SIMULATOR SICKNESS IN A VIRTUAL ENVIRONMENTS DRIVING SIMULATOR

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Some users of virtual environments experience adverse effects known as simulator sickness. Common symptoms are generally grouped into nausea, oculomotor discomfort, and disorientation. This research examined whether the severity and type of simulator sickness differs due to the type of driving environment or the gender of the driver. Three environments with variations in driver workload were developed: Highway, Rural, and City. Tests were conducted using Northeastern University's Virtual Driving Simulator. The Simulator Sickness Questionnaire (SSQ) and postural stability tests, were used to gather data before and after participants drove the virtual environments based driving simulator. In comparison with past research, a different SSQ profile was found in that most of the symptoms reported were in the oculomotor discomfort category. This included eye strain, headaches, difficulty focusing, and blurred vision. Subjects who drove the Highway or Rural Road environments had more symptoms than those who drove the City environment. This indicates that vehicle velocity may be a factor in driving simulator sickness since subjects drove 60 mph in the Highway and Rural Road environments, but only 25 mph in the City environment. In both the before and after tests, females had less postural stability than males. Females also had a greater increase in oculomotor discomfort symptoms than males. Additional research is needed to determine why females experience more simulator sickness than males.

INTRODUCTION

This study investigated simulator sickness in a fixed-base virtual environments driving simulator which is described in Mourant and Jaeger (2000). In a fixed-base simulator, the visual system senses motion while the driver remains stationary. This conflict of sensory cues may result in simulator sickness that manifests itself in terms of a subject becoming nauseous and/or disorientated. Indicators of simulator sickness in fixed-based simulators previously reported have included nausea, disorientation, and ocular problems such as eyestrain, blurred vision and eye fatigue (Casali, 1986).

Measuring Simulator Sickness

The Simulator Sickness Questionairre (SSQ) (Kennedy, Lane, Berhaum, & Lilienthal, 1993) has been used extensively in studies of simulator sickness. Cobb, Nichols, Ramsey, and Wilson (1999) report the results of nine experiments using the SSQ. The SSQ has 26 possible symptoms and provides scores in four categories: nausea, oculomotor discomfort, disorientation, and general factors.

Another indicator of simulator sickness is the difference in postural stability before and after a simulator experience (Kennedy & Lilienthal, 1995; Kennedy and Stanney, 1996). Cobb & Nichols (1999) found a strong correlation between diminished postural stability and the oculomotor discomfort and disorientation categories of the SSQ.

METHOD

Subjects

Thirty subjects (15 males and 15 females) participated in the study. They ranged in age from 18 to 36 and had 20/20 or corrected to 20/20 vision. Participants were students at Northeastern University and were paid $10 for their services.

Procedure

Subjects were randomly assigned to one of three groups (highway, rural, or city) with the restriction that each group contain five females and five males. Detailed descriptions of the highway, rural, and city driving environments are given in Thattacherry (1999).

Upon arrival for the experiment, each subject's propensity for motion sickness was determined by a questionnaire which asked about nausea, headache, and dizziness in connection with automobile driving, amusement rides, air travel, ship travel, computer usage and simulators on a four point scale of 0 (never) to 3 (nearly always). If a subject had more than three incidences of nearly always, the subject was eliminated; however this never occurred.

Subjects were then given the SSQ followed by a postural stability test of trying to stand on one leg with eyes closed and arms folded across their chest for a maximum of 30 seconds. The postural stability test was repeated for two trials and the average time of maintaining stability was computed.

Each subject was given a two minute practice session using the driving simulator using a computer monitor as the display device. Then the helmet mounted display (HMD) was fitted to the subjects and adjustments were made for inter-pupillary distance and focus. Participants then drove the simulator for a five minute period. Subjects who drove the city route were asked to maintain a speed of 25 mph while those who drove the highway or rural routes were requested to maintain a speed of 60 mph.

Following immersion in the virtual environments driving simulator, subjects were tested again (two trials) for postural stability. This was followed by completing the SSQ questionnaire again.

