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Driver headway choice: A comparison between driving simulator and real-road driving

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ABSTRACT

Driving simulators have become an established tool in driver behaviour research by offering a controllable, safe and cost-effective alternative to real world driving. A challenge for using driving simulators as a research tool has been to elicit driving behaviour that equals real world driving. With respect to driver headways few studies have made a direct comparison between behaviour in real and virtual environments. The present study compared driver headway choice in a driving simulator and in an instrumented vehicle. Twenty-two participants carried out instructions to either change their headway to a specific value or to choose a headway as they would normally do. The speed of the lead vehicle (80, 100 or 120 km/h) as well as the target headway (1, 1.5, 2 s) were varied between trials. Specific headway instructions were provided in seconds as well as metres. The attained headways were compared between the virtual and the real environment. Results show no significant difference between headway choice in the simulator and on a real road, neither for self-chosen nor for instructed headways. The results provide support for the use of driving simulators in studies on headway choice.

1. Introduction

Driving simulators provide a controllable, safe and cost-effective environment for gathering data, which makes them a valuable tool for research on driving behaviour (Kaptein, Theeuwes, & Van Der Horst, 1996). In a virtual environment, the safety of the driver is guaranteed even during dangerous driving manoeuvres, such as driving at short headways. Furthermore, these environments provide researchers with an increased level of experimental control. This enables them to perform experiments on driver behaviour that would not be possible on real roads. For example, new forms of driver support can quickly be implemented and tested in a controlled environment without the need to conform to road safety regulations (Schieben, Heesen, Schindler, Kelsch, & Flemisch, 2009; van Waterschoot, 2013).

Driving simulators may vary in their physical appearance and their realism regarding the reproduction of the driving experience. Kaptein et al. (1996) differentiate between three broader categories of driving simulators: low-level, mid-level and high-level. Low-level simulators usually consist of desk-mounted computer monitors and gaming like vehicle control equipment (i.e. steering-wheel, gear shift and pedals). Mid-level simulators include a vehicle mock-up, placed in front of a larger projection screen with one or more projectors. High-level simulators usually provide a 180–360° field of view, often affording the use of side- and rear-view mirrors, and a vehicle mock-up on a moving base with several degrees of freedom.

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1.1. Driving simulator validity

Regardless of a simulators elaborateness, the results obtained during driving simulator research need to be questioned with regard to their generalizability to the real world, their external validity (Allen, Rosenthal, & Cook, 2011; Engen, 2008; Kaptein et al., 1996; Mullen, Charlton, Devlin, & Bédard, 2011). Driver behaviour data that is gathered in an artificial scenario in a controlled environment may not resemble driver behaviour that is displayed in a comparable real world situation (Carsten & Jamson, 2011; Loomis, Blascovich, & Beall, 1999). The validity of results, that are produced in a driving simulator study, can be judged in more than one dimension. Several forms of validity of driving simulators have been identified (for an overview see, for example, Blana, 1996; Mullen et al., 2011). Of great importance is that the simulated environment elicits the same driving behaviour as does driving on a real road. This is denoted as behavioural validity. An important distinction here is made between absolute- and relative behavioural validity. Absolute validity is obtained when measures of driver behaviour in a simulated environment produce the same numerical values as driving on a real road (Blaauw, 1982). If that is not the case, measures can still have a relative validity when numerical values (in response to an experimental manipulation) point in the same direction, with a similar magnitude (Törnros, 1998). These definitions of validity make it impossible to refer to the overall validity of a driving simulator. Driving simulator validity has to be defined in relation to a specific research question (Kaptein et al., 1996). For example, several studies investigated whether driving simulators are suitable for research on speed behaviour specifically (Bella, 2008; Godley, Triggs, & Fildes, 2002; Shinar & Ronen, 2007). For a more comprehensive overview of driving simulator validation studies see Mullen et al. (2011).

1.2. Headway choice

The choice of an appropriate following distance is an essential skill in driving. Short distances have been identified as a major contributor to rear-end collisions (e.g. Knipling, 1993). Another term that has gained popularity in this context is headway. A distinction is made between distance headway, that describes the space between two vehicles in units of space (equal to following distance) and time headway, that describes the time difference between a vehicle arriving at a point on the road and the following vehicle arriving at that same point. For distance headways it can be argued that a driver's headway choice involves an estimation of the egocentric, absolute distance to the vehicle in front. In contrast to distance headway, the choice of a time headway involves the estimation of the time interval between the lead vehicle passing a particular point in space and the following vehicle passing that same point. This would imply that the process behind the estimation of distance headway is different from that of estimating time headway. Furthermore, time headway is an established measure for driving safety. The Netherlands, Sweden and France stand as examples for jurisdictions where drivers are taught that a time headway of 2 s is considered to be safe.

The importance of headway as an indicator of driving safety demands a better understanding of the relationship between the various forms of headway choice in the real world and in a driving simulator. However, few studies have compared headway estimation or headway choice between the two environments. Staplin (1995) observed that with oncoming traffic at an intersection the minimum gap that was still considered safe for a left turn was estimated larger in a simulator setting compared to the real world. Another study, using a truck-driving simulator, showed that, in verbal estimations, drivers underestimated distance headways in the stimulator compared to real driving (Panerai et al., 2001). Duncan (1998) found that keeping a constant headway was regarded as more difficult by participants driving in a simulator. These studies provide some direct comparisons regarding headway estimation, and maintenance in a simulator and the real world. However, they may be considered dated taking into account the technological development that has taken place in driving simulator research.

1.3. The role of visual cues in headway choice

A common criticism of driving simulators is the reduced level of realism of the simulation compared to the real world. The estimation of the egocentric, absolute distance is guided by an evaluation of certain visual cues that provide information about the position of objects in space (Jamson & Jamson, 2010; Kemeny & Panerai, 2003), such as optic flow (Bremmer & Lappe, 1999), binocular disparity (Cutting & Vishton, 1995) and motion parallax (Rogers & Graham, 1979). In comparison to real world driving, simulated environments provide only a limited set of these visual cues, at a lower quality (Kemeny & Panerai, 2003). While it may be argued that this reduces a simulator's physical correspondence to the real world, it is not clear to what extent it has an effect on the behavioural validity of the results. The evidence for the necessity of specific visual cues to correctly estimate egocentric distance (and with it distance headways) is often contradictory. For example, a lack of visual complex imagery (e.g. natural texture, lighting) has been linked to less accurate perceptions of egocentric distance in virtual environments (Loomis & Knapp, 2003). Yet, according to a study by Thompson and colleagues (2004) using a directed-action task (that is, physically approaching a particular location in space), distance in photorealistic virtual environments was estimated with a similar accuracy as in more artificial appearing environments. According to the Known-Size-Apparent-Distance hypothesis "discrete changes in the size of the retinal image of an object, whose known size remains constant, will be perceived as corresponding changes in the apparent distance of that object" (Epstein, 1961, p. 333). However, Haber and Levin (2001) argue that distance perception is independent of the perceived size of an object. In earlier experiments it was found that egocentric distance perception was affected by binocular compared to monocular presentation