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Alleviating Motion Sickness through Presentations on Interior Panels of Autonomous Vehicles

Human Factors and Engineering Psychology

Master Thesis

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Abstract

This study investigated the possibility of alleviating motion sickness in passengers of autonomous vehicles through visual stimuli on interior car panels. Past research has demonstrated that persons being driven in an autonomous vehicle are considerably more at risk of developing symptoms of motion sickness, which forms a major hindrance for their broad implementation. The sensory conflict theory suggests that a conflict between expected and felt motion is what triggers sickness. In line with this, anticipation has been attributed a major role in sickness prevention. We implemented motion cueing stimuli that were providing information about either current or near future heading direction and velocity on interior presents in our experiment. There was a significant effect of both conditions on motion sickness, indicating that these implementations can effectively be used to alleviate sickness.

Introduction

The automotive industry is currently evolving. Development of electric vehicles is progressing in the course of rising concerns about environmental impact and sustainability of fossil fueled vehicles. Another major innovation is the introduction of autonomous vehicles, which are considered to be one of the next big things in the field. Companies like Tesla, Mercedes, Uber and Google are experimenting with the relatively new concept to develop a self-driving car and be the first to profit from the emerging technology. In addition to the economical possibilities that this kind of vehicle provides, autonomic cars are expected to provide maximum safety, utility and comfort to passengers, while minimizing environmental impact (Gerla, Lee, Pau, & Lee, 2014).

Besides evoking a number of different issues in multiple domains, like ethics, safety, legal frameworks and regulations or broad societal acceptance; a problem for the passengers in these vehicles is that the risk of suffering from motion sickness is considerably higher compared to non-autonomous vehicles (Diels & Bos, 2016). The objective of this study was to tackle this issue and find a possibility to ease passenger's sickness using visual stimuli implemented in the interior of the vehicle.

Motion sickness, or kinetosis, manifests itself in symptoms like nausea, cold sweating,

fatigue, salivation, dizziness, vomiting, impaired coordination and even relatively long enduring impairment of general performance. It is believed that activity of the vagus nerve, which is a part of the autonomic nervous system, is responsible for the symptoms associated with motion sickness (Kennedy, Drexler, & Kennedy, 2010). Motion sickness is known to show very large interindividual differences, with some people experiencing almost no motion sickness at all, while others start feeling uneasy at comparatively low intensity of the corresponding cause of sickness (Lackner, 2014). Motion sickness occurs in real, physical motion (e.g. being passenger in a car or ship) as well as in apparent motion (e.g. fixed-base driving simulator, virtual reality). There are generally three types of scenarios from which sickness arises: physical motion in the absence of visually perceived motion, visually perceived motion in the absence of physical motion and a mismatching perception of motion from these systems. If the sickness results from only visually perceived motion the term ‘visually induced motion sickness’ (VIMS) is widely used to describe this phenomenon (Dichgans & Brandt, 1971).

Theoretical Framework – The Sensory Conflict Theory

So far multiple theories about the causes of motion sickness have been proposed to explain the development of sickness symptoms. Generally it is believed that motion sickness is a defensive mechanism of the body to induce vomiting when showing signs of having ingested neurotoxic poison. A mismatch between sensory organ’s inputs supposedly is interpreted as fulfilling the requirements to start this physiological reaction. The most influential and most discussed theory about the etiology of motion sickness elaborates on how exactly this mismatch is formed, the Sensory Conflict Theory. It as was formulated first by Reason (1978) under the name of Sensory Rearrangement Theory and states that motion sickness results from a discrepancy between expected and sensed motion (like conflicting input from the vestibular, visual or non-vestibular graviceptors). The vestibular system is located in the inner ear and assesses only linear and rotational acceleration of the head. This system forms the basis of motion sickness, following the argumentation of Reason. It is believed to be a prerequisite for motion sickness to occur. This is supported by the reported immunity of motion sickness of individuals who do not possess this organ. Any sensory conflict involves a discrepancy between what is expected and what is actually felt, although this does not necessarily need to be a visual-vestibular conflict, past experiences and mental representations play a major role in the theory. When based on past experience a specific motion or motion pattern is expected, but is not experienced in reality, the resulting

conflict might lead to motion sickness. Vice versa, when being presented with the same situation over and over again, it has been shown that habituation occurs and sickness sensitivity decreases over time. This is because the individual has formed a mental representation and knows what to expect in this type of situation, enabling the autonomous nervous system to accommodate the motion accordingly and not trigger a sensory conflict (Reason, 1978).

