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Simulator Sickness Questionnaire: Twenty Years Later

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SIMULATOR SICKNESS QUESTIONNAIRE: TWENTY YEARS LATER

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Summary: The present study used simulator sickness questionnaire data from nine different studies to validate and explore the work of the most widely used simulator sickness index. The ability to predict participant dropouts as a result of simulator sickness symptoms was also evaluated. Overall, participants experiencing nausea and nausea-related symptoms were the most likely to fail to complete simulations. Further, simulation specific factors that increase the discrepancy between visual and vestibular perceptions are also related to higher participant study dropout rates. As a result, it is suggested that simulations minimize turns, curves, stops, et cetera, if possible, in order to minimize participant simulation sickness symptoms. The present study highlights several factors to attend to in order to minimize elevated participant simulation sickness.

INTRODUCTION

Simulator sickness is similar to motion sickness in that it generally results in feelings of nausea, dizziness, vertigo, and sweating (among other symptoms). Simulator sickness is generally the result of the discrepancy between simulated visual motion and the sense of movement stemming from the vestibular system. In many simulators, the visual system receives information that suggests movement (e.g., roadway scenes passing by the viewer), yet the vestibular system interprets a stationary status or movement that is not synced with the visual motion (e.g., delays in a motion system attached to the simulator). It is this discrepancy that causes simulator sickness in many people.

There are many different ways to assess simulator sickness (e.g., Gianaros, Muth, Mordkoff, Levine, & Stern, 2001); however the most popular is the Simulator Sickness Questionnaire (SSQ). The SSQ was published 20 years ago (Kennedy, Lane, Berbaum, & Lilienthal, 1993) and has since been cited over 800 times (Google Scholar, 2012). The three major objectives of developing this questionnaire were: "(a) to provide a more valid index of overall *simulator* sickness severity as distinguished from *motion* sickness; (b) to provide subscale scores that are more diagnostic of the locus of simulator sickness in a particular simulator for which overall severity was shown to be a problem; and (c) to provide a scoring approach to make monitoring and cumulative tracking relatively straightforward."

The SSQ is widely used to describe and assess simulator sickness. The questionnaire asks participants to score 16 symptoms on a four point scale (0-3). A factor analysis revealed that these symptoms can be placed into three general categories: Oculomotor, Disorientation, and Nausea (Kennedy et al., 1993). Weights are assigned to each of the categories and summed together to obtain a single score. Although the score is not intended to predict illness, it does

provide a description of overall simulator sickness scores for a given simulation or simulator environment.

Given that simulator technology has changed significantly over the past 20 years and that the SSQ is in widespread use, it is important to revisit the questionnaire. The present work sought to meet several goals. The first is to perform a factor analysis using data from a series of driving simulator studies to examine the similarities with the results of Kennedy et al. (1993; who utilized flight simulators). Furthermore, the current work explores the relationship between SSQ scores and participants' dropout rates as a result of simulator sickness symptoms. Very few participants actually arrive at emesis (vomiting) before electing to terminate participation in a simulation. As a result, the relationship of SSQ scores and individual symptom scores with participant dropouts are explored. Identifying a score, or range of scores, that leads to participant dropout may be useful in minimizing participant illness. For example, if a participant's symptom and SSQ scores elevate throughout a simulation and begin to approximate the dropout values, an experimenter would be able to stop the simulation in order to prevent sickness in the participant. This obviously has the potential to reduce the negative experiences of the participant.

The current study utilizes SSQ data from nine driving simulator studies, all performed in the same driving simulator. Simulation/experiment specific factors (e.g., stops, curves, turns, etc.) that may lead to higher SSQ and dropout rates are also explored.

METHOD

Driving Simulator

The simulator cab is a 1998 Saturn SL1. It is mounted on a platform that is raised three feet above the floor of the laboratory and is surrounded by a 240 degree wrap-around projection screen. The driving simulator utilizes a three degree-of-freedom motion base, defined in pitch, roll, and heave (Z). The motion base has the capability to generate low frequency vibrations to simulate roadway surface textures in addition to leans on turns and dips while braking. The following index shows the physical angular and linear limits of motion:

Mechanical Limits:

Pitch: +14.605° to –13.841°	Front Bumper: +20.93"-19.86", Rear +22.69"-20.98"
Roll: ±18.877°	Car Side: ± 10.68"
Heave (Z): 8"	

Software Imposed Limits (Filters):

Pitch: ± 12%	Front Bumper: ± 17.26", Rear ±18.71"
Roll: ± 15%	Car Side: ± 8.54"
Heave (Z): 8"	

Participants

SSQ data were collected from 995 participants over 9 different driving simulator studies (completed 2003 – 2012). It has been shown that illness decreases motion sickness thresholds (e.g., DeWitt, 1957; Kellogg et al., 1965). As such, participants in all studies were screened for

recent illness and recent alcohol consumption. Those reporting anything other than a healthy state were not allowed to participate.

