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Driving simulator sickness: Impact on driving performance, influence of blood alcohol concentration, and effect of repeated simulator exposures

Arne Helland[a,b,*], Stian Lydersen[c], Lone-Eirin Lervåg[d], Gunnar D. Jenssen[d], Jørg Mørland[e], Lars Slørdal[a,b]

[a] Department of Clinical Pharmacology, St. Olav University Hospital, Trondheim, Norway
[b] Department of Laboratory Medicine, Children's and Women's Health, Norwegian University of Science and Technology, Trondheim, Norway
[c] Regional Centre for Child and Youth Mental Health and Child Welfare—Central Norway, Norwegian University of Science and Technology, Trondheim, Norway
[d] SINTEF Technology and Society, Department of Transport Research, Trondheim, Norway
[e] National Institute of Public Health, Oslo, Norway and Institute of Clinical Medicine, University of Oslo, Norway

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ABSTRACT

Simulator sickness is a major obstacle to the use of driving simulators for research, training and driver assessment purposes. The purpose of the present study was to investigate the possible influence of simulator sickness on driving performance measures such as standard deviation of lateral position (SDLP), and the effect of alcohol or repeated simulator exposure on the degree of simulator sickness. Twenty healthy male volunteers underwent three simulated driving trials of 1 h's duration with a curvy rural road scenario, and rated their degree of simulator sickness after each trial. Subjects drove sober and with blood alcohol concentrations (BAC) of approx. 0.5 g/L and 0.9 g/L in a randomized order. Simulator sickness score (SSS) did not influence the primary outcome measure SDLP. Higher SSS significantly predicted lower average speed and frequency of steering wheel reversals. These effects seemed to be mitigated by alcohol. Higher BAC significantly predicted lower SSS, suggesting that alcohol inebriation alleviates simulator sickness. The negative relation between the number of previous exposures to the simulator and SSS was not statistically significant, but is consistent with habituation to the sickness-inducing effects, as shown in other studies. Overall, the results suggest no influence of simulator sickness on SDLP or several other driving performance measures. However, simulator sickness seems to cause test subjects to drive more carefully, with lower average speed and fewer steering wheel reversals, hampering the interpretation of these outcomes as measures of driving impairment and safety. BAC and repeated simulator exposures may act as confounding variables by influencing the degree of simulator sickness in experimental studies.

1. Introduction

Driving simulation has numerous uses, such as training purposes, assessment of possibly unfit drivers and research in the fields of traffic safety and driving under the influence of alcohol and drugs (DUI) (Classen and Brooks, 2014). Driving simulators enable researchers to assess performance in various driving environments (i.e., city driving, highway driving, or situations or settings with high accident risk) under controlled laboratory conditions. Furthermore, simulators allow convenient measurement of several aspects of driving behavior.

One major obstacle to the use of driving simulators is the phenomenon of simulator sickness, a syndrome resembling motion sickness with symptoms including dizziness, cold sweats, drowsiness, nausea and vomiting. Simulator sickness is most likely caused by an incongruity of sensory input, with conflicting signals from simulated and actual motion, although other theories of causation also exist (Brooks et al., 2010). A variable but considerable proportion of test subjects in simulator trials experience simulator sickness, some to the extent that they are unable to complete simulator testing. For example, a study combining the results from

* Corresponding author at: Department of Clinical Pharmacology, St. Olav University Hospital Pb 3250 Sluppen, NO–7006 Trondheim, Norway.
E-mail address: arne.helland@stolav.no (A. Helland).

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several simulator studies reported a dropout rate due to simulator sickness of 17% (Brooks et al., 2010). Increased dropout rates reduce power and, perhaps more problematic, could introduce bias in the study population and confound results (Brooks et al., 2010; Classen et al., 2011).

The scientific literature on what influences driving simulator sickness and its impacts on performance is limited. Some factors that increase the likelihood of simulator sickness have been identified. These are related to the test subjects (i.e., older age, female sex, certain psychological states and traits), the test scenario (longer duration, more curves and turns, higher speeds, increased visual detail) and the technical setup of the simulator (broader field of vision, disagreement or delay between instrument operation and response of the virtual car) (Classen et al., 2011; Milleville-Pennel and Charron, 2015). Some techniques to alleviate simulator sickness have also been identified, including adaptation over time and neural or sensory stimulation (Domeyer et al., 2013; Galvez-Garcia et al., 2015). Hence, researchers of simulated driving may employ measures to limit the problem of simulator sickness to a certain extent. Various screening questions (i.e., history of motion sickness) and pre-trial testing are commonly used to exclude subjects that are prone to severe simulator sickness from experimental studies. Nevertheless, it is presently impossible to avoid completely the occurrence of simulator sickness in such studies (Brooks et al., 2010).