The Sensory Conflict Theory is and has been widely used in the scientific literature, and the described conflict has consistently been shown to indeed elicit motion sickness (Diels & Bos, 2014; Duh, Parker, Philips, & Furness, 2004; Warwick-Evans, Symons, Fitch, & Burrows, 1998). Flanagan, May and Dobie (2002) investigated the etiological causes of motion sickness and based their research on the Sensory Conflict Theory and two alternative theories, the Eye Movement Hypothesis and the Postural Instability Hypothesis. According to the former a mixture of slow and fast-phase eye movement, the optokinetic nystagmus, stimulates the nervus vagus and is believed to trigger motion sickness. The latter states that the perception of having an unstable body positioning and being in imbalance suffice to elicit sickness. The authors included variables that they believed would test either one of the corresponding theories and then evaluated their impact on the sickness reported by the nine participants. The results showed a significant main effect of Sensory Conflict on motion sickness and the authors concluded that although different explanations could not be ruled out categorically, their findings generally provide support for the Sensory Conflict Theory.

Although conflicting theories exist and there is no final consensus in the scientific community what exactly the underlying causes of motion sickness are, a sensory conflict in the sense of Reason is taken as a theoretical foundation for this study. It is the most adopted framework and studies based on it have continuously and successfully evoked motion sickness in participants.

Role of Anticipation in the Onset of Motion Sickness

Of particular importance in the context of self-driving cars is that there is evidence that of all passengers in a non-autonomous vehicle the driver is the least prone to experiencing symptoms of motion sickness (Rolnick & Lubow, 1991). In their study Rolnick and Lubow examined 44 males' motion sickness while putting them together in pairs on a rotatable platform. One of them had control about the movement of the platform and the other was effectively a passenger. While both of them were subjected to the same motion, significant differences in sickness and well-

being ratings were found between the two groups, with those having no control showing significantly more sickness and diminished well-being. The authors mention that this finding stands in disagreement with Reasons' Sensory Conflict Theory, as both groups were subjected to exactly the same conflict. However, this argumentation does not correctly reflect Reasons' theory, which describes a mismatch between expected and felt motion to be the cause of motion sickness. So the findings of Rolnick and Lubow are very well in line with the theory. The person steering the platform had the possibility to estimate the expected sensory feedback resulting from his or her inputs, subsequently leading to a mitigation of sensory conflict and hence less motion sickness.

Others have reported similar findings, with the driver getting less motion sick than passengers. It is believed that this is due to the driver's ability to anticipate the vehicle's future state (Diels & Bos, 2016), which allows the central nervous system to make predictions about future movements and accommodate these accordingly (Bos, Hogervorst, Munnoch, & Perrault, 2008). Being able to predict future acceleration, deceleration, rotation as well as vibration of the vehicle, which is another factor in the emergence of motion sickness (Mackie, O'Hanlon, & McCauley, 1974), puts the person steering the vehicle in an advantageous position. This is particularly true for the person being in control of the vehicle, but also for those who have a clear view ahead and therefore can anticipate what motion will be experienced. Griffin and Newman (2004) found this in their study while investigating the effects of different visual fields on the road ahead on motion sickness. Those who had a clear view on the road showed significantly less sickness, while it did not matter whether or not they could see through the side windows of the vehicle. Interestingly they also tested a condition involving a screen providing real-time video footage of the road ahead (and no clear forward view). In theory should put participants in a better position to anticipate the motion of the vehicle as opposed to those having no additional information about the upcoming path. However, they found no effect of this manipulation on motion sickness, which does not necessarily mean that this kind of intervention cannot be fruitful, but could also hint at some shortcoming of the application in the study. For example the positive effect of the anticipatory information might have been cancelled out by the motion sickness inducing gaze direction (looking downwards on the screen) or missing visual compensation of lateral head movements on the relatively small display, as the authors observed themselves.