In all studies at least two SSQs were administered (baseline and completion), though most studies included questionnaires throughout testing (e.g., during driving breaks). However, only the last SSQ for each participant was included in this data set. Participants who completed the study, but responded with a 0 for all symptoms were excluded. Participants who dropped out and had an overall SSQ score less than 10 were removed as it was believed these individuals chose to discontinue their participant for reasons other than simulator sickness (e.g., boredom). Additionally, participants who did complete and had an overall SSQ score greater than 55 were removed as it was assumed these individuals chose to "stick it out" despite obvious simulator sickness symptoms (combined there were 14 people in these two groups). There were 530 participants included in the final data set used in the analysis. A frequency distribution of the final data set is presented in Table 1 (each study was assigned a number 1 – 9). Each of the presented nine studies differed in the total number of participants. The values reflected in Table 1 represent the number of participants remaining after the above screening criteria were applied and not the total number of participants in a specific study.

RESULTS

Of the 530 participants, 72 experienced simulator sickness symptoms strong enough to terminate participation in the research study (not necessarily emesis) and are considered dropouts. Of those participants who scored greater than 0 on the SSQ, a dropout rate of about 14% across all simulations was found. Individual study dropout rates and summary statistics for the SSQ are shown in Table 1.

Table 1. Distribution of participants scoring greater than 0 on the SSQ, mean, standard deviation, minimum, and maximum for the SSQ scores; and dropout percentage by study

Study	*N*	*Mean*	*SD*	*Min*	*Max*	*Dropout %*
1	62	15.68	12.79	3.74	56.10	17.74
2	52	16.47	12.15	3.74	48.62	7.69
3	50	17.58	14.46	3.74	63.58	8.00
4	14	27.25	18.41	7.48	78.54	71.43
5	40	21.32	12.34	3.74	41.14	12.50
6	79	8.62	5.33	3.74	29.92	0.00
7	155	21.84	19.12	3.74	97.24	23.23
8	20	12.72	8.5	3.74	29.92	0.00
9	58	17.28	20.55	3.74	134.64	3.45

Confirmatory factor analyses are used to confirm a priori factor structure based on previous research. However, the exploratory factor analysis utilized in the development of the SSQ resulted in cross loadings (i.e., symptoms are assigned to more than one of the three factors). Thus, these results violated the best practice of single factor loadings preferred for a confirmatory factor analysis. As such, an exploratory factor analysis with a normalized varimax rotation and three factors restriction was performed and simply compared to the results of Kennedy et al. (1993). The rotated factor pattern is presented in Table 2.

As can be seen in Table 2, the simulator sickness symptoms load on the three factors identified by Kennedy et al. (1993) in a fairly similar manner (any value >.30 was considered a factor

relevant symptom). There are, however, a few notable differences. First, unlike in the Kennedy data, no symptoms were attributed to more than one factor (a desirable outcome in a factor analysis). Second, in the present data set, five symptoms were not attributed to any factor: burping, fatigue, headache, blurred vision, and fullness of head.

Table 2. SSQ symptom loadings based on the present data (2013) and that of Kennedy et al. (1993). The symptoms in grey did not load on to any of the three factors in the present data set

Symptom	Nausea		Oculomotor		Disorientation	
	2013	1993	2013	1993	2013	1993
Nausea	**.74** *	**.75** *	**.10**	**.08**	**.09**	**.30** *
General discomfort	**.64** *	**.65** *	**.22**	**.40** *	**.06**	**.18**
Stomach awareness	**.48** *	**.64** *	**-.03**	**.03**	**.27**	**.21**
Sweating	**.40** *	**.31** *	**.06**	**.24**	**.04**	**.08**
Increased salivation	**.32** *	**.53** *	**.01**	**.21**	**-.11**	**.13**
Vertigo	**.31** *	**.18**	**.29**	**.08**	**.27**	**.37** *
Burping	.18	.41 *	-.05	.04	.10	.22
Difficulty concentrating	**.17**	**.32** *	**.57** *	**.39** *	**.18**	**.27**
Difficulty focusing	**.05**	**-.01**	**.51** *	**.61** *	**.09**	**.43** *
Eyestrain	**-.17**	**.00**	**.37** *	**.74** *	**-.02**	**.17**
Fatigue	-.03	.15	.29	.54 *	-.13	-.04
Headache	.11	.22	.28	.53 *	.00	.15
Blurred vision	-.11	.01	.12	.36 *	.18	.40 *
Dizzy (eyes open)	**.07**	**.17**	**.01**	**.07**	**.58** *	**.76** *
Dizzy (eyes closed)	**.17**	**.17**	**.00**	**.09**	**.58** *	**.65** *
Fullness of head	.13	.12	.28	.17	.20	.37 *

*A factor loading of .30 or greater (as defined by Kennedy et al., 1993)

Next, the relationship between participant dropout rates and overall SSQ scores were examined (see Table 3). As one would expect, there was a significant relationship between SSQ score and whether participants completed a study (M = 14.00) or dropped out (M = 39.63) due to simulator sickness symptoms ($Z = 11.01$, $p < .001$).

