Accident Analysis and Prevention 74 (2015) 192–202

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Do mental workload and presence experienced when driving a real car predispose drivers to simulator sickness? An exploratory study

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ARTICLE INFO

Article history:
Received 13 March 2014
Received in revised form 18 July 2014
Accepted 20 October 2014
Available online 14 November 2014

Keywords:
Driving simulator
Virtual reality
Presence
Simulator sickness
Mental workload
Stress

ABSTRACT

This study is aimed at determining whether the simulator sickness (SS) experienced by some drivers is influenced by psychological factors, such as cognitive solicitation, affective factors and a feeling of presence. We also wished to determine whether SS is caused by an individual reaction to the virtual environment (VE) itself or can be attributed to a more general personal predisposition. For this reason, we considered three conditions: driving a simulator, driving one's own vehicle and driving a school-owned vehicle. Fourteen expert drivers participated in the study. Each drove under a different experimental condition and then responded to various questionnaires (SSQ, NASA-TLX and QPF). Our results showed that it is possible to identify at least three sources of explanation of why some people are more liable to feel sick in a driving simulator.

1. Theoretical framework

1.1. Driving simulator and applications

Virtual environment (VE) technology is advancing rapidly, with new applications becoming commonplace. One such application is the driving simulator. A virtual driving environment acts on the driver at both the cognitive and perceptive levels. To gain a better understanding of the relevance of this technology, it is important to consider that driving simulators allow people to drive safely in situations where their behaviour might otherwise put them at risk. In this respect, driving simulators have many uses. For example, they have been shown to be a useful teaching tool (Ekeh et al., 2013); they can also be used to test cognitive processes that are specifically involved in driving (Muhrer and Vollrath, 2011; Charlton, 2009; Chan et al., 2010; Horberry et al., 2006; Jamson and Jamson, 2010). Driving simulators are also well suited to assessing driving ability and increasing the standardization of evaluation (Milleville-Pennel et al., 2010).

Nevertheless, despite advances in technology and creativity, the use of driving simulators often features drawbacks. These drawbacks can be categorized under the heading of "simulator sickness (SS)" and can limit the development of this promising technology. Thus, in order to clearly establish safe parameters for VE exposure, it is essential that we first investigate and understand the factors that induce such a negative effect.

1.2. Driving simulator sickness

Many factors can make a person susceptible to the influence of SS and/or cause SS. Nevertheless, simulator sickness is generally considered to be a particular case of motion sickness. It consists of a physical reaction to being exposed to a VE; symptoms include disorientation, nausea, dizziness, sweating, drowsiness, eyestrain, headache, loss of postural stability, and vomiting (although the latter occurs infrequently). The severity of the side effects varies according to the participants and the VE in question; they can range from mild discomfort to debilitating illness (Drexler, 2006). In particular, the percentage of simulator users affected by SS varies widely, depending on the type of simulator used, the task being carried out and the way in which SS is determined. For example, Mullen et al. (2010) indicated that out of 25 participants, 13 (52%) failed to complete a simulated drive because of SS. Meanwhile, Park et al. (2008) indicated that out of 20 participants, 7 (35%) were considered to be too sick to continue on the driving simulator after 60 min had passed. These participants obtained an above-average score in the SSQ (simulator sickness questionnaire). Using a Virtual Research V6 helmet-mounted display (HMD), Stanney et al. (2003) reported that, of 1102 participants who were

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http://dx.doi.org/10.1016/j.aap.2014.10.021
0001-4575/

exposed to the VE, 142 (12.9%) were unable to continue because of sickness and, of the 960 participants who completed their exposure time, 81% reported higher levels of symptoms on the SSQ.

1.3. Measurement of simulator sickness

Usually, two types of measurement can be used to assess simulator sickness. Choosing one above the other depends on whether physiological manifestations are taken into account or whether a subjective assessment is carried out.

If we consider physiological parameters, many indicators can be used, including the cardiovascular system, respiratory system, gastrointestinal system, cold sweating and electrodermal activity. For example, Warwick-Evans et al. (1987) showed a consistent and positive association between increases in skin conductance and self-reports of motion sickness. However, the authors noted that the measure was overly sensitive to psychological (e.g. anxiety) and physiological (e.g. ambient temperature, motor-activity) influences. With regard to the cardiovascular system, Harm (2002) reported that studies of heart rate (HR), blood pressure (BP) and HR variability showed variable results concerning the direction of changes in each of these parameters during motion sickness. This variability can be due to a number of factors, including individual differences in response to motion sickness, the specific stimulus conditions (duration, intensity, type of sensory conflict), and/or the severity of motion sickness at test termination.