Implications for Autonomous Driving

Diels and Bos (2016) found that already a low level of automation leads to more motion sickness in passengers of autonomous vehicles. Especially those in vehicles with a high degree of automation are more susceptible, because they are not required to actually drive anymore and can engage in recreational or work-related side activities, thus ultimately leaving their role as driver and effectively becoming a passenger. As explained above not actively steering the car enlarges the risk of getting motion sick. On top of that, when not observing the road ahead anymore another source for anticipatory information is taken away and the susceptibility to motion sickness is increased further. The same consequences are to be expected from the possible alterability of the seating arrangement in such a way that passengers face backwards. Intended to enable passengers to engage in joint activities, it might turn out to be a significant disadvantage, as they cannot observe the road ahead anymore and hence experience more motion sickness. According to the Sensory Conflict Theory these hindrances to form a valid expectation of upcoming motion enlarge the mismatch between expected and experienced motion and eventually lead to an increase of sickness.

Past Research to Counteract Motion Sickness

So far effective means to reduce motion sickness for passengers have primarily been of a pharmacological nature (Shupak & Gordon, 2006). This is not a desirable long term solution and has been addressed by other studies. Krueger (2011) tested the effect of a head mounted display (HMD) including an artificial horizon and a visual fixation target projected in the field of view to help highly susceptible individuals and persons undergoing vestibular rehabilitation in coping with motion sickness. Although a few of the participants reported problems with using the device, the majority reported the HMD to be helpful in mitigating the strength of their experienced symptoms.

The implementation of visual motion cues to achieve a reduced prevalence of motion sickness has been investigated in other studies. Morimoto, Isu, Okumura, Araki, Kawai and Masui (2008) implemented cues around or within an infotainment system and found it to be an effective intervention to lessen symptoms of sickness. The cues were aligned only with the yaw rotation of the vehicle. Similarly, Jeng-Weei Lin, Parker, Lahav and Furness (2005) evaluated the effectiveness of reducing motion sickness in vehicle passengers through cues about the upcoming turning direction. Participants were put in a fixed base driving simulator and were to do a

memory task. The simulator was made of a mockup car and three surrounding screens to project the visuals on. On these screens the fictional landscape ‘Crayoland’ was projected, in which the motion cues were included. After 120 second long trials, participants were instructed to report how sick they felt. In the conditions involving visual motion cues, levels of sickness were significantly lower; especially highly susceptible individuals profited from the implementation.

A recent study by McGill, Ng and Brewster (2017) first evaluated the use of virtual reality (VR) in moving cars and how carsickness could possibly be alleviated. In one condition the movement of a basic landscape (trees, bushes etc.) was synchronized with the current physical motion of the car. In another condition a stable view was provided in foveal vision together with a moving environment in the peripheral vision. It was hypothesized that in the latter condition the conflict between perceived and actual motion should be diminished. However, it elicited significantly more motion sickness in participants, even though it was generally preferred by highly susceptible individuals (those scoring above the 75th percentile of the Motion Sickness Susceptibility Questionnaire) and slowed the onset of sickness symptoms in these individuals. The authors note that the implementation of motion cues mimicking vehicle motion was considerably limited by the available equipment and they recommend retesting higher fidelity landscapes incorporating sufficient landmarks, implementing abstract cues. They also mention the possibility of incorporating anticipatory information.

Feenstra, Bos and van Gent (2011) put participants in a flight simulator and assessed their motion sickness while either having (1) no additional information, (2) being provided with simulated images that were moving along with the physical motion of the person in the simulator, or (3) by additionally having anticipatory information about the upcoming track. They found their hypothesis confirmed by their data in that the second condition did decrease the motion sickness, and the third experimental condition was even more effective in countering the severity of motion sickness. The anticipation condition enabled them to decrease motion sickness by a factor as large as 4.2, being an immense improvement through a relatively easy manipulation. Although the overall sickness scores in their study were comparatively small making a large relative reduction more likely, this further hints at importance of anticipatory information in the context of motion sickness.

This finding is of special importance in the prevention and alleviation of motion sickness in self-driving cars, because this kind of vehicle can potentially predict future trajectory and necessary acceleration, deceleration and steering better than manually driven vehicles can. Even

more so, if the majority or all of the vehicles in a specific area are driving autonomously, interconnectedness increases the level of certainty the vehicles have about eminent future situations (Friedrich, 2016).

