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Looking forward: In-vehicle auxiliary display positioning affects carsickness

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ABSTRACT

Carsickness is associated with a mismatch between actual and anticipated sensory signals. Occupants of automated vehicles, especially when using a display, are at higher risk of becoming carsick than drivers of conventional vehicles. This study aimed to evaluate the impact of positioning of in-vehicle displays, and subsequent available peripheral vision, on carsickness of passengers. We hypothesized that increased peripheral vision during display use would reduce carsickness. Seated in the front passenger seat 18 participants were driven a 15-min long slalom on two occasions while performing a continuous visual search-task. The display was positioned either at 1) eye-height in front of the windscreen, allowing peripheral view on the outside world, and 2) the height of the glove compartment, allowing only limited view on the outside world. Motion sickness was reported at 1-min intervals. Using a display at windscreen height resulted in less carsickness compared to a display at glove compartment height.

1. Introduction

Motion sickness can be defined as a state of discomfort caused by real or apparent motion (Reason and Brand, 1975). Signs and symptoms of motion sickness are initially, among other things, (cold) sweating, pallor, burping, salivation, apathy, that may subsequently be followed by nausea, retching and finally vomiting. The occurrence and degree of these symptoms may vary considerably between people, however everyone with a functional vestibular system appears susceptible to motion sickness to some extent (Money, 1970). The underlying mechanism of motion sickness has been theorized to be a mismatch between actual and anticipated sensory signals, typically modulated through visual-vestibular conflicts (Bles et al., 1998; Bos et al., 2008). Alternatively, motion sickness has been proposed to result from postural instability, stemming from sensory information incongruent with how balance is maintained in a natural or known environment (Riccio and Stoffregen, 1991). Therefore, under either theory, *in*congruences in what is seen and (normally) experienced through other senses, such as when below deck at sea, or when reading a book in a car, can *aggravate* motion sickness. Conversely, congruent sensory information, e.g. looking at the earth-fixed horizon when on a moving ship, *alleviates* motion sickness, even when this is presented artificially (Bos et al., 2008; Feenstra et al., 2011; Tal et al., 2012).

Carsickness is a form of motion sickness of which two-thirds of all people have suffered from at some point in their life (Reason and Brand, 1975). Passengers in particular, rather than drivers, become motion sick, even when exposed to identical motion (Rolnick and Lubow, 1991; Dong et al., 2011; Chen et al., 2012). One reason for this is that when controlling a vehicle, motion can correctly be anticipated, reducing the discrepancy between sensed and expected motion. Another, related, reason for the increased risk of motion sickness of passengers is the fact that passengers are not required to have a view out-the-window to operate the vehicle. Restricted vision of the outside world was found to aggravate carsickness (Griffin and Newman, 2004). As opposed to the world outside the vehicle, the vehicle interior moves in conjunction with its occupant, increasing sensory incongruences as more of the visual field is occupied by the vehicle interior. The beneficial effect on motion sickness of out-the-window view holds was found to hold true for both central and peripheral vision independently.

Autonomous vehicles, or rather *highly automated vehicles* (Reilhac et al., 2016), are expected to replace conventional vehicles in the coming decades (see e.g. Litman, 2014). Potential benefits of these future self-driving vehicles are safer roads, reduced traffic congestion, increased fuel efficiency, and time saved by the possibility to engage in non-driving activities (Begg, 2014). However, extensive adoption of self-driving vehicles could lead to increased motion sickness in the general population. Currently, over three quarters of commuters in the US are the sole occupant of their vehicle when getting to work

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(McKenzie, 2015). This population of drivers will become passengers once automated vehicles are widely adopted. As mentioned, passengers have an increased risk of motion sickness compared to drivers. In addition to this, a key benefit of automated vehicles, i.e. engagement in non-driving activities, may further inhibit passengers' out-the-window view. This, in turn, exacerbates the visual-vestibular mismatch believed to underlie carsickness. However, concept car designs often show sizable, possibly even head mounted, displays to be used for work or entertainment. If engagement in such in-vehicle displays becomes the default state of the occupants of future vehicles, preventing carsickness is expected to become a considerable challenge for vehicle manufacturers. Consequently, display positioning could become a potentially important factor modulating motion sickness in future automated vehicles through influencing available peripheral out-the-window view.

In the present study we therefore aimed to investigate the effect of display positioning on motion sickness in car passengers using an in-vehicle display. We elaborated on an exploratory on-road study (Diels et al., 2016) which included a head-up versus head-down display position. Findings suggested that a head-up display may be able to reduce motion sickness. However, the study suffered from several confounding factors, most crucially the variability in vehicle motions due to the experiment taking place in traffic. For the current study we realised an experiment with reproducible vehicle motion and an hypothesis based on a within-subjects design with two conditions manipulating display position. In one condition the display was at windscreen height (HIGH), and in the other condition at glove compartment height (LOW), the latter offering only limited peripheral vision. The hypothesis tested was that the condition which allowed for more optimal peripheral vision, thus minimal visual-vestibular incongruences, would result in the least motion sickness. To be able to better interpret the main analysis concerning the effect on motion sickness between the two conditions, motion sickness across participants was also analysed both in proportional terms, and in terms of difference in increase in illness over time.