The most widely acknowledged subjective measure is undoubtedly the simulator sickness questionnaire (SSQ), first introduced by Lane and Kennedy (1988). This questionnaire contains 16 items, which are split into three component parts: (a) oculomotor symptoms (i.e. eyestrain, difficulty concentrating, etc.), (b) disorientation (i.e. dizziness, vertigo, etc.) and (c) nausea (i.e. nausea, burping, increased salivation, etc.). This structure has been widely used since its introduction (e.g. Kennedy et al., 1993, Brooks et al., 2010; Bouchard et al., 2011Kennedy et al., 1993, Brooks et al., 2010; Bouchard et al., 2011 Bouchard et al., 2011). Moreover the factor analysis revealed a global measure of overall sickness severity similar to the MSQ, known as the total severity (TS) score, that could be used as a general index of whether a particular device was producing a sickness problem (Kennedy et al., 1993).

1.4. Theoretical interpretation

Several theories have been proposed to explain motion sickness. The three theories most often considered are: sensory conflict theory, evolutionary theory and postural instability theory.

According to sensory conflict theory (Reason, 1978), the sickness that results from exposure to fixed-base simulators or virtual reality devices occurs because the visual stimuli provided by the device (i.e. apparent motion) disagree with the vestibular and proprioceptive input that indicates the body is stationary.

According to evolutionary theory (Treisman, 1977), motion sickness is the result of an erroneous interpretation that motion-induced inconsistency between sensory cues is caused by ingested toxins rather than the motion itself. Thus, motion-induced inconsistency stimulates the mechanisms of the vestibular system that normally facilitate the vomiting response to poisons. This theory is reinforced by many observations that show, for example, that people who are more susceptible to motion sickness are also more susceptible to toxins, chemotherapy, and post-operative nausea and vomiting (Golding, 2006; Money et al., 1996).

Postural instability theory (Riccio and Stoffregen, 1991) is an ecological theory of motion sickness. In contrast with sensory conflict theory, which assumes that sensory cue redundancy is a common occurrence, Riccio and Stoffregen (1991) claimed that redundancy of sensory system stimulation is, in fact, rare. They also claimed that non-redundant sensory information is common in natural and artificial environments, including many non-provocative situations. Conversely, prolonged postural instability is present in motion sickness situations, but not in other (non-provocative) situations. Riccio and Stoffregen (1991) hypothesized that motion sickness is caused by prolonged postural instability, which occurs in situations where an individual has not learned effective strategies to maintain postural stability. Studies carried out by Stoffregen and Smart (1998) and by Stoffregen et al. (2000) confirmed that postural instability precedes visually induced motion sickness in a physical moving room and in a virtual simulation of such a room (Villard et al., 2008).

1.5. Factors influencing SS

Whilst explanations of SS remain controversial, factors that may lead to SS are becoming more well known. These factors can be split into three categories: technological, user characteristics and psychological factors.

Technological factors consist of all the properties of the apparatus used to create and interact with the VE. The most-often cited are: navigational control (giving participants control of their actions will reduce their VE side effects; Stanney and Hash, 1998); display field of view (a larger field of view increases the probability of experiencing side effects; DiZio and Lackner, 2000; Lawson et al., 2002); spatial frequency of the visual display (lower frequency movements of <2 Hz are more nauseogenic than higher frequencies and that nauseogenicity increases as a function of exposure time and acceleration intensity; Drexler, 2006; Golding, 2006).

With regard to user characteristics, age, experience and gender, all play key roles in determining whether a participant will become sick. For example, Brooks et al. (2010) used a fixed-base driving simulator to show that older participants are more likely to develop simulator sickness than younger ones. Usually, infants and very young children are immune to motion sickness. Gender is also an important factor, with women appearing to be more susceptible to motion sickness than men (Dobie et al., 2001; Golding, 2006; Lawther and Griffin, 1988).

Individual experience can also influence SS. For instance, Stanney et al. (2003) indicated that previous exposure to provocative environments (e.g. simulators, aircraft, roller coasters, merry-go-rounds and carnival rides) decreases the likelihood of motion sickness. Thus, although sickness is positively related to exposure duration (Lawson et al., 2002), it can be reduced or eliminated by repeated exposure to motion (Hill and Howarth, 2000). A link between driver performance and SS has also been shown (Mullen et al., 2010). According to this study, participants who were unable to complete a simulated drive because of symptoms of SS showed better on-road driving performance than did those who completed the simulated drive. One interpretation of this result could be that more experienced drivers have more expectations about what they should feel in the VE in comparison with reality. These expectations might influence the way in which the brain interprets the information provided by the VE. This leads us to the final factor we wish to address in this section, the influence of psychological factors.

Psychological factors are certainly the least investigated and the least known. There is also the weakest consensus for them as factors in the occurrence of SS. This is mainly due to the fact that they extend over a vast field of investigation and they are often difficult to measure. Nonetheless, psychological factors that intervene when a user is evolving in a VE can be divided into three categories: cognitive solicitation (e.g. it may be worth considering how cognitive resources are solicited during a task in