Another possible feature of autonomous vehicles is the incorporation of large projection areas as part of interior elements, as can already be seen in the Mercedes Benz F 015. This is an opportunity for presenting visual information to passengers which in turn possibly alleviate symptoms of sickness through reducing the conflicting inputs from different modalities.

Research Question and Hypotheses

The research question that was sought to be answered was: Can motion cueing stimuli on interior panels of autonomous vehicles alleviate motion sickness in passengers? Following the body of research and past findings, providing additional information should alleviate motion sickness as it decreases the visual-vestibular conflict that could be the cause of carsickness. Since anticipation has been shown to be of critical importance in the prevention of motion sickness, anticipatory information should decrease sickness as well. The hypotheses following from that are:

H1: Providing motion cues that are in line with current motion on interior panels alleviates motion sickness.

H2: Providing motion cues that are in line with near future motion on interior panels alleviates motion sickness.

Design of the Present Study

In the present experiment the participants were subjected to three different visual conditions in virtual reality while being placed on a motion platform. They were seated in a simulated autonomous vehicle facing backwards and engaging in a simple task while gazing downwards in order to simulate a realistic user situation. During and after each of the experimental trials motion sickness was assessed. The differences in visual conditions were the kind of stimuli presented on the interior panels of the simulated vehicle. These presented either no information, information about the current vehicle motion, or information about the future vehicle motion.

It was critical to determine how the participants were provided with the motion cues. Two findings were taken as the theoretical basis for their design, optic flow information and population stereotypes. Optic flow is the visual perception people have of their surroundings

while being in motion. Vice versa, this kind of visual information also induces the perception of self-motion (Lappe, Bremmer, & van den Berg, 1999). It was expected that providing optic flow that is congruent with the vehicle's motion improves one's perception of self-motion. According to the peripheral dominance hypothesis, vection and perceived heading direction are primarily based on the environment perceived in the periphery of the field of view (Dichgans & Brandt, 1978). Although some authors reported somewhat conflicting findings about where in the field of view exactly heading direction and the sense of motion are extracted from (cf. Warren & Kurtz, 1992), the peripheral dominance hypothesis is generally supported by the literature (Webb & Griffin, 2003).

Bergum and Bergum (1981) looked into population stereotypes, which can be described as rapidly and automatically executed associations shared by a large group of people (e.g. within one culture). They found that the colors 'red' and 'green' were perfectly associated by the participants with the concepts of 'stop' (100%) and 'go' (99.2%). In their study they thus found that almost all of their participants linked the colors to the corresponding associative concepts. Most certainly derived from ongoing interaction with traffic lights on a daily basis. Following the spreading activation theory, it can also be argued that the context of the current study (driving in a vehicle, traffic) made it more likely that participants would implicitly choose this associated meaning over conflicting ones (Anderson, 1983). This particular property of the two colors, amplified by the contextual factors, was made use of as it formed the theoretical basis on how to communicate acceleration ('go') and deceleration ('stop') to individuals who took part in the experiment.

The time ahead that the future information stimuli should provide was chosen to be set at 500ms, so half a second into the future motion was presented in this condition. Tovee, Rolls, Treves and Bellis (1993) found that neurons in the temporal cortical visual areas remained active for up to 500ms after stimulus presentation. Although the particular neural areas studied by them are involved in the processing of faces, they argue that because of similar constraints in other areas, properties of processing are likely to be the same.

So the visual motion cues that provided the participants with either current or 500ms into the future information, were designed based on the principles of optic flow and on the concepts associated with the colors red and green.

Because an implementation of the proposed intervention was not feasible in a real autonomous car, the study was conducted on a hexapod motion platform and under the use of

VR. The motion platform provided the physical motion coherently in order to match what was presented in VR.

Method

Participants

In total the study included 19 participants (mean age = 27.74, SD = 4.46). 14 of them were employees of the Max Planck Institute for Biological Cybernetics; the remaining five were recruited from the institute's participant database. Seven were male and 12 were female. Participants reported to be in normal health and were naïve regarding the differences in conditions of the experiment. Superficial screening was done during participant collection, as they were asked whether they were susceptible to motion sickness. Approximately 60 persons were approached before having gathered the desired number of participants. Only those who reported to feel sick sometimes, were included in the experiment. For those who were approached via the participant database, motion sickness susceptibility was listed as a requirement for taking part in this study. External participants were compensated with 8 Euros per hour.

