A Method to Evaluate Temporal Appearances of Simulator Sickness during Driving Simulation Experiments

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Abstract *– Driving simulator is an important tool for driver's training and driving behavior studies. A driving simulator offers a safe and replicable virtual driving environment, but on the other hand causes simulator sickness for many drivers. Our motivation was to study what kind of simulator sickness symptoms subjects will have in our driving simulator with stereoscopic driving view. Simulator Sickness Questionnaire (SSQ) offers a valuable tool for the evaluation of the appearance of simulator sickness. It does not give, however, temporal information on the levels of nausea or on the exact instant of the appearance of different adverse symptoms during driving. In this paper, we present a method for studying the time course of the appearance of nausea and different symptoms during a driving experiment (TMSS, Temporal Method for Simulation Sickness). The method is based on periodically asking the driver on the intensity of possible nausea or other symptoms during driving. According to the present study, the method reveals that driver's level of nausea may vary a lot during a single simulation experiment, and in many cases it does not correlate with the results of Simulation Sickness Questionnaire. TMSS is also a useful tool in determining factors related to the appearance of nausea and other symptoms of simulator sickness.*

Key words: Simulator sickness, Driving simulator, Motion base, Stereoscopic view, SSQ

1. Introduction

Driving simulation is an invaluable tool for research, training, and product development in driving studies. Not only can it produce scenarios that are ethically, logistically, and financially impossible in the real world, but it also eliminates risks associated with performing dangerous tasks in the real world [1]. Driving simulators also offer human-computer interaction (HCI) researchers distinct advantages over real vehicles in terms of repeatability. By keeping a simulation scenario exactly the same from trial to trial or from subject to subject, one can study differences between in-car devices or interfaces with fewer complications, confounds and consumed time [14].

Although simulation can eliminate crash risks associated with on-road research, the use of simulation induces a symptom known as the simulator sickness. This malady, similar to motion sickness in the real world, can potentially confound the data, limit the effectiveness of training, and influence drop-out rates of the participants of a simulation test.

Simulator Sickness Questionnaire (SSQ) has been frequently used method in the evaluation of the driver's simulator sickness after it was published by Kennedy et al. in 1993 [8]. An SSQ form is usually filled before and after the driving examination or training. The SSQ gives a score for the subject's level of simulator sickness, based on weighted symptoms [8]. However, the SSQ method does not offer any temporal information on the level of nausea or on the instant of the appearance of different symptoms.

The aim of the present work was to develop a method to determine how much and when simulator sickness occurs and to study factors that may be related to the appearance of the simulator sickness. This kind of information may be crucial in order to decrease subject's drop-out rate in the future experiments.

In this study, we developed the Temporal Method for Simulation Sickness (TMSS). In order to use the TMSS method, the subjects were advised to use a

scale from 1 to 5 when estimating the level of the nausea during the driving task. The estimation was prompted with a frequency of 1/min. Additionally, the subjects were advised to inform immediately if the level of nausea changed or if any other simulator sickness symptoms occurred during driving. An SSQ form was also filled before and after each simulation experiment. According to our studies, driver's level of sickness may vary a lot during a single simulation experiment and sometimes does not correlate with the results of SSQ.

Simulator sickness was initially reported by Havron and Butler in 1957 in a helicopter trainer [Häk5]. It was documented to be similar to motion sickness, but it could occur without any actual motion of the subject. The most common symptoms of simulator sickness are a general discomfort, apathy, drowsiness, headache, disorientation, fatigue, sweating, salivation, stomach awareness, nausea, retching, and vomiting [8]. Postural instability and flashbacks (sudden recurrence of symptoms) have also reported to occur [10].

According to Mollenhauer and Romano, symptoms of simulator sickness can affect driver's performance in a variety of negative ways causing inappropriate behaviour, loss of motivation, avoidance of tasks that are found disturbing, and distraction of the normal attention allocation processes [12].

