A simulation sickness study on a driving simulator equipped with a vibration platform

Guillaume Lucas [a,b], Andras Kemeny [a,b,c], Damien Paillot [b], Florent Colombet [a]

[a] Renault, DEA-TD, TCR AVA 013, 1 avenue du golf, 78280 Guyancourt, France
[b] Institut Image, Arts et Métier, LISPEN, CNRS, 2 rue Thomas Dumorey, France
[c] AVSimulation, 1 Cours de l'Île Seguin, 92100 Boulogne-Billancourt, France

A B S T R A C T

Simulator sickness is a well-known side effect of driving simulation which may reduce the passenger well-being and performance due to its various symptoms, from pallor to vomiting. Numerous reducing countermeasures have been previously tested; however, they often have undesirable side effects. The present study investigated the possible effect of seat vibrations on simulator sickness. Three configurations were tested: no vibrations, realistic ones and some that might affect the proprioception. Twenty-nine participants were exposed to the three configurations on a four-minute long automated driving in a simulator equipped with a vibration platform. Simulator sickness was estimated thanks to the Simulator Sickness Questionnaire (SSQ) and to a postural instability measure. Results showed that vibrations help to reduce the sickness. Our findings demonstrate that some specific vibration configurations may have a positive impact on the sickness, thus confirming the usefulness of devices reproducing the road vibrations in addition to creating more immersion for the driver.

Keywords:
Driving simulation
Simulator sickness
Motion sickness
Vibrations

1. Introduction

In the past few years, driving simulators have been increasingly used in the automotive industry, such as for the testing of new interfaces or driver-assistance systems, and they will be even more used in the development of the future autonomous vehicles. Indeed, before their releases, these vehicles need to be validated over billions of kilometers to achieve the expected level of performance (Wachenfeld & Winner, 2016). Besides, the driving simulation with "Driver in the Loop" (DiL) will be one of the solutions to ease this process (Winkle, 2016), among massive digital simulations and real driving tests.

Nonetheless, the use of driving simulation can sometimes be limited by its well-known side effect the simulator sickness (Crowley, 1987; Kolasinski, 1995). This phenomenon is a specific form of motion sickness, which is quite similar to those that appear in virtual reality or transportation. Motion sickness is mainly due to the perception of movements and this not only concerns physical motions but also visual motions (Hettinger & Riccio, 1992). With varying susceptibility, most people suffer from motion sickness in their own way, except people without organs of balance who have been shown to be insensitive to both physical and visual motion (Golding, 2006; Reason & Brand, 1975). Motion sickness is mostly considered as a comfort

E-mail addresses:
guillaume.lucas@renault.com (G. Lucas),
andras.kemeny@renault.com (A. Kemeny),
damien.paillot@u-bourgogne.fr (D. Paillot),
florent. colombet@renault.com (F. Colombet)

issue in transports; however, in the case of driving simulation, it also affects task performance (Money, 1970) and limits the duration of the simulations because of its symptoms which can range widely from pallor to vomiting (Kennedy & Fowlkes, 1992). Although motion sickness has been extensively studied over the past decades, its causes and the mechanisms involved are not fully understood yet and several theories exist (Reason, 1978; Riccio & Stoffregen, 1991; Treisman, 1977). The most prominent, the sensory conflict and rearrangement, suggests that the sickness occurs when the information delivered by the visual, vestibular and somatosensory senses are not congruent with each other or with what is expected based on the internal models built from previous experiences (Reason, 1978).

Several countermeasures have already been investigated, like medication, which has been proved to be effective, but comes with significant side effects such as drowsiness, fatigue and impaired cognitive abilities (Benson, 2002; Zhang et al., 2016). Other behavioral methods have been tested, like habituation (Benson, 2002), restraint of the body (Chang, Pan, Chen, & Stoffregen, 2013), reduction of eye movements (Webb & Griffin, 2003), stroboscopic vision (Reschke, Somers, & Ford, 2006) and even pleasant music (Keshavarz & Hecht, 2014). They have also been shown to be effective to reduce motion sickness; however, their application can be limited because some are time-consuming and others may restrain the user or disturb him.