The experiment was in accordance with the Declaration of Helsinki and approved beforehand by the ethics committee of the University of Twente (Enschede, The Netherlands; application number 18058). All participants signed an informed consent form before the experiment was conducted.

Apparatus and Materials

The whole study was conducted in the MotionLab facilities of the Max Planck Institute for Biological Cybernetics, Tübingen, Germany. To simulate the physical movement of an autonomous vehicle, we first created three different tracks with a script written in MATLAB (The MathWorks Inc., Natick, United States, version R2016a). Tracks were generated as self-avoiding random walks: 100 two dimensional (x,y) data points were specified, each dependent and in direct proximity of the prior one. A straight stretch of 3 additional datapoints was added at the start to aid the automated driver. After that, changes between successive data points were smoothed using a 3-point moving average filter. The roads were then scaled to be 7.5 kilometers long by cubic interpolation to prevent the track from featuring overly sharp turns, a 2nd order Butterworth filter was then applied, with a half power frequency of .05. The resulting paths can be seen in figure 1.

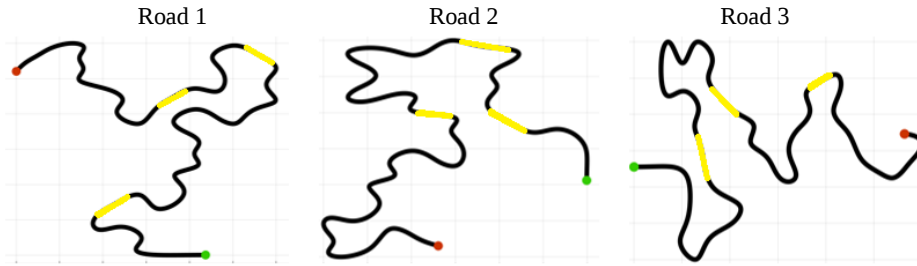


Figure 1. Trajectories of the three roads used for the motion profiles. The green dot is the starting point and the red one the end point. The yellow marked parts is where the braking maneuvers with subsequent acceleration were performed.

To generate autonomous motion profiles, we used CarSim® (Mechanical Simulation Cooperation, Ann Arbor, United States). The resulting translational accelerations and angular velocities were recorded and used as simulator motion profiles. Each profile was approximately 10 minutes long. For generation of physical motion cues, we used an eMotion 1500 hexapod motion system (Bosch Rexroth AG, Lohr am Main, Germany) with six degrees of freedom. And for visualizations of the virtual environment, we used custom software written to work with the Unity® game engine (Unity Technologies, San Francisco, United States, version Unity 4.2.2f1). The software created a visual world corresponding to the previously generated random-walk tracks. For presenting the virtual environment, the HTC Vive® (HTC Cooperation, New Taipei City, Taiwan) was used. This head mounted display (HMD) has a refresh rate of 90 Hz, a resolution of 2160x1200 (1080x1200 per eye), a horizontal field of view of 100° and a vertical field of view of 110°, therefore it provides a pixel density of approximately 11 pixels per degree. For head tracking, an HTC lighthouse system was employed allowing for translation of participants' head movements in corresponding changes in what was visually presented to them in the HMD. To not interpret movement of the simulator as head movement, motion compensation was employed. This was done through strapping an HTC Vive® controller to the Stewart platform and employing the program OpenVr-InputEmulator (matzman666, 2017). This program can alter the received input from VR devices and has a built in function to compensate for the specific motion registered by one device, which in this was the Vive® controller on the platform. During the experiment the participants were to give inputs for a simple computer game,

this was done using Xbox 360 (Microsoft®, Redmond, United States) handheld controllers. Logics and communication between the experiment-control PC, the real-time controller (Speedgoat GmbH, Bern, Switzerland), the motion platform, and the visualization PC were implemented in a custom written Simulink® model (The MathWorks Inc., Natick, United States, version R2016a).