Even though a driver is able to experience driving during a simulation with the help of visual and audio cues, psychological studies have revealed the importance of vestibular sensations in the driving experiment [7]. In a fixed-based simulator, the subject has the experience of visual motion while the corresponding vestibular stimulation is missing [4]. This conflict is believed to lead to simulator sickness in a fixed-based driving simulator.

In comparison with fixed-based driving simulators, simulator sickness has been reported to be less frequent in motion-based driving simulators [3], [16]. Slob even states that the main reason why a motion system is important is the prevention of simulator sickness [15]. Nevertheless, the level of motion-base inaccuracy or conflicts between the two different inputs (e.g., visual and vestibular) are known to be related to increased simulator sickness rates [1].

One of the first tools for measuring motion or simulation sickness was the Pensacola Motion Sickness Questionnaire (MSQ) by Kellogg et al. [6]. An MSQ is a self-report form divided in 23 symptoms. Symptoms are estimated on a 4-level severity scale [10]. Because of the slight difference in symptoms as well as their lower incidence and severity, an improved questionnaire was needed. Some symptoms included in the scoring of MS are irrelevant for SS, and several are misleading [8]. The SSQ was designed especially for simulator purposes and soon replaced previously prevailing MSQ. An SSQ form consists of a list of 16 symptoms which are estimated by the subject on a 4-level scale [1], [10].

Other frequently used questionnaires are the Motion Sickness Assessment Questionnaire (MSAQ) [1] and Revised Simulator Sickness Questionnaire (RSSQ) [9].

The SSQ has also been used in order to evaluate simulator sickness during driving. The SSQ was filled every 5 minutes during the driving experiment [13]. However, it is probable that asking a series of 16 questions during a driving experiment influences the driver's behaviour and may, therefore, affect the results of the study.

Chen et al. [2] proposed a joystick-based method for continuously reporting passenger's nausea in a scale from 1 to 5 during driving simulation. The subjects were sitting in a motion-based driving simulator as passengers and a joystick was used to continuously report the level of nausea**.** However, this kind of method is not suitable for the study of the simulator sickness when the subjects are driving themselves.

2. Methods

2.1 Driving simulator with the motion-base

The base for our simulator and the driving control system are manufactured by Frex GP (Osaka, Japan). The system consists of two degrees of freedom (2 DOF) motion platform, high quality steering wheel, pedals, and gear shifter. We used a single high performance laptop to run the simulator environment. The computer, Sager NP8120, has an Intel 1,6 GHz i7 720QM quad core with 8 GB DDR3 RAM memory and Windows 7 operating system. We used two nVidia GTX 285M graphic adapters for the video output. These graphic adapters provide the 3D view for 3D Projector (Acer H5360) in scalable link interface (SLI) parallel processing mode. The resolution of the projected image was 1280x800, and it was projected on a 3x3 meter flat canvas. The size of the projected image was 2.2 x 1.375 m. Subject's distance from the centre of flat canvas was 1.9 meters. nVidia 3D Vision Home kit with a shutter glass technique was selected for the presentation of stereoscopic 3D view (refresh rate 120hz).

We added a number of details from real cars to the simulator in order to increase the realistic driving experience. These include a middle console with a gear shifter, a hand brake and a seat from Volvo, and a high impact speaker installed inside the driver's seat for adding a feeling of vibration while driving. We used a Logitech Z-5500 high quality 5.1 speaker system for creating realistic driving sounds. A small display including gauges for speed, RPM, fuel level and engine temperature was added behind the steering wheel to create an illusion of real car indicators. A further developed version of the driving simulator is presented by Koskela et al. [11].

2.2 Temporal Method for Simulator Sickness

Motivation for our studies was to develop a temporal method for simulator sickness (TMSS) 1) to study how much the new driving simulator derives nausea and other simulator sickness symptoms during driving, 2) to study factors that may be related to appearance of simulator sickness (driving view, motion base movements etc.), and 3) to study the relation between the appearance of symptoms and severity of simulator sickness for different subjects.

We considered a number of published methods to measure simulator sickness during driving. Unfortunately, none of them directly met our needs. We saw it important that the method would interfere as little as possible with the subject's driving.