External validity is a precondition to the use of simulators – we must be able to trust that the data are relevant to real life. Thus, aspects of the simulator experience that differ significantly from the real-life driving experience must be investigated to determine if they influence measurements of driving safety directly, or if they in some way introduce bias in the interpretation of data. When present, simulator sickness may cause significant behavioral changes that could conceivably influence outcomes. Therefore, research on simulator sickness is important to assess the validity of simulator data, and to be better able to minimize the impact of simulator sickness on the results.

Although negative effects of virtual reality-induced symptoms (a syndrome resembling simulator sickness) on psychomotor control have been described (Cobb et al., 1999), little is known about the influence of simulator sickness on validated and commonly used measures of impaired driving in experimental studies, such as standard deviation of lateral position (SDLP). Thus, there is a risk that simulator sickness may confound the results. In addition, if simulator sickness leads to significant changes in the way test subjects drive, this could weaken the generalizability and validity of driving simulation results. In DUI research, alcohol is often used as a positive control (Walsh et al., 2008), yet alcohol inebriation may be associated with nausea as well as other complex central nervous effects that could influence symptoms of simulator sickness. Therefore, simulator sickness could be a source of operational confounding in such studies. Moreover, many studies use a design with repeated driving trials, where for instance a drug is given in different doses and/or compared to a placebo. Repeated exposures to the simulator might influence the degree of simulator sickness through either habituation or sensitization, which could pose a risk of procedural confounding. Two previous studies lend support to a habituation effect of repeated exposures (Kennedy et al., 2000; Domeyer et al., 2013). In an unpublished pilot study we conducted, we observed that the test subjects tended to complain less about simulator sickness when driving under the influence of alcohol, and after repeated exposures to the simulator. Given these observations, it seems prudent to further investigate the influence of such factors on the degree of simulator sickness.

In this paper, we explore the possible influence of simulator sickness on several measures of impaired driving, including SDLP, without making any pre-specified predictions regarding the direction of the outcomes. Based on findings in our pilot study, we also investigate the effect of blood alcohol concentration (BAC) and repeated exposures to the simulator on the reported degree of simulator sickness, hypothesizing that alcohol and repeated exposures attenuate simulator sickness.

2. Material and methods

The data presented in this article were generated in a validation study designed to compare driving performance in real and simulated driving at three levels of alcohol inebriation.

2.1. Test subjects

Twenty healthy, Caucasian males aged 25–35 years (mean: 28.7 years) were included in the study. The test subjects were recruited through medical students' organizations, student- and employee networks at the Norwegian University of Science and Technology, and the employee website of the SINTEF research institute. They were all recreational drinkers, and had all been in possession of a driver's license for at least 5 years (mean: 10.6 years) As a group they drove slightly more and were somewhat higher educated than the average population. For instance, 25% of our test subjects drove <10,000 km/year, compared to 35% in the general population, and 25% drove >20,000 km/year, compared to 18% in the general population. We recruited a rather narrow age group to minimize variability in driving experience and ethanol tolerance. Exclusion criteria were female sex, non-Caucasian ethnicity, prior or present drug/alcohol abuse, previous history of deviant (violent or aggressive) alcohol reactions or driving under the influence, intolerance to blood sampling, daily intake of any drug, or high likelihood of simulator sickness. We chose to exclude females because of the teratogenic effects of ethanol, which would necessitate interviews and administration of pregnancy tests before each test run. Non-Caucasians were excluded to avoid uncontrolled variation in ethanol tolerance and metabolism. The subjects received written information about the possibility of nausea/simulator sickness prior to inclusion, and that they were free to terminate the simulator driving anytime during the session. To avoid a high likelihood of simulator sickness, all volunteers were assessed with a modified version of the Apfel risk scale for postoperative vomiting (Apfel et al., 1998). The scale contained three items: Smoking status (yes = 0, no = 1), previous nausea/vomiting after surgery or other invasive procedures (yes = 1, no = 0), and car sickness after the age of 10 (yes = 1, no = 0). Persons with a score of 2 or higher were excluded. This method has not been validated to identify persons with high risk for simulator sickness. Before final inclusion, prospective participants underwent a screening trial of 20 min' duration in the simulator to exclude persons with excessive simulator sickness and familiarize them with the simulator to minimize learning effects. Three potential participants were excluded due to simulator sickness during the pretest trial. Information about the possibility of simulator sickness was repeated orally both at the pretest trial and at each study session. Each participant gave his informed consent and the study was approved by the Regional Ethics Committee.

2.2. Trial design

Each participant underwent three 1-h nighttime driving tests in the simulator, with at least 2 days between each test. The experiment was conducted as a randomized, placebo-controlled, single blind study, using a counterbalanced, multi-condition design to randomize the order in which the subjects were tested at different BAC. The intervention was concealed from study subjects, who also received sham treatment in the form of a placebo pill before