The goal of the present study was to investigate an alternative solution to reduce simulator sickness with some seat vibrations. Vibrations of the seat has already been suggested by M. McCauley and T. Sharkey in 1992 McCauley and Sharkey (1992), that it may be effective to reduce simulator sickness by providing noise to the vestibular and proprioceptive senses. However, Casali (1985) has shown that simple random vibrations alone is not enough to eliminate the sickness. Nonetheless, we know that motion sickness only occurs at motion frequencies below 1 Hz (O'Hanlon & McCauley, 1974), which are motion frequency, while higher vibrations frequencies are not sickening. Based on these assumptions, Bos (2015) proved that motion sickness due to low-frequency motion can be reduced by adding a high-frequency vibrations directly to the head, but not through the seat. However, providing vibrations to the head might not be feasible in some situations and can really disturb the driver. Seat vibrations, on the other hand, provides more proprioceptive cues and can influence the abdominal motion sensors, but could also deliver a subtle vestibular cue.

The first assumption is that some specific whole-body vibrations may disturb the senses, especially the vestibular and proprioceptive, which could have an impact on the simulator sickness. For example, the proprioceptive sense can be tricked by applying some specific vibrations (within the range of 60–100 Hz) on the muscles (Petroni, Carbajal, & Sigman, 2015; Bergenheim, Ribot-Ciscar, & Roll, 2000). This vibration can give the illusion of your body moving although he hasn't. These vibrations are also in a range where they can disturb the vestibular sense (Lackner & Graybiel, 1974).The hypothesis here was that these vibrations may give a small illusion of movement during the simulation, or, on the contrary, maybe disturb the senses and maybe make it worse. In addition to the first assumption, the effect of more realistic and consistent seat vibrations is also studied in the present study. They are more and more used in driving simulators and are known for improving the perception of speed (Sandin et al., 2016) and may deliver additional kinesthetic cues of speed and longitudinal accelerations. These cues will be in accordance with the visual perception of motion to the detriment of the vestibular information of no movements. Consequently, the sensory patterns should be more similar to the ones we are used to and the sensory conflict could be reduced and thus leading to less simulator sickness, according to the theory of Reason (1978). Consequently, we wanted to test whether different kinds of vibrations applied to the seat could have an influence on simulator sickness.

2. Methods

2.1. Experimental design

Three configurations of vibrations were considered in this study: first in the reference condition, no vibrations were rendered. In the second condition, realistic vibrations were rendered consistently with the simulation, thanks to the SCANeR Studio software and was based on the vehicle speed and the road surface. Then in the third condition, vibrations were rendered randomly in the frequency domain that can disturb the proprioception.

2.2. Simulator design

This study has been held at the Arts et Métiers ParisTech Institut Image in Chalon-sur-Saône on the SI2M simulator platform. This simulator platform consists of one car seat, pedals and steering wheel mounted on 4 D-BOX actuators (see Fig. 1). It was first designed to operate in a CAVE, but for this study we used the Oculus Rift CV1 Head-Mounted Display (HMD) for the visual and sound rendering. The D-BOX actuators system allows the platform a small liberty of movements in order to make the users feel the road (turn, speed bumps, etc.), but specially they are fast enough to generate vibrations to simulate the road contact (frequency ranges 0–100 Hz). This simulator is running thanks to three computers: one to manage the platform, the second to handle the visual rendering on the HMD and the last, the master, to manage the two others and handle the simulation, scenario, etc. The visual refresh rate was clocked to 75 Hz for the software (see Fig. 2).

Fig. 1. SI2M Simulator.

Fig. 2. Visual overview of the driver vision.

2.3. Scenario design

The scenario has been developed with SCANeR Studio 1.7. participants were placed in an autonomous vehicle driving in a city environment and doing three tours of the same circuit (see Fig. 3) for a total duration of 3 min 45 s. The car was driving at 50 km/h with some slowdown at 30 km. All traffic lights were green so the car did not have to stop. Some other traffic cars were simulated on the road but no pedestrian. The participant was virtually immersed at the driver's seat of a Renault Scenic. The autonomous car accelerated at the beginning of the simulation with a slow acceleration of 1 m/s^2 and stopped at the end of the simulation with a deceleration of 1 m/s^2 also, so that the participant could put and remove the HMD in a car at a standstill.