Table 3. Mean, median, standard deviation, minimum, and maximum for the SSQ scores by dropout status (dropout or completion of study)

	Mean	*Median*	*SD*	*Min*	*Max*
Dropout	39.63	33.66	21.52	11.22	134.64
Complete	14.00	11.22	11.33	3.74	52.36

To further explore the relationship between SSQ scores and participant dropout, individual symptoms were examined next. Table 4 shows the correlation between each symptom and dropout. Overall, nausea was the most strongly correlated with participant dropout. Furthermore, the six symptoms loading to the factor '*nausea*' in the factor analysis were strongly correlated with participant dropout.

While those people who dropped out typically obtained higher SSQ scores than those who did not, it is not clear what score (or range of scores) will result in participant dropout. The ability to predict participant dropout could be of great benefit (both to the experimenter and participant by stopping an experimental session before frank illness is experienced).

Table 4. The rank biserial correlations between individual symptom scores and dropping out of a study as the result of simulator sickness symptoms

Symptom	*Correlation*	*Symptom*	*Correlation*
Nausea	0.7088***	Dizziness with Eyes Open	0.1116**
General Discomfort	0.6515***	Fullness of Head	0.0998*
Stomach Awareness	0.3475***	Dizziness with Eyes Closed	0.0860*
Sweating	0.3315***	Difficulty Focusing	0.0962*
Increased Salivation	0.2043***	Headache	0.0727
Difficulty Concentrating	0.1927***	Blurred Vision	-0.0024
Vertigo	0.1793***	Fatigue	-0.0458
Burping	0.1414***	Eye Strain	-0.0590

*Significant at p <.05; **Significant at p <.01; ***Significant at p <.001

To examine dropout predictability, a multiple logistic regression analysis was performed on the raw symptom scores. The backward selection method was used with a 0.05 stay probability. In this fashion, symptoms that did not significantly affect the outcome of a dropout were removed from the logistic regression model. Participant dropout was the response variable, where a value of 1 indicated the participant dropped out and a value of 0 indicated the participant completed the experiment. The method iterated 10 times and the final model is presented below in Figure 1.The logit of the event is the log odds of the event. Odds range from 0 to ∞, where values less than 1 correspond to probabilities below 0.5 and odds greater than 1 correspond to probabilities above 0.5.

$$logit[\pi(\boldsymbol{x})] = \log\left[\frac{\pi(\boldsymbol{x})}{1-\pi(\boldsymbol{x})}\right] = -4.63 + 1.48x_N + 1.10x_G + 1.06x_D + 1.02x_S + 0.91x_B + 0.86x_C$$

Figure 1. Formula. Log odds of dropping out based on scores for nausea (N), general discomfort (G), dizziness with eyes open (D), sweating (S), burping (B), and difficulty concentrating (C)

Based on the model, if a participant does not exhibit symptoms (i.e., all predictor scores are 0), then the odds of him/her dropping out are $e^{-4.63} = 0.01$ which corresponds to a probability of 0.01. The odds of dropping out change multiplicatively by a factor of $\exp(\beta_i)$ for each one-unit increase in score for the *i*-th symptom when all other predictors are held fixed. For example, consider the scenario where a participant completes the SSQ after each of two trials in the simulator. If the participant exhibits a one-unit increase in his/her nausea score from the first SSQ to the second SSQ, and all other symptom scores remain the same, then the odds of him/her dropping out increase by $e^{1.48} = 4.39$. This model accounts for 29.22% of the variance and produces 91.4% concordant pairs. The cutoff probability value was selected to be 0.20, meaning that a predicted probability greater than or equal to 0.20 would result in the observation being classified as a participant dropout. At this level, the false positive (predicting a dropout where the participant completes the study; i.e., suggests an unnecessary study termination to prevent participant illness) rate is 47.3% and the false negative (predicting study completion, when a participant actually drops out) rate is 3.3%. The sensitivity (80.6%) and specificity (88.6%) of the model were high.

