Accident Analysis and Prevention 42 (2010) 788–796

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Simulator sickness during driving simulation studies

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ARTICLE INFO

Article history:
Received 13 August 2008
Received in revised form 1 December 2008
Accepted 21 April 2009

Keywords:
Simulator sickness
Motion sickness
Driving
Simulation
Simulator

ABSTRACT

While driving simulators are a valuable tool for assessing multiple dimensions of driving performance under relatively safe conditions, researchers and practitioners must be prepared for participants that suffer from simulator sickness. This paper describes multiple theories of motion sickness and presents a method for assessing and reacting to simulator sickness symptoms. Results showed that this method identified individuals who were unable to complete a driving simulator study due to simulator sickness with greater than 90% accuracy and that older participants had a greater likelihood of simulator sickness than younger participants. Possible explanations for increased symptoms experienced by older participants are discussed as well as implications for research ethics and simulator sickness prevention.

1. Introduction

Simulation is an invaluable research tool. Not only can it produce scenarios that are logistically or monetarily impossible, but it also eliminates a great deal of the risk associated with performing tasks in the real world. For this reason, although nearly any task can be simulated, simulation is most often used for tasks involving some degree of danger in order to provide an avenue for training, research, and even entertainment. It should come as no surprise then that some of the most commonly simulated tasks include flight, medical procedures, and the focus of the current study, driving.

Although simulation can eliminate the crash risks associated with on-road research, the use of simulation introduces another risk, a syndrome known as simulator sickness (SS). This malady, similar to motion sickness (MS), can potentially confound data (Lerman et al., 1993; Cobb et al., 1999), limit the effectiveness of training (Hettinger et al., 1990), and influence participant dropout rates (Cobb et al., 1999). This article addresses the various theories of MS and SS as well as some common measurement scales. Next, this article will present a method used in the Clemson University driving simulator laboratory to protect participants from simulator sickness. Finally, this article will consider practical concerns for practitioners and researchers dealing with simulator sickness and ways in which these concerns may be addressed.

1.1. The relationship between motion sickness and simulator sickness

Like MS, SS has been described as a syndrome because of the breadth of its symptoms, including headache, sweating, dry mouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting (Ebenholtz, 1992; Kennedy et al., 1993; Cobb et al., 1999). Cobb et al. (1999) have also documented a negative effect on psychomotor control, believed to be the product of SS. Moreover, user characteristics such as age, experience, gender, illness, mental rotation ability, and postural instability play key roles in determining whether a participant will become sick.

Older adults tend to be more susceptible to SS than younger participants (Roenker et al., 2003). Additionally, SS may vary by exposure time; Cobb et al. (1999) have suggested that SS symptoms steadily increase for up to one hour during exposure to a virtual environment before returning to nominal levels 15 min later. During this adaptation period, however, some subjects may become too ill to continue and thus never reach the 1-h mark. Finally changes in scene content may affect the likelihood and severity of SS (Jones et al., 2004).

While some researchers view SS as a type of MS which occurs in a simulated environment, there are several reasons to treat MS and SS as related but separate maladies. To begin with, MS appears to occur in a larger portion of the population and tends to be more severe than SS. Additionally, a key indicator of MS, drowsiness, does not necessarily indicate SS (Kennedy et al., 1993). Furthermore, eye movement disturbances are more common in SS.

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doi:10.1016/j.aap.2009.04.013

1.2. Theories of motion sickness and simulator sickness

Over the years, researchers have developed numerous theories explaining how MS and SS occur. The three most widely accepted by the MS and SS research community are the sensory conflict, postural instability, and eye movement theories. A fourth theory, the evolutionary theory, explains why, rather than how, MS and SS occur.

1.2.1. Sensory conflict theory

Reason and Brand's (1975) sensory conflict theory is probably the most widely accepted theory of MS and SS. The theory proposes that a conflict between or within sensory systems causes MS symptoms to arise. Specifically, conflicts between the motion one sees and the actual motion one is experiencing as well as conflicts between the structures within the vestibular system which detect and perceive direction and acceleration of motion are the two main contributors to MS and SS (Reason and Brand, 1975; Regan, 1994; as cited in Cobb et al., 1999).

In 1978, Reason proposed a Neural Mismatch Model suggesting that, for sickness to occur, sensory information must also be in conflict with one's own past experiences of a motion environment. Based on this model, sickness is most likely when sensory information is repeatedly contradictory, greatly disparate, or does not match one's expectations. More recently, Bles et al. (1998) have suggested that the visual–vestibular conflict is necessary and sufficient to produce motion sickness.