2.4. Realistic vibrations

For the generation of vibrations consistent with the virtual driving, we used a dedicated option of the SCANeR Studio driving simulation software. This option generates vibrations on the platform in addition to its movement. These vibrations depend on the road surface (granularity), the vehicle speed and the torque applied to the steering wheel. Moreover, this rendering also differentiates the left and the right. Vibrations are defined in the source code thanks to a Perlin noise method. During the experience the vehicle was on the asphalt and driving mostly at 50 km/h with some slowdowns at 30 km/h which gives the peaks frequency every 3.5 Hz with some higher at 21 Hz and 7 Hz (see Fig. 4).

2.5. Proprioceptive vibrations

As we have seen previously, the proprioception can be disturbed by vibrations in the range of 60–100 Hz. For this configuration we computed with Matlab software a white noise filtered with a band-pass filter in this range. The filter was set

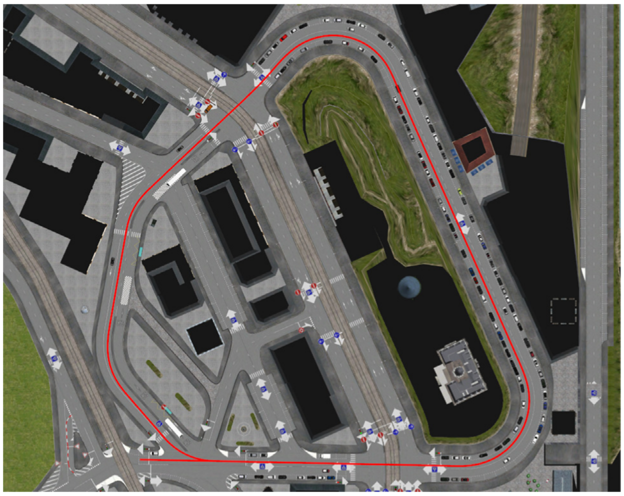

Fig. 3. Scenario circuit.

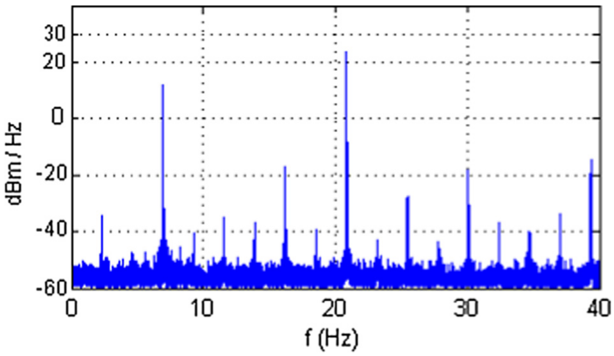

Fig. 4. Part of the power spectral density of the realistic vibrations.

with a band pass from 60 to 100 Hz and the attenuation of 80 dB (Fig. 5). This computed vibrations lasted 5 s and were played in loop during the simulation.

3. Measurements

The simulator sickness was measured with two different procedures: a subjective one (questionnaires) and an objective one (measure of a physical state). Participants were asked to fill in a translated version of the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993; Bouchard, Robillard, & Renaud, 2007) before and after each configuration tested, to evaluate their level of simulator sickness due to each configuration. The SSQ is a standardized

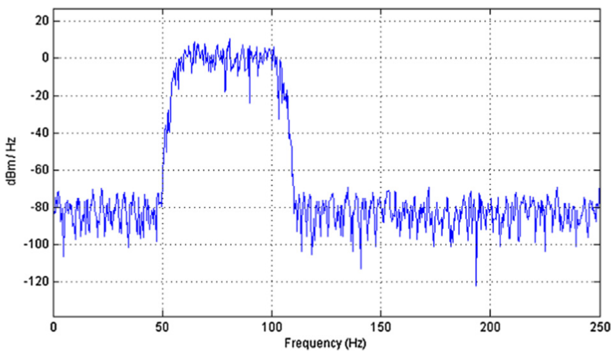

Fig. 5. Power spectral density of proprioceptive vibrations.