The TMSS questionnaire consists of a scale indicating the level of nausea (1 = none, 2 = mild, 3 = mediocre, 4 = strong, and 5 = severe). The nausea level is asked with one minute intervals during simulation. The subjects are also advised to inform immediately if the nausea level changes. When the nausea level changes, the subjects are asked to describe the symptoms they have (headache, stomach ache, dizziness, blurriness of eyes, nausea, and general discomfort).

We evaluated two parameters describing the overall level of sickness of subjects during driving. The parameters are

1. TMc, defined as the cumulative sum of the symptom values given by a subject during the simulation experiment.

2. TMm, defined as the maximum among the symptom values given by the subject during the simulation experiment.

We also studied the relation between the SSQ score and TMSS values TM_c and TM_m. Therefore, we used both methods in the experiments.

2.3 Measurements

SSQ method: Before and after both drives the Ss filled a simulator sickness questionnaire (SSQ) in order to evaluate different simulator sickness symptoms on a scale of none to severe (16 questions dealing, e.g. with the distraction of eyes or dizziness). The answers were calculated together to compose a general score using the conversion table by Kennedy et al. [8].

TMSS method: Before the driving task, the Ss were shown the nausea scale. The Ss were advised to use these numbers in the estimation of their nausea level during the driving task. The nausea level was asked with one minute intervals. Before each driving task, we introduced the subject with different kinds of symptoms. All changes in nausea level or any other feelings the subject informed were written down minute by minute into a measurement protocol note. In addition, every driving session was recorded by using two video cameras (one recording the driver and another recording the driving view).

Telemetry: We collected a number of telemetry data indicating the state of the simulation such as the distance from the start, speed, acceleration, wheel position, throttle and brake positions. The data was recorded with accuracy of one millisecond. The recorded data was used to study the relation of distance information to the S's nausea level.

2.4 Subjects

Twelve subjects (Ss) (6 men and 6 women, aged from 22 to 32 years, mean 25.8) participated in the experiments which consisted of two driving situations (Drive 1 and 2). One subject got too sick at the first driving session and suspended the second session. All Ss were in good general health, and they were instructed to come well rested and abstain from alcohol 12 hours before testing. All Ss had a normal or a corrected-to-normal vision. S's background, driving experience, and sensitivity to motion sickness were filled out. None of them had previous experience of driving simulator. All Ss were informed about the scope and design of the study, and they gave their written consent for participation.

2.5 Experimental protocol

The two parts of the experiment (Drive 1 and 2) were carried out during different days. Drive 1 consisted of driving on an asphalt road with some hard turns and fast straights (ADAC 24h). In Drive 2 the Ss had to drive on a very lumpy and rough gravel road which changed into winding asphalt after four kilometres of driving (Lienz Rally Hillclimb).

Before Drive 1 each subject filled out a subject's background questionnaire, heart rate monitor was attached, and the driving position was adjusted. The SSQ-form was filled. Thereafter, the Ss were given instructions of the driving task. All subjects drove with automatic shift and used 3D-glasses. Subjects were also informed that they are free to abort driving if they are feeling too sick to continue. Subjects were also advised to start carefully and then drive a speed they feel comfortable. Subjects were instructed that driving would last about 15 minutes. The simulator and the heart rate monitor were synchronized by pressing on the simulator and the Polar wrist computer's lap key at the same time. The temporal method was applied as presented in the previous section. After the driving task the subjects were free to relax for a couple of minutes before the SSQ-form was filled out. Lastly, the heart rate recording was stopped.

3. Results

The data gathered in this study consisted of the SSQ data of subjects collected before and after each experiment and the temporal sickness data (TMSS) collected during each driving simulator experiment. Additionally, we stored telemetry information of simulator experiment consisting of, e.g., the distance from the start point at the road, the time used for driving, and the speed of vehicle.