1.2.2. Postural instability theory

Riccio and Stoffregen (1991) opposed the sensory conflict theory by noting that congruent information from sensory systems is unusual even in normal, everyday tasks. Instead, they point out that maintaining postural stability is a natural inclination in most animals. According to this theory, MS occurs when one is placed in a novel environment in which effective ways to maintain balance have not been learned (Duh et al., 2004). For example, travelers at sea must learn ways to adjust to a ship's motion, often referred to as getting one's "sea legs." Once they return to land, their sea legs come with them, sometimes causing them to sway when standing or walking until they adapt to being back on land.

1.2.3. Eye movement theory

According to the eye movement theory of MS, certain stimuli can cause eye movements which create such tension in the eye muscles that they stimulate the vagus nerve resulting in MS (Ebenholtz, 1992). Ebenholtz (2001) has proposed that two specific eye movements, optokinetic nystagmus and vestibular ocular response, lead to MS and SS. In optokinetic nystagmus the eye pursues a target object from one end of a visual scene to the other. When the eye can pursue the object no further, it snaps back to the far side of the visual field where it begins to pursue again. Similarly, the vestibular ocular reflex is responsible for keeping a target object on the fovea (i.e. the center of the retina where one's vision is sharpest) when the head is turning. Thus, if one rotates one's head to the right 3° while fixating an object straight ahead, the vestibular ocular reflex causes the eye to rotate to the left 3°. Errors in these eye movements can result in headache, eye strain, and difficulty concentrating.

1.2.4. Evolutionary theory

Treisman's (1977) evolutionary theory of MS differs from the three aforementioned theories in that it attempts to explain why MS and SS occur rather than how they occur physiologically. Specifically, Treisman suggests that the human species has not had sufficient time to adapt to the relatively new modes of transportation we use today and that the body responds to conflicts in sensory information as if it had ingested poison, the effective reaction being vomiting, a common MS symptom (Money and Myles, 1974; Money and Cheung, 1983).

1.3. Methods of measurement

Two common surveys measuring symptoms of MS and SS are the Motion Sickness Assessment Questionnaire and the Simulator Sickness Questionnaire (SSQ). Although there are other measures of MS and SS, such as heart rate (Cobb et al., 1999), they are often recorded as secondary data.

1.3.1. Simulator Sickness Questionnaire (SSQ)

The SSQ (Kennedy et al., 1993) is the most frequently used measure of SS. It was developed to replace the Pensacola Motion Sickness Questionnaire (Kellogg et al., 1965) as a measure of the MS-like symptoms sometimes experienced during or after simulator use. The developers of the SSQ felt that a separate measure for SS was needed because of the slight difference in symptoms as well as their lower incidence and severity.

The SSQ contains 16 items rated by participants as "none", "slight", "moderate", or "severe". These items form three subscales, (1) nausea, (2) oculomotor disturbances (such as headache, eyestrain, and blurred vision), and (3) disorientation, which are combined by a series of mathematical computations to produce an overall SS score.

In 2006, Drexler suggested it may be possible to use the symptom subscales of the SSQ to distinguish various types of simulated environments based on the symptoms participants exhibit over a large number of exposures. It could also be possible to make predictions as to what symptoms a given simulator may produce given its attributes and the symptom sets produced by similar simulators.

1.3.2. Motion Sickness Assessment Questionnaire (MSAQ)

The MSAQ (Gianaros et al., 2001), another common measure of MS, asks subjects to rate the severity of four types of symptoms: (1) gastrointestinal (sick to stomach, queasy, nauseated, may vomit), (2) central (faint-like, lightheaded, disoriented, dizzy, spinning), (3) peripheral (sweaty, clammy/cold sweat, hot/warm), and (4) sopite-related (annoyed/irritated, drowsy, tired/fatigued, uneasy). The measure requires participants to rate the degree to which they are experiencing 16 symptoms from 1 (not at all) to 9 (severe). An overall MS score can then be calculated along with a score for each particular domain.

1.4. Use of SS Questionnaire in the Clemson University driving simulation laboratory

When we first began running participants in our driving simulator laboratory, we followed numerous suggestions for preventing SS, including screening for a history of motion sickness, migraine headaches, and pregnancy; keeping the room at a cool temperature; designing studies to allow participants ample opportunity to slowly adjust to the simulator experience; and encouraging participants to express any discomfort they felt during the study. Despite all of these precautions, we were unable to prevent all incidences of SS in the lab. Thus, we decided that a new screening measurement for SS, both before and during the study, was necessary.

This tool had to be quick and easy to administer as well as reliable at predicting SS. Pilot tests using both the SSQ and MSAQ revealed that participants were frustrated with the standard MSAQ rating scale. Specifically, participants with no symptoms repeatedly told us their score should be a "0" instead of a "1" (the lowest score on the MSAQ) since they were not experiencing symptoms while participants with severe symptoms felt their score should be a "10"