questionnaire which covers the wide range of simulator sickness symptoms (e.g., nausea, dizziness, fatigue, eyestrain, etc.) through 16 items that are judged on 4-point scales (not at all, slight, moderate, severe). The SSQ can be interpreted in three subscales (nausea, disorientation, oculomotor) and a total score. The participants were asked to fill out the questionnaire before each simulation to ensure that symptoms observed were not already there before the simulation.

Simulator sickness was also measured more objectively with the postural instability (Smart, Stoffregen, & Bardy, 2002; Kennedy & Fowlkes, 1992) using the Stabilotest balance board from Techno Concept (TechnoConcept, 2007). The measure was taken before and after each simulation in order to quantify the effect of the simulation on the postural instability. For this measure we recorded the mean area covered by the projection of the center of gravity on the ground. The participants were asked to keep their arms along the body, while looking straight forward at a target in front of them on the wall one meter away and trying to stand as still as possible during the measure. The recordings were made over a period of 51.2 s, at a sampling rate of 5 Hz in order to remain within the norms AFP 85.

In order to assess postural instability, we used two indicators, first, the spatial magnitude with the surface of the confidence ellipse containing 90% of the positions of the center of gravity (norm AFP 85). And also the multifractality of the displacement of postural sway (Munafo, Curry, Wade, & Stoffregen, 2016) using multifractal detrended fluctuation analysis, MF-DFA using open source code for MATLAB (Ihlen, 2012). We have selected a minimum scaling range of 16 data points with 19 increasing segment sizes uniformly spaced up to the maximum of the time series length.

3.1. Participants

Thirty participants volunteered for this study, twenty-five men and six women, from 19 to 69 years old (Mean = 27.5; SD = 14.7). All the participants had their driving license, with various driving experience but most of them were regular drivers. Participants were informed about the purpose of the study and were free to abort the experiment at any time, especially if they felt too sick during one simulation. All the participants have driven in the three configurations separated by at least 6 h in order to avoid interference like sickness accumulation or habituation effects (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989; Johnson, 2007), but most of the time there have been 24 h minimum between each condition. Configurations order was random among the participants in order to avoid rank effects.

4. Results

All statistical analyses have been computed thanks to the R project software. For the analysis we used the Wilcoxon paired Signed-Rank Test, a non-parametric test allowing comparison of the effects of a parameter on correlated samples (within subject design). We used a non-parametric test because the samples cannot be assimilated to a normal distribution. For each indicator we have analyzed the difference of the indicator before and after each simulation.

4.1. Simulator sickness questionnaire

The participants reacted very differently to the simulations.The population is scattered (mean $\approx$ standard deviation), some were not really affected by the simulation, but, on the other hand, some others were really affected and became quite sick. This also involves that the samples cannot be assimilated to a normal distribution, confirmed with a Shapiro–Wilk test of normality ($p_{without} = 1.5 \times 10^{-3}$; $p_{realistic} = 1.1 \times 10^{-4}$; $p_{proprioceptive} = 2.8 \times 10^{-4}$). This also confirms that we needed to keep the same participants through the three configurations to be able to compare the data.

Fig. 6 shows the different mean scores gathered by subscales scores of the SSQ depending on the configuration of vibrations. The most affected subscale is "Disorientation", followed by "Oculomotor".We observed a significant effect of vibrations reducing the symptoms of simulator sickness ($V = 406$ - $p_{w-c} = 1.94 \times 10^{-6}$; $V = 423$ - $p_{w-p} = 4.39 \times 10^{-6}$). However we can also observe a significant difference between the two types of vibrations ($V = 37$ - $p_{c-p} = 5{,}76 \times 10^{-3}$), with a reduction of 57% for the realistic vibrations and 47% for the proprioceptive one (see Figs. 7 and 8).

