptualization of vision as an autonomous proprioceptive sense is in clear opposition to the classical view claiming vision to be only exteroceptive that only concerns the pickup of information about the environment (see also Lee, 1978, and Lee & Aronson, 1974). Milner and Goodale (2006, 2008) hold a similar standpoint against the view of human vision that strongly emphasizes 'passive' internal representation of the outside world. In their view, the ultimate function of vision to ensure an effective and adaptive output is reflected in an efficient linkage of visual input and motor output by a visuomotor system. This is far from the sequential processing stages of sensation, perception, and decision preceding action, which are more or less implicit in an overemphasizing of 'passive' internal representation or of a postulated more 'non-active' observer.

What then connects this short portrayal of visual functioning with the aim for improving driving simulation? One connection is that because perception is fundamentally connected to *action* or *movement* (e.g., Flach & Holden, 1998; Gibson, 1950; von Hofsten, 2004, 2009) it might not be sufficient to rely exclusively on presentation of *vehicle motion* to establish a simulation that is closer to an experience of authentic driving. What is fundamentally missing is the coupling between