Experimental Design

This study used a 2x3 between groups experimental design. Gender had two levels: female and male. Driving Environment had three levels: highway, rural, and city. Five female and five males were in each level of the Driving Environment factor.

Apparatus

The helmet mounted display worn by the subjects was a Virtual Research VR8. It has a horizontal field of view of 60 degrees, resolution of 640 x 480, and eye relief of 10-30 mm to accommodate subjects who may wear glasses. The HMD weighs 34 ounces and thus had little effect on head turning. An InterSense IS300 gyro-based head tracking sensor was mounted on the HMD to provide real-time head rotation data around the x, y, and z axes. The IS300 is not subject to electromagnetic interference.

The three-dimensional scene was generated using a 400 MHZ Pentium II computer. Frame rates ranged between 15 and 20 frames/second. There was no discernible lag when a subject turned his/her head. Subjects drove using the steering wheel, gas pedal, and brake pedal while seated in the cab of a real Dodge Caravan minivan.

RESULTS

Analyses of variance were done on the before and after scores. Paired t-tests were used to analyze differences between the before and after conditions.

Before and After Differences by Gender- SOPL

Average times for the two trials of the postural stability test of Standing On the Preferred Leg (SOPL) before and after immersion in the virtual environments based driving simulator were computed for all subjects. Shown in Figure 1 is the average time for SOPL as a function of gender and before and after immersion. The difference between the females' before scores (16.1 seconds) and their after scores (13.3 seconds) was statistically significant at $p < .001$. For males, the before scores averaged 24.0 seconds and the after scores 21.4 seconds. The difference approached statistical significance at $p < .06$.

Gender Differences within Before and After– SOPL

The difference between the females before SOPL scores (16.1 seconds) and the males before SOPL scores (24.0 seconds) was statistically significant at $p< .005$. Also statistically significant ($p < .01$) was the difference between the females after SOPL scores (13.3 seconds) and the males after SOPL scores (21.4 seconds).

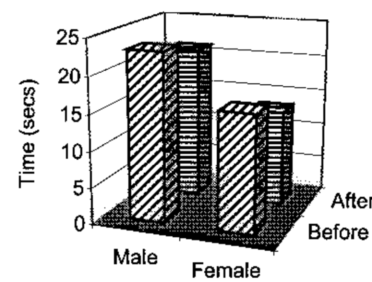

Figure 1. Before and after SOPL times by gender.

Before and After Differences by Driving Environment – SOPL

Figure 2 presents the average time for SOPL by driving environment before and after immersion in the virtual environments driving simulator.

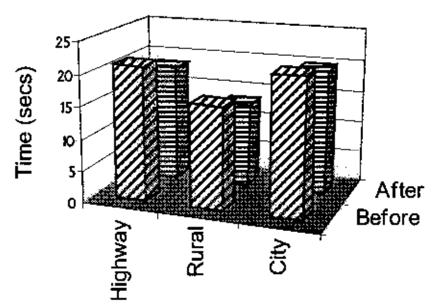

Figure 2. Before and after SOPL times by driving environment.

For the subjects who drove in the highway driving environment, the average before SOPL scores (21.1 seconds) were significantly higher ($p < .05$) than the average after SOPL scores (18.4 seconds). Also statistically significant ($p < .01$), the average before scores (16.2 seconds) for the subjects who drove in the rural environment were significantly higher than the average after SOPL scores (13.5 seconds). The before SOPL scores (23.0 seconds) for the subjects who drove in the city environment were not statistically significant from their after scores (19.8 seconds).

Driving Environment Differences within Before and After - SOPL

When considering the before means for the driving environments, the only statistical significant result ($p < .05$) was that the scores for the subjects in the city group (23.0 seconds) were significantly higher than those for the subjects in the rural group (16.2 seconds). Tests on the after SOPL scores revealed that the scores for the subjects in the city group (21.4 seconds) were again significantly higher ($p < .05$) than those for subjects in the rural group (13.4 seconds). No other differences were statistically significant.

Before and After Differences by Gender- Oculomotor (SSQ)

Figure 3 shows the SSQ oculomotor discomfort scores by gender before and after immersion in the virtual environments driving simulator.