We can observe (Fig. 6) that symptoms of sickness is also reduced in all the three subscales of simulator sickness. The vibration not only affects the disorientation (−53%,−48%), which we thought will be the more affected. But also the nausea symptoms (−54%,−45%) and the oculomotor (−61%,−48%).

4.2. Postural instability measure

The postural instability also confirmed the SSQ test results, except for the difference between the two vibrations configurations. Like previously, the data cannot be assimilated to a normal distribution and a Shapirow-Wilks test confirms this assumption ($p_w = 0.00131$; $p_c = 0.178$; $p_p = 0.0363$). Like for the SSQ test results, any type of vibrations seemed to help to reduce the simulator sickness ($V = 381$ - $p_{w-c} = 8.72 \times 10^{-5}$; $V = 343.5$ - $p_{w-p} = 3.33 \times 10^{-6}$) nevertheless, no significant difference was found between the two vibrations configurations ($V = 166$ - $p_{c-p} = 0.137$).

The analyze of multifractality of the displacement of postural sway show the same kind of results. We can see that any type of vibrations seemed to help to reduce the augmentation of the width of the multifractal spectrum ($V = 395$ - p_{w-c}

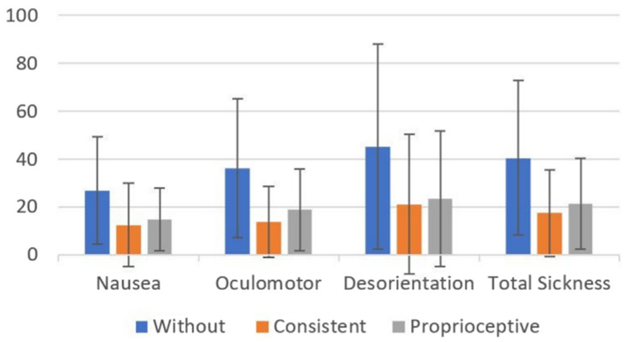

Fig. 6. Mean SSQ scores for each subscale with their standard deviation.

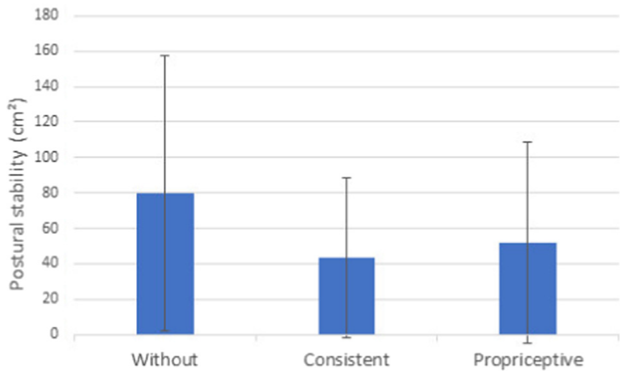

Fig. 7. Means and standard deviations of the difference of the surface of the postural sway.

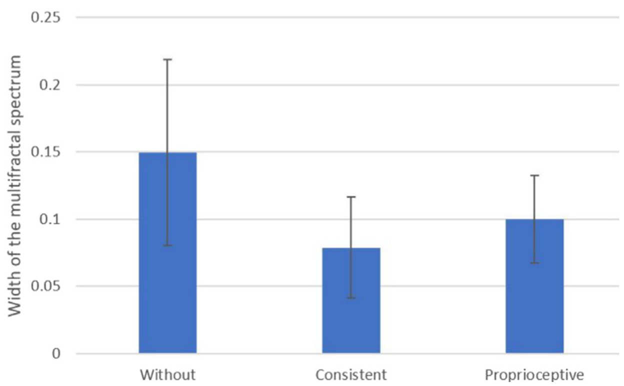

Fig. 8. Width of the multifractal spectrum and standard deviations of the postural sway.

$=9.523 \times 10^{-6}$; V = 355 - $p_{w-p} = 4.55 \times 10^{-5}$). As for the comparison between the two vibrations configurations isn't significant for the experiment (V = 195 - p_{c-p} = 0.0735).