We first studied subject's tendency for simulator sickness. In the analysis, the subjects were divided, on the basis of the appearance of nausea, in three groups:

1. Subjects who got severe symptoms
2. Subjects who got moderate and varying nausea levels
3. Subjects who did not have any symptoms

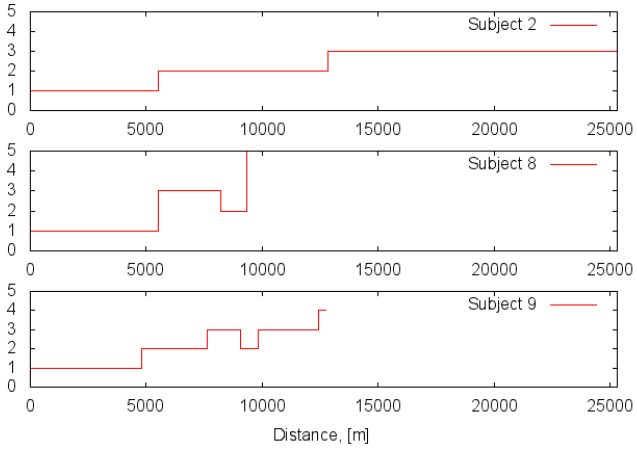

Figure 1. The appearance of nausea (scale in the ordinate) as a function of the section of the road (distance) during driving (group of subjects with severe symptoms).

Subjects belonging to the Group 1 got symptoms quite quickly after the start of the simulation. On the other hand, the level of their sickness grew rather quickly and led to an interruption in two cases out of three. Results for the group getting severe symptoms are presented in Figure 1.

Subjects belonging to the Group 2 reported the first symptoms later than the subjects belonging to the Group 1. We originally assumed that the level of sickness should monotonically increase with the increasing distance from the beginning of simulation. The findings did not support this hypothesis as can be seen in the results for the Group 2 (Fig. 2). It was also interesting to find out that the level of nausea could both increase and decrease during the experiment.

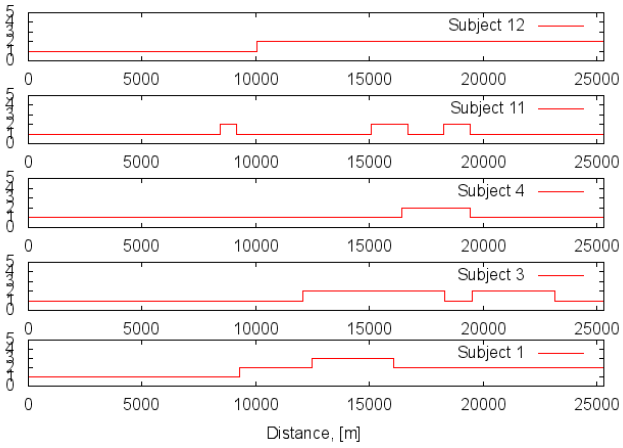

Figure 2. The appearance of nausea (scale in the ordinate) as a function of the section of the road (distance) during driving (group of subjects with average symptoms).

We then studied subject's sensitivity for simulator sickness with respect to the distance from the starting place of driving. For each subject, we calculated distances at the road where the subject's symptoms changed their value or state for the first time.

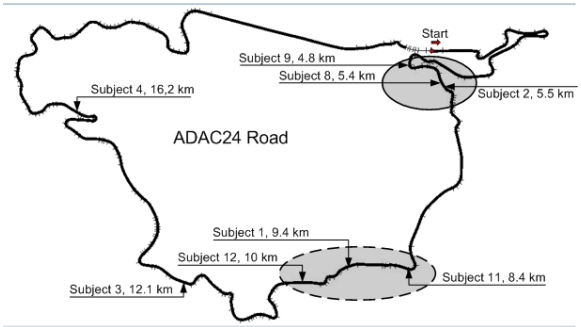

Figure 3. Profile of ADAC24 road and two areas where nausea appeared for the most of subjects.