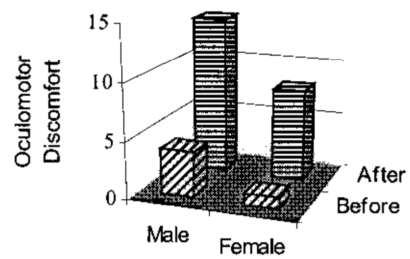

Figure 3. Before and after SSQ oculomotor discomfort scores by gender.

The average after oculomotor discomfort score for the males (14.1) was significantly ($p < .01$) higher than their before average (4.0). For females, the average after oculomotor discomfort score (8.1) was also significantly ($p < .01$) higher than their before average (1.0).

Gender Differences within Before and After– Oculomotor (SSQ)

The average before oculomotor discomfort score for males (4.0) was not significantly higher than the average before oculomotor discomfort score for females (1.0). Also not statistically significant was the difference between male (14.1) and female (8.1) after oculomotor discomfort scores.

Before and After Differences by Driving Environment - Oculomotor (SSQ)

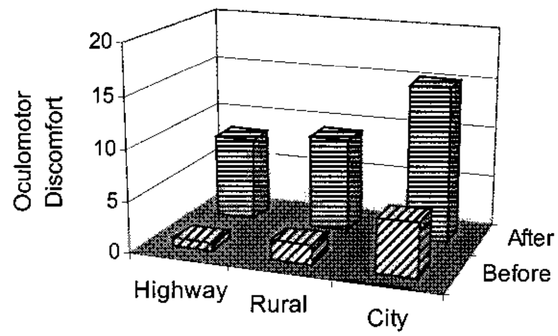

Figure 4. Before and after SSQ oculomotor discomfort scores by highway environment.

The SSQ oculomotor scores by driving environment before and after immersion in the virtual environments driving simulator are presented in Figure 4.

The difference between the average before and after oculomotor discomfort scores for each level of the highway environment factor was statistically significant (highway ($p < .05$), rural ($p < .05$) and city ($p < .01$)).

Driving Environment Differences by Before and After - Oculomotor (SSQ)

None of the differences between the levels of the highway environments factor for the before and after conditions were statistically significant.

DISCUSSION

SSQ Profiles

In Table 1 are the SSQ category scores for some recent studies on simulator sickness in virtual environment

Table 1
SSQ Category Scores After VE Exposure With a HMD

Study	Nausea	Oculomotor Discomfort	Disorientation
Kolasinski, et. al. (1998)	18.13	16.11	22.97
Ehrlich, et. al. (1998)	14.91	15.40	21.75
Stanney & Kennedy (1998)	30.21	25.74	41.47
Present Study	1.75	11.0	8.7

Stanney and Kennedy (1997) reported the D>N>O post-exposure pattern for sickness in virtual environments. This is what can be seen in Table 1 for the Kolasinski, et. al. (1998) and the Stanney and Kennedy (1998) studies. The Ehrlich, et. al. (1998) may be considered to be D>O=N. However, the subscale magnitudes and profile for the present study (O>D>N) is clearly different. This may be attributed to improvements in VE technology. This study used a high quality HMD, a very fast head tracker with no magnetic interference, and a computer graphics card that produced rapid frame rates.

Gender

In both the before and after conditions in this study males had significantly greater postural stability than females as measured by the amount of time they could stand on their preferred leg. This may be reflective of males having greater physical strength. Interestingly, the after SSQ oculomotor discomfort scores for males were higher than those for females, but the percent increase from the before condition was greater for females. In contrast, Kolasinski, et. al. (1998) reported higher post-exposure oculomotor discomfort scores for females (20.84) than males (11.37).

Highway Environment

Participants who drove in the highway or rural environments (speed about 60 mph) experienced significant decreases in the time they could stand on their preferred leg. This was not significant for those who drove in the city environment at about 25 mph. McCauley and Sharkey (1992) found that simulator sickness was related to the rate of global visual flow, or the rate at which objects flow through the visual scene. Thus, vehicle velocity in a virtual environment based driving simulator may have an effect on simulator sickness.

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