5. Discussion

5.1. Main findings

The goal of this study was to investigate whether the seat vibrations could reduce the simulator sickness. Three configurations were compared: no vibrations, realistic ones and some that might affect the proprioception. Our findings show that some specific seat vibrations could alleviate the symptoms of simulator sickness, as indicated by reductions in the SSQ as well as in the postural instability measure. However, the difference between the two vibrations configuration was not really significant, even if the realistic vibrations has better scores. The remainder of this discussion will further elaborate on these results from different points of view.

5.2. Vibrations

As stated in the introduction, functioning organs of balance are essential in the origin of motion sickness, because people lacking them do not get sick from the motion. However, the vibrations were applied to the seat and not directly to the head like in the study of Bos (2015). In both studies, the frequency of the vibrations were well above 1 Hz, which is known to be the limit for causing sickness. Because the proprioception and the abdominal tissues may have a role in the genesis of motion sickness, we have here chosen to explore the effect of seat vibrations. As shown by the third configuration, vibrations in the range that can disturb the proprioception are effective to alleviate simulator sickness. Furthermore, in the second configuration with realistic vibrations, we can observe that some of their peaks vibrations density are in this range. Consequently, in addition to being consistent with reality, it may also affect the proprioception in a similar way than the third configuration.

Despite the vibrations were here applied to the seat and not directly to the head, the vestibular system is still affected by these vibrations. Indeed, even if the body acts as a shock absorber, here because the participant is seated there is just the high part of the spinal column that absorbs the vibrations before the head, even less if the participant put his head against the headrest. Thus, the sickness reduction may also be due to a similar effect than the one observed by Bos.

In static driving simulation, some disturbing moments are during the turns (Kolasinski, 1995). Several verbal reports from the participants show that noticed a disturbance at these moments in all three configurations but were the most disturbing in the first configuration when there was no vibration rendering. This seems to suggest that the vibrations are blurring the vestibular signals and they may have served as a mental distractor. This mental distractor can also explain the reduction of oculomotor symptoms which are mostly due to the visual system (Oculus Rift) which didn't change during the experimentation. The vibration may have distracted the participants who were less focus on the visual.

The motion sickness arises from conflicts between actual and expected sensory patterns. In simulation the vestibular and proprioceptive senses are not concordant to the visual one. Therefore, with the "proprioceptive vibrations" we are adding noises on this non-coherent sense. Consequently, their signals are less clear compared to the visual and so probably we tend to base our patterns more on the visual sense, which will create less sickness. For the "realistic vibrations" the patterns are more similar to ones we are used and tend to create less sickness. In addition, the realistic vibrations add a kinesthetic sense of the speed and the linear accelerations which will reinforce the visual information of speed and accelerations to the detriment of the vestibular information.

As we have seen, there was no significant difference on the postural instability measure between the two configurations with vibrations. Nonetheless, the participants found the third configuration less pleasant although it is not supported by significant results either. Since the scenario was quite short ($\approx$4 min) it could explain why the difference was not significant. But with a longer simulation the "annoying" effect of the proprioceptive vibrations could induce a significant less comfortable feeling. The link with motion sickness is yet to be proved and validated in further experiments.

5.3. General remarks

As shown in the results, the significance of the postural instability measures was lesser than the SSQ scores, especially between the two types of vibrations where there is no significant difference, this difference could be due to the seated position of the participants during the simulation. Indeed, in this position, the postural control is less used because instability movements are limited. For this reason, the adaptation of the postural control (Riccio & Stoffregen, 1991) is reduced which led to less instability after the simulation and specially during the measurement.

Also the postural stability could have been disturbed by the vibrations pattern, not only by the simulator sickness. Indeed whole body vibration training is used for improving or correcting the postural control of peoples affected by different medical problems (Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007; van Nes, Geurts, Hendricks, & Duysens, 2004). This fact may reduce the significance of the postural instability measure for this kind of experimentation. On the other hand, these studies show an improvement of postural sway after exposition to whole body vibration, so based on the theory of Stoffregen and Smart (1998), the motion sickness comes from prolonged postural instability, this effect could also reduce the motion sickness after the simulation.

