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The effects of simulated fog and motion on simulator sickness in a driving simulator and the duration of after-effects

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ABSTRACT

In the study, we checked: 1) how the simulator test conditions affect the severity of simulator sickness symptoms; 2) how the severity of simulator sickness symptoms changes over time; and 3) whether the conditions of the simulator test affect the severity of these symptoms in different ways, depending on the time that has elapsed since the performance of the task in the simulator.

We studied 12 men aged 24–33 years ($M = 28.8$, SD = 3.26) using a truck simulator. The SSQ questionnaire was used to assess the severity of the symptoms of simulator sickness. Each of the subjects performed three 30-minute tasks running along the same route in a driving simulator. Each of these tasks was carried out in a different simulator configuration: A) fixed base platform with poor visibility; B) fixed base platform with good visibility; and C) motion base platform with good visibility. The measurement of the severity of the simulator sickness symptoms took place in five consecutive intervals.

The results of the analysis showed that the simulator test conditions affect in different ways the severity of the simulator sickness symptoms, depending on the time which has elapsed since performing the task on the simulator. The simulator sickness symptoms persisted at the highest level for the test conditions involving the motion base platform. Also, when performing the tasks on the motion base platform, the severity of the simulator sickness symptoms varied depending on the time that had elapsed since performing the task. Specifically, the addition of motion to the simulation increased the oculomotor and disorientation symptoms reported as well as the duration of the after-effects.

1. Introduction

The ongoing need to reduce human error leads to more and more frequent use of simulators in both experimental studies and training (e.g., Edquist et al., 2011; Yang et al., 2013). An important advantage of the use of simulators in experimental studies is the ability to control many environmental factors, as well as the possibility of recording a number of variables relating to the cardiovascular system, electrodermal response or oculomotor response – to name just a few (e.g., Brookhuis and de Waard, 2010, 2011; Haarmann et al., 2009; Underwood et al., 2011; Zuzewicz et al., 2011). An analysis of these variables can be helpful in assessing the impact of specific tasks on the occurrence of fatigue or workload (Davenne et al., 2012; Sung et al., 2005). The data collected from these studies allow, on the one hand, an optimal working environment to be constructed from the point of view of a man as an operator, and on the other, an assessment of the influence of certain occupational conditions or used substances on the functioning of humans (Siedlecka and Bortkiewicz, 2012; Stoner et al., 2011; Stough et al., 2012). Simulators are also increasingly used in the treatment of patients with post-traumatic stress disorder (PTSD) and fear of flying, as well as for training (Classen et al., 2011; Devlin et al., 2012; Kraft et al., 2010).

A wide range of applications for simulators, together with their increased use in scientific research and training, has highlighted the problem of simulator sickness (SS) (Brooks et al., 2010; Biernacki and Dziuda, 2012; Kennedy et al., 2010).

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Simulator sickness can affect the reliability of the measurement (this applies to both physiological variables and the performance of the task), limit the effectiveness of one's training, and increase the number of people who are not able to complete the task (Brooks et al., 2010; Stoner et al., 2011). The occurrence of simulator sickness can also provide an additional source of stress. This is particularly important in the case of the use of simulators in the treatment of PTSD or in the treatment of fear of flying (Beck et al., 2007; Classen et al., 2011; Devlin et al., 2012; Kraft et al., 2010).

Research on simulation sickness includes an even wider number of factors relating to individual characteristics (e.g. gender, age, experience), the time of the study and test conditions, to name just a few. A detailed review of the studies devoted to this subject can be found in the articles by Classen et al. (2011), Kennedy et al. (2010) and Stoner et al. (2011). However, from the perspective of our research, we were particularly interested in two issues: the impact of test conditions on the intensification of simulator sickness symptoms and the after-effects of simulation sickness.