The profile of ADAC24 road is presented in Figure 3. The starting point of Drive 1 is located in the right-up corner of the figure. Figure 3 also presents the sections of the road (grey areas) where the subjects expressed their increasing nausea levels at the first time. At the oval rounded by solid line, subjects 2, 8, and 9 got their first nausea symptoms. Respectively, the oval rounded by the dashed line indicates the area of the first nausea symptoms for subjects 1, 11, and 12. According to the results, the subjects that had increasing symptom levels at the early stage of the experiment also suffered from the most severe symptoms. We also noticed that six subjects had the first appearance of nausea immediately after a series of steep curves with red-and-white coloured curbs (see the section of the road with continuous line in Fig. 3). Also many of the subjects reported short period of dizziness symptoms (2-5 sec) in steep curves and downhills.

The results of SSQ questionnaire were computed using the scoring procedure table by Kennedy et al.

[Ken8]. We compared the results of our TMSS method with the results obtained by SSQ forms. SSQ_d is defined as the difference between the sum of values of the SSQ before and after a simulation experiment. We evaluated TM_c by adding together values of 15 evenly distributed samples of symptom values. After that, TM_c was normalized to start from 0 by subtracting 15 from the cumulative value.

Table 1. Comparison of SSQ and TMSS. SSQ_d: difference in SSQ values, TM_c: cumulative value of temporal method, TM_m: maximum value of symptom levels (Q = quitted from the experiment).

	Drive 1			Drive 2		
Subject	***SSQ_d***	***TM_c***	***TM_m***	***SSQ_d***	***TM_c***	***TM_m***
1	11.5	11	3	3.0	5	2
2	23.0	17	3	23.3	23	4
3	5.8	6	2	6.8	0	1
4	14.3	2	2	18	2	2
5	1.0	0	1	1.0	0	1
6	-1.0	0	1	4.8	0	1
7	28.5	0	1	42.8	0	1
8	41.3	Q	5	-	-	-
9	21.3	Q	4	19.3	Q	4
10	23.8	0	1	21.8	0	1
11	4.5	2	2	8.8	0	1
12	27.8	9	2	10.5	0	1

On the basis of the comparisons in Table 1 the subjects were divided in two groups:

1. Group “consistent”: Subjects who had high SSQ value and high TM values OR low SSQ value and low TM values.
2. Group “inconsistent”: Subjects who had high SSQ value, but low TM values

Subjects belonging to the Group “consistent” were subjects 1, 2, 3, 5, 6, and 8. Subjects having high SSQ_d value, but low TM_c and TM_m values belonging to the Group “inconsistent” were 7, 10, and 12. Also subjects 4 and 11 showed inconsistent values in drive 2. Reason to this is possibly that SSQ measures simulator sickness changes before and after drives. In many cases the symptoms of simulator sickness may increase or decrease quickly after the experiments and before the post SSQ form is filled. TMSS offers a more accurate method to analyse simulator sickness during driving.

4. Conclusions and future work

In this paper, we have presented the temporal method for simulation sickness (TMSS) for the study of the time course of the appearance of nausea during a simulation experiment. We also have compared TMSS and SSQ methods.

We divided the subjects in three groups according to the severity of the symptoms they had. We noticed that the subjects having the most severe symptoms got their first nausea symptoms much earlier than the others. Most of the subjects got their first nausea symptoms after a series of steep curves with red-white curbs. We noticed that the TMSS and SSQ tools do not correlate in many cases.

The present results indicate that the TMSS provides a useful tool for exploring nausea levels and other unpleasant symptoms during a driving experiment. The TMSS can be used to specify simulation related factors that may cause simulator sickness. This information can be used in further development of simulators in order to decrease the drop-out rates of subjects.

By using the TMSS we can evaluate both the driving distance and the driving time in relation to the appearance of nausea. We can also determine changes in the nausea levels of a subject during the experiment. Our results show that the level of nausea may vary a lot during a simulation experiment. Furthermore, the method offers the possibility to evaluate the severity of nausea and other symptoms during simulation.

The TMSS can also be utilized in preliminary tests as an analysis tool for the evaluation of the subject’s sensitivity to simulator sickness. Subjects having high TMSS values may be then excluded from the main experiment.