Even though the visual refresh rate was clocked to 75 Hz, we observe some decreased rate during the simulation ($\approx$50 Hz). This phenomenon could have induced more sickness specially in the "Oculomotor" SSQ subscale.

Many participants, in their feedback, raised the issue of the turns, they find them very disturbing and quite sickening. Indeed our realistic vibrations give some cues about the speed and the longitudinal accelerations, but not for transverse accelerations, which are mostly due the turns. Thus, for future experimentation, it may be interesting to add some other haptic cues for the turns by moving the vibrations to one side or another during the turns.

6. Conclusion

The present study investigated the effects of seat vibrations in driving simulation and more specifically its role as a countermeasure against simulator sickness. Our findings showed that some specific vibration configurations have a positive impact. This study thus confirms the usefulness of devices reproducing road vibrations in driving simulation, not only for the driver immersion but also to reduce simulator sickness occurrence and severity.

References

Baltzley, D. R., Kennedy, R. S., Berbaum, K. S., Lilienthal, M. G., & Gower, D. W. (1989). The time course of postflight simulator sickness symptoms. *Aviation, Space, and Environmental Medicine, 60*(11), 1043–1048.

Benson, A. J. (2002). Motion sickness. In K.B. Pandof, R.E. Burr, editors. Medical aspects of harsh environments, vol. 2, Chap 35, 2002, ISBN 978-0-16-051184-4 (pp. 1048–1083).

Bergenheim, M., Ribot-Ciscar, E., & Roll, J. P. (2000). Proprioceptive population coding of two-dimensional limb movements in humans: I. Muscle spindle feedback during spatially oriented movements. *Experimental Brain Research, 134*(3), 301–310.

Bogaerts, A., Verschueren, S. M. P., Delecluse, C., Claessens, A. L. M., & Boonen, S. (2007). *Effects of whole body vibration training on postural control in older individuals: A 1 year randomized controlled trial*, vol. 26(2) (pp. 309–316).

Bos, J. E. (2015). Less sickness with more motion and/or mental distraction. *Journal of Vestibular Research, 1*, 23–33.

Bouchard, S., Robillard, G., & Renaud, P. (2007). Revising the factor structure of the Simulator Sickness Questionnaire. *Annual Review of Cybertherapy and Telemedicine, 5*(Summer), 128–137.

Casali, J. G. (1985). Vehicular Simulation-Induced Sickness. Volume 1. An Overview., Tech. Rep. IEOR-8501, Virginia Polytechnic Inst And State Univ.

Chang, C.-H., Pan, W.-W., Chen, F.-C., & Stoffregen, T. A. (2013). Console video games, postural activity, and motion sickness during passive restraint. *Experimental Brain Research, 229*(2), 235–242.

Crowley, J. S. (1987). Simulator sickness: A problem for Army aviation. *Aviation, Space, and Environmental Medicine, 58*(4), 355–357.

Ihlen, E. A. F. (2012). Introduction to multifractal detrended fluctuation analysis in Matlab. *Frontiers in Physiology, 3*.

Golding, J. F. (2006). Motion sickness susceptibility. *Autonomic Neuroscience, 129*(1–2), 67–76.

Hettinger, L. J., & Riccio, G. E. (1992). Visually induced motion sickness in virtual environments. *Presence: Teleoperators and Virtual Environments, 1*(3), 306–310.

Johnson, D. M. (2007). Simulator Sickness Research Summary. *Tech. rep., Army research inst for the behavioral and social sciences fort rucker al.*

Kennedy, R. S., & Fowlkes, J. E. (1992). Simulator sickness is polygenic and polysymptomatic: Implications for research. *The International Journal of Aviation Psychology, 2*(1), 23–38.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203–220.

Keshavarz, B., & Hecht, H. (2014). Pleasant music as a countermeasure against visually induced motion sickness. *Applied Ergonomics, 45*(3), 521–527.