Finally, because all of the data are from the same simulator, it is possible to explore simulation specific factors that may influence simulator sickness symptoms. Simulations vary on many factors which cannot be fully quantified. However, the two simulations with the lowest dropout

rates were different from those with the greatest in some consistent ways. As can be seen in Table 1, of the people who reported SSQ scores greater than 0, none dropped out in studies 6 and 8. Study 8 is perhaps the least demanding and simplest study included in this group. In this study, participants drove a 21 minute straight route without curves, stops, or turns. Participants were asked to make several gradual speed adjustments in both urban and rural environments. This procedure minimized the potential discrepancy between the visual and vestibular systems. Given that this is the presumed cause of simulator sickness, one would not expect high SSQ scores or dropout rates. In study 6, participants drove along a straight road with multiple stoplights, however all but three lights turned green before it would be necessary to slow for that light. The drive lasted approximately 30 minutes. There were no curves or turns present in this simulation. It is likely that once again this simulation minimized the discrepancy between visual and vestibular inputs.

Given that the two studies included in this data set with the lowest participant dropout rate (0) were those with the lowest incongruence between visual and vestibular information, one would expect high dropout rates from those studies that accentuate the differences between the two sources of information. This was indeed the case. Studies 4 and 7 had the highest participant dropout rates (see Table 1). In study 4, participants drove through four diamond interchanges that required a total of four left turns and six stops within a drive that lasted approximately 12 minutes. The drive was especially challenging in that the visuals continually changed, while the physical movement did not match what would occur in the real world (i.e., stopping and turning). In study 7, participants were asked to drive down a straight road and to make stops at stop lights. Participants were required to make a minimum of 10 stops wherein the simulation that lasted at least 20 minutes. However, depending on performance, many more stops may have been required, with a total drive time lasting up to 40 minutes. Again, it is likely that the stops required accentuate the difference is cues provided to the vestibular and visual systems.

DISCUSSION

The simulator sickness questionnaire is widely used to quantify simulator sickness symptoms. There were many goals of the present study. First, the factor analysis used to generate the SSQ total score created from flight simulators by Kennedy et al. (1993) was compared to a factor analysis that utilized more recent driving simulator data. Overall, the two factor analyses were quite similar. This highlights the robustness of the questionnaire across simulator types (flight and driving). In addition, it validates the original data of Kennedy et al. (1993). However, there were a few major differences. First, the present factor analysis did not include factor cross loadings. This is desirable because each symptom is associated with only a single factor. Second, there were five symptoms that were not associated with a factor using Kennedy et al.'s (1993) .30 cutoff: burping, fatigue, headache, blurred vision, and fullness of head. This finding does not necessarily mean that these symptoms are not associated with simulator sickness. Rather, it suggests that these symptoms are not associated with the three identified factors. However, because these five symptoms have weightings computed into the total SSQ score, it may be worthwhile to reevaluate the weight system and/or final score computation if it is to be used as a diagnostic tool.

A second goal of the present work was to examine the relationship between both overall SSQ scores and individual symptom scores with participant dropouts. Not surprisingly, those with

higher SSQ scores were more likely to drop out of an experiment than those with lower scores. Overall, the six symptoms (nausea, general discomfort, stomach awareness, sweating, increased salivation, and vertigo) that loaded on to the nausea factor were strongly correlated to participant dropout. Thus, it appears that feelings of nausea and related symptoms are the most likely to result in participant dropout. Difficulty concentrating, burping, dizziness with eyes open, dizziness with eyes closed, fullness of head, and difficulty focusing are also are significantly correlated with study completion. Although burping was not associated with a specific factor, it was significantly correlated with participant dropout. Beyond this, burping is included in the regression model and a one-unit increase in burping corresponds to a 2.48 increase in the odds of dropping out. Furthermore fullness of head was not associated with a factor but had a significant relationship with participant dropout. Given these data it may be better to attend to individual symptom score elevation rather than overall SSQ scores.

A final goal of this study was to identify simulation scenarios that are likely to increase participant dropout. It appears that simulations which maximize the apparent discrepancy between visual and vestibular inputs (e.g., stops, turns, curves) are more likely to result in elevated simulator sickness symptoms and ultimately to participant dropout. While more detailed analysis of individual drive components and elevated illness is needed, it does appear that some large scale elements can be addressed. If it is within the constraints of research requirements, it is desirable to minimize turns, curves, and stops within the simulation scenarios.

The simulator sickness questionnaire is still relevant today. The present data confirm the three-factor findings of the Kennedy et al. (1993). The present data also confirm that elevated simulator sickness symptoms do indeed lead to higher dropout rates. Furthermore, individual symptom scores are more predictive of dropout than factor scores.

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