2. Methods

2.1. Motion stimulus and test environment

The study was undertaken using a typical medium-sized estate car (Volkswagen Passat). The vehicle was equipped with an automatic gearbox and cruise control. An accelerometer (Xsens Technologies B.V.) was mounted on the floor of the vehicle behind the front seats. An on-board computer recorded the motion sensor data in conjunction with controlling the task.

For controllability and safety reasons the experiment was realised on a privately owned tarmac road approximately 600 m long, without any other traffic present. Slaloms were driven around markers on the centre of the road 20 m apart, resulting in 13 40 m cycles on the 600 m long track. Each slalom manoeuvre was followed by a U-turn at the end of the track immediately followed by another slalom (see Fig. 1). Each slalom was driven at a constant speed of 25 km/h using the vehicle's cruise control.

Following a pilot study exploring the effectiveness of different slalom profiles, we found that a distance of 1 m between the vehicle and the markers at the peak of each lateral motion resulted in a stimulus that was provocative yet not leading to vomiting in a short period of time. As a result, each slalom had an amplitude of 1.5 m and a frequency of 0.16 Hz. This frequency in particular has been shown to be most provocative for motion sickness (O'Hanlon and McCauley, 1974). These slaloms were repeated 8 times, lasting 15 min in total, including the U-turns. There were two drivers, both of whom had practised driving the slalom at the test track beforehand. Participants were assigned to only a single driver to control for any variation between drivers.

2.2. Experimental conditions

Two display conditions were realised in otherwise identical circumstances. In the HIGH condition, the display was positioned at eye-height in front of the windscreen, providing considerable peripheral out-the-window view. In the LOW condition, the display was positioned at the height of the glove compartment, offering considerably less view on the outside world as compared to the HIGH condition. The display was pitched to ensure that the viewing angle was equal in both conditions. The seat could be raised vertically to compensate for participant height, keeping the display at eye-height.

2.3. In-vehicle display and task

The task was presented on a tablet with an 18 cm (7 inch) screen diameter mounted to the dashboard by the passenger seat in the two possible configurations (see Fig. 2). The distance to the screen was 60 cm, resulting in a FOV of about 15°. The task required constant visual attention, preventing participants from taking their eyes off the display and thus influencing their available peripheral vision. The task itself was an adaptation of the SuRT task (SuRT, ISO14198, 2012) and consisted of a continuous series of trials over the entirety of each of the 15-min conditions. In every trial a static grid of 36 arrows was presented with arrows pointing down, left, or right. In half of the trials a single arrow pointing up was present. The participant was instructed to push a ‘yes’ button on a hand-held box when an up-arrow was identified, and a ‘no’ button when the upward pointing arrow was absent. After responding, the next grid was immediately displayed regardless of response given, to keep the participant engaged. If within 3 s no button was pressed, a fixation cross was presented for 1s to indicate a miss, immediately followed again by the next trial. No other feedback on task performance was given. Participants were instructed to keep their visual attention on the task throughout the experiment and to keep their head in approximately the same position (i.e. “don't make large adjustments in posture during the experiment”).

2.4. Motion sickness measures

During each 15-min condition, participants provided self-ratings of

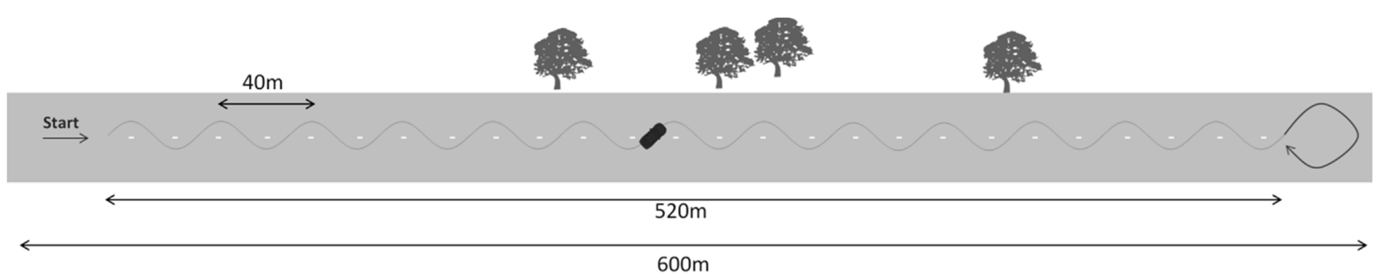

Fig. 1. Schematic of the test track. The vehicle was driven around 26 markings in slalom driving, corresponding to 13 cycles of 40 m. At the ends of the test track there was ample room to do a controlled U-turn. The amplitude of each slalom was 1.5 m measured from the markings to the centre of the car. The maximum angle of yaw as seen from the centre-line was about 20°.