Kolasinski, E. M. (1995). Simulator Sickness in Virtual Environments., Tech. Rep. No. ARI-TR-1027, Army research inst for the behavioral and social sciences Alexandria VA.

Lackner, J. R., & Graybiel, A., (1974). Elicitation of Vestibular Side Effects by Regional Vibration of the Head,, Tech. Rep. NAMRL-1204, Naval aerospace medical research lab Pensacola FL, naval aerospace medical research lab Pensacola FL.

McCauley, M., & Sharkey, T. (1992). Cybersickness: Perception of self-motion in virtual environment. *Presence, 1*, 311–318.

Money, K. E. (1970). Motion sickness. *Physiological Reviews, 50*(1), 1–39.

Munafo, J., Curry, C., Wade, M. G., & Stoffregen, T. A. (2016). The distance of visual targets affects the spatial magnitude and multifractal scaling of standing body sway in younger and older adults. *Experimental Brain Research, 234*(9), 2721–2730.

van Nes, I. J. W., Geurts, A. C. H., Hendricks, H. T., & Duysens, J. (2004.) *Short-Term Effects of Whole-Body Vibration on Postural Control in Unilateral Chronic Stroke Patients: Preliminary Evidence*, vol. 83(11): 867.

O'Hanlon, J. F., & McCauley, M. E. (1974). Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. *Aerospace Medicine, 45*(4), 366–369.

Petroni, A., Carbajal, M. J., & Sigman, M. (2015). Proprioceptive body illusions modulate the visual perception of reaching distance. *PLOS ONE, 10*(6), e0131087.

Reason, J., & Brand, J. (1975). *Motion sickness* (vol. vii) Oxford, England: Academic Press. ISBN 978-0-12-584050-7.

Reason, J. T. (1978). Motion sickness adaptation: A neural mismatch model. *Journal of the Royal Society of Medicine, 71*(11), 819–829.

Reschke, M., Somers, J., & Ford, G. (2006). Stroboscopic vision as a treatment for motion sickness: Strobe lighting vs. shutter glasses. *Aviation, Space, and Environmental Medicine, 77*, 2–7.

Riccio, G. E., & Stoffregen, T. A. (1991). An ecological theory of motion sickness and postural instability. *Ecological Psychology, 3*(3), 195–240.

Sandin, J. F. M., Erikson L., & Augusto, B. (2016). Effects of sensory cues on perceived simulated speed. DSC 2016 Europe, (pp. 171–178).

Smart, L. J., Stoffregen, T. A., & Bardy, B. G. (2002). Visually induced motion sickness predicted by postural instability. *Human Factors, 44*(3), 451–465.

Stoffregen, T. A., & Smart, L. J. (1998). Postural instability precedes motion sickness, vol. 47(5): (pp. 437–448).

TechnoConcept, Techno-concept balance board manual.

Treisman, M. (1977). Motion sickness: An evolutionary hypothesis. *Science, 197*(4302), 493–495.

Wachenfeld, W., Winner, H. (2016). The release of autonomous vehicles. In Autonomous Driving, 425–449, Springer Berlin Heidelberg, Berlin, Heidelberg, 2016, ISBN 978-3-662-48845-4 978-3-662-48847-8.

Webb, N. A., & Griffin, M. J. (2003). Eye movement, vection, and motion sickness with foveal and peripheral vision. *Aviation, Space, and Environmental Medicine, 74*(6), 622–625.

Winkle, T. (2016). Safety benefits of automated vehicles: Extended findings from accident research for development, validation and testing. In M. Maurer, J. C. Gerdes, B. Lenz, H. Winner, editors. Autonomous Driving, 335–364, Springer Berlin Heidelberg, Berlin, Heidelberg, 2016, ISBN 978-3-662-48845-4 978-3-662-48847-8.

Zhang, L.-L., Wang, J.-Q., Qi, R.-R., Pan, L.-L., Li, M., & Cai, Y.-L. (2016). Motion sickness: Current knowledge and recent advance. *CNS Neuroscience & Therapeutics, 22*(1), 15–24.