One important aspect of tests involving simulators is how different simulator test conditions affect the severity of simulator sickness symptoms. Among the simulator test conditions, we should specify those related to the mobility of the platform as well as those related to the type of visual stimuli (e.g. Drexler, 2006; So et al., 2001). For example, Sharples et al. (2008) conducted a study in which she decided to check whether the severity of simulator sickness symptoms is different in the case of four virtual reality display conditions. The conditions that were used in the study included head-mounted display (HMD), desktop, projection screen and reality theatre. This study also involved user control (active vs. passive viewing) and lighting conditions (light vs. dark conditions). To assess simulator sickness symptoms, the Simulator Sickness Questionnaire (SSQ) was used, which allows the relevant assessment on the level of total severity and three subscales that represent separable dimensions of simulator sickness: nausea, visuomotor disturbances and disorientation (Kennedy et al., 1993). The obtained results showed that in 60–70% of cases, exposure to HMD was associated with an increase in simulator sickness symptoms. In the case of comparisons between HMD and desktop, a significant change in nausea symptoms was observed, while in the comparison of HMD and reality theatre an increase in regard to nausea, oculomotor disturbances and disorientation was noted. An intensification of simulator sickness symptoms was also recorded, particularly with regard to oculomotor disturbances and Total SSQ symptoms, in persons who were passive viewing compared to the participants who had control over their movements in the virtual environment (VE) (Sharples et al., 2008). The severity of simulator sickness symptoms also varies depending on the kind of traditional simulator used. The research by Drexler (2006), who compared a fixed-wing, rotary-wing and driving simulator, indicates that the greatest severity of symptoms related to disorientation, compared to fixed-wing and rotary-wing simulators, is observed in the case of using a driving simulator. The highest level of oculomotor disturbances was noted for the fixed-wing, then the rotary-wing, and finally for the driving simulator. On the other hand, the level of nausea remained at a similar level in all test conditions applied. In the case of using a driving simulator, the most severe symptoms were observed in oculomotor disturbances, then disorientation, and the least severe symptoms were recorded for nausea ($D > O > N$ SSQ profile). Apart from the kind of applied visual stimuli, another factor taken into account in research on simulator sickness is the type of platform used (fixed base vs. motion base platform). In the case of experiments using fixed base platforms, information concerning the motion is provided to the tested person via visual information. Motion base platforms are used to increase the fidelity or realism of the simulation. In the case of motion base platforms, information concerning the motion provided via changes in visual display are supplemented with the changes in the position of the platform (motion base platforms enhance the sense of self-motion provided by the visual display (Stoner et al., 2011). Thus, motion base platforms used in simulators can provide two types of inertial cues: acceleration and tilt (Kennedy et al., 1987; Stoner et al., 2011).

Curry et al. (2002) decided to assess the differences in the severity of simulator sickness between a fixed base and a motion base with a 6 degrees of freedom (6 DOF) driving simulator. The analysis of results showed that the severity of simulator sickness symptoms was higher when using a fixed base simulator compared to the motion base one. However, in both cases, the profile of individual SSQ subscales was the same ($D > O > N$). On the other hand, some studies indicate that when the perceived motion is only based on visual stimuli, as it is in the case of fixed base platforms, a particular increase is observed for the nausea symptoms (e.g. McCauley and Sharkey, 1992; May and Badcock, 2002). Stoner et al. (2011) also point to the fact that the use of motion base platforms may not result in a difference between the severity of simulator sickness compared to fixed base platforms, and may even increase the severity of its symptoms. Therefore, it seems that the research on the influence of the type of the simulated motion (fixed base vs. motion base platforms) on simulator sickness symptoms needs to be undertaken in the future.

Another question highlighted in the studies on simulator sickness refers to how long the effects of exposure to simulated conditions persist over time and how quickly the symptoms of simulator sickness appear. For example, Min et al. (2004) assessed the level of simulator sickness, estimated by SSQ and psychophysiological indicators, in 5-minute intervals in the course of performing a 60-minute task in a driving simulator. The analysis of the results showed that subjectively experienced simulator sickness symptoms already appeared 10 min after the main experiment started in the case of nausea, disorientation and Total SSQ, and after 15 min in the case of oculomotor disturbances. Moreover, the severity of the symptoms increased linearly with each next measurement. This result confirms that simulator sickness is a result of the time spent in a simulator (e.g. Kennedy et al., 2000; Kennedy and Fowlkes, 1992 Lampton et al., 1994; Stanney et al., 1998). In addition to this, the changes in psychophysiological variables, for both the autonomic and the central nervous system, already showed a significant change after 5 mins from the start of the study. This means that the subjective psychological evaluation is delayed compared to the response of the physiological indicators. Demonstrating that the physiological parameters react faster to the simulator test conditions compared to the subjective evaluation can help identify early signs of simulator sickness, before it is noticeable under the subjective evaluation of the tested person. The fact that the duration of the experiment on the simulator is accompanied by the intensification of simulator sickness symptoms and the changes in the level of physiological variables raises the question how long simulator sickness symptoms persist (after-effects) after the cessation of performing the task on the simulator. This issue was investigated, inter alia, in the study conducted by Muth (2009), which assessed the level of cognitive functions (Cognitive Test Battery), the individual's balance (Sharpened Romberg) and the integrity of the visual-vestibular interaction (Dynamic Visual Acuity Test) before the test, immediately after it, and 2, 4, 6, 8 and 24 h after the simulator test. The analysis of the results showed that "uncoupled motion scenario" resulted in a deterioration in cognitive functioning. This deterioration was particularly evident 2–4 h after the exposure to the simulated conditions. The changes in physiological parameters were noted 1–2 h after the end of the experiment. Muth points out, however, that the resulting after-effects in cognitive functions should be not be associated with the experienced symptoms of simulator sickness. Baltzley et al. (1989), in a study on a group