In the future, we aim to use the TMSS tool in order to study the relation between the simulator sickness and heart rate variability. Additionally, we will study whether the stereoscopic driving view increases/decreases the occurrence of simulator sickness.

Acknowledgements

This research is funded by European Regional Development Fund, the Joint Authority of Kainuu Region, and Sunit Oy. We are grateful for the support.

References

[1] Brooks J. O., Goodenough R. R., Crisler M. C., Klein N. D., Alley B. L., Logan W. C., Ogle J. H., Tyrell R. A., and Wills R. F., Simulator Sickness During Driving

Simulator Studies. *Accident Analysis and Prevention* 42, Elsevier, 2010, pp. 788 – 796.

[2] Chen Y.-C., Duann J.-R., Chuang S.-W., Lin C.-L., Ko L.-W., Jung T.-P., and Lin C.-T., Spatial and temporal EEG dynamics of motion sickness, *Neuroimage*, 49, 2010, pp. 2862 – 2870.

[3] Curry R., Artz B., Cathey L., Grant P., and Greenberg J., Kennedy SSQ results: fixed- vs. motion-based FORD simulators, *Proceedings of Driving Simulator Conference,* 2008, pp. 289 – 300.

[4] Havron, M. and Butler, L., *Evaluation of training effectiveness of the 2FH2 helicopter flight trainer research tool.* Naval Training Device Center, Port Washington, New York, NAVTRADEVCEN 1915-00-1, 1957.

[5] Häkkinen J., Pölönen M., Takatalo J., and Nyman G., Simulator Sickness in Virtual Display Gaming: A Comparison of Stereoscopic and Non-stereoscopic Situations, *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services*, Stockholm, Sweden, 2006.

[6] Kellogg, R. S. and Gillingham, K. K., United States Air Force experience with simulator sickness, research and training. *Proceedings of the 30th Annual Meeting of the Human Factors Society*, 1986. vol. 1. pp. 427 – 429.

[7] Kenemy A. and Panerai F., Evaluating perception in driving simulator experiments, *TRENDS in Cognitive Sciences,* 7(1), 2003, pp. 31 – 37.

[8] Kennedy R. S., Lane N. E., Berbaum K. S., and Lilienthal M. G., Simulator Sickness Questionnaire: An Enhancement Method for Quantifying Simulator Sickness, *International Journal of Aviation Psychology*, 3(3), 1993, pp. 203 – 220.

[9] Kim, D.H., Parker, D.E., Park, M.Y. *A New procedure for measuring simulator sickness - the RSSQ.* Seattle, WA, USA 2004, University of Washington, Human Interface Technology Laboratory Technical Report R-2004-52.

[10] Kolasinski E. M., *Simulator Sickness in Virtual Environments,* Technical Report 1027, U. S. Armey Research Institute, Education and Training Technology, 1995.

[11] Koskela K., Nurkkala V.-M., Kalermo J., and Järvilehto T., Low-cost Driving Simulator for Driver Behavior Research. *The 2011 International Conference on Computer Graphics and Virtual Reality, CGVR'11,* July 18 – 21, 2011, Las Vegas, Nevada, USA, 2011.

[12] Mollenhauer M. A. and Romano R. A., The Evaluation of a motion Base Driving Simulator in a Cave at Tacom, *Proceedings for the Army Science Conference*, Orlando, Florida, 2005.

[13] Min B.-C., Chung S.-C., Min Y.-K., and Sakamoto K., Psychophysiological evaluation of simulator sickness evoked by a graphic simulator. Applied Ergonomics, 35, 2004, pp. 549 – 556.

[14] Rieber L. P., Seriously considering play: Designing interactive learning environments blending of microworlds, simulations, and games, *Educational Technology Research & Development,* 44(2), 1996, pp. 45 – 58.

[15] Slob J. J., *State-of-the-Art Driving Simulators, a Literature Survey*, DCT 2008.107, DCT report, Eindhoven University of Technology, 2008.

[16] Watson G., A Synthesis of simulator sickness studies conducted in a high fidelity driving simulator, *Proceedings of Driving Simulator Conference*, 2000, pp. 69 – 78.