Setup

CarSim® provides an automatic driver which was used to drive around the generated tracks. The automatic driver accelerated from zero to 50km/h at the onset of the track, and was set to drive at a constant velocity of 50 kilometers per hour for the remainder of the track. The driver slowed down before going around corners and at the end of the track. It also decelerated from 50 kilometers per hour to once either 30, 20 or 10 kilometers per hour and accelerated again to the original speed after going at this speed for approximately 10 seconds.

The motion profiles generated with MATLAB were passed to the platform control software, and translated into motions using the platform built-in washout filter. Road rumble with an intensity proportional to the simulated car's speed was added to the motion profiles, using a built-in feature of the Stewart platform. The motion of the simulated vehicle was in synchrony with the physical motion cues of the platform. Visual motion cues were presented to the participants using the HMD.

To increase the realism of the simulation, motor noises proportional to the simulated cars velocity were added to the simulation. The noises were generated in the Unity game engine, and played back over wireless, noise-cancelling headphones. The whole physical setup is presented in Figure 2.



Figure 2. The setup of the experiment. The participant is placed on the motion platform while wearing an HMD, noise cancelling headphones and giving inputs using the handheld controller.

Task and Stimuli

The study had a within-subjects design, with three different experimental conditions. The dependent variable was motion sickness, as assessed by questionnaires (see below). The independent variable was the information presented on interior body panels of the virtual car. There were three different visual environments: no information (control condition; Figure 3, left panel); additional information on the present motion (Figure 3, right panel); and additional information on future motion. In the latter conditions, this information was presented in the form of (virtual) earth-stationary dot clouds surrounding the car. Motion of the dots was generated by capturing motion through the dot-clouds outside of the car by virtual cameras, and subsequently showing monoscopic views on the aforementioned interior panels. The visualizations were shown on panels on the doors, between the backseats and on the floor of the car. The dots visible on the panels can be interpreted as an abstract representation of the outside world, as dots that were closer to the car would appear bigger and move faster (at constant speed) on the panels than those further away in the stereoscopic entity. In the condition where future motion was shown, the

virtual cameras capturing the car's environment were looking 0.5s ahead in the simulation motion profile.

In addition to their motion, the dots gradually changed their color when accelerating or decelerating, either turning green on acceleration (population stereotype 'go') or red (population stereotype: 'stop') on deceleration. The intensity of the color change depended on the strength of the corresponding change in velocity. For the condition showing future motion, the color change corresponded to the acceleration/deceleration 0.5s in the future.

The participants were seated facing rear-wards in the virtual car so that they did not have a view on the road ahead (see above for implications on motion sickness). In the interior of the virtual car, a tablet-like screen was present that featured the video game 'Pong'. Participants were instructed to play this game, which they were able to do using the hand held controller. The purpose of playing pong was to present them with a task that resembles activities which often lead to increased levels of motion sickness (e.g. reading; see introduction). The tablet-like virtual screen also featured a red light. The experimenter activated this light briefly at two-minute intervals within each trial, starting immediately at the onset of the trial. The participants were instructed to report their FMS score verbally each time they saw the light blinking.

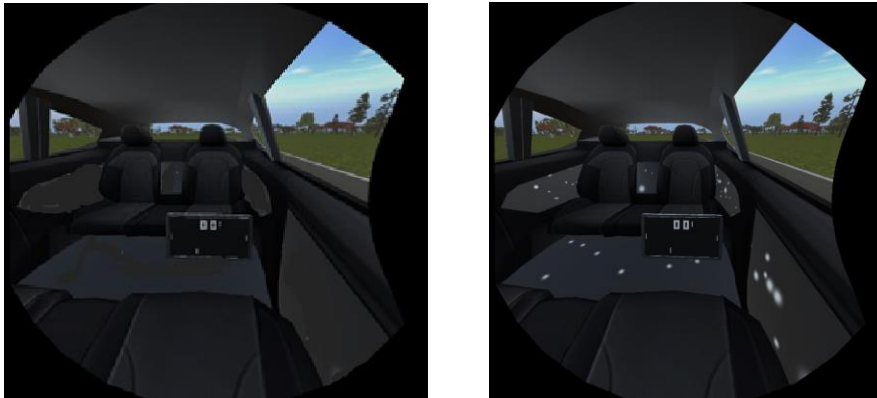


Figure 3. Interior of the simulated vehicle with the control condition on the left and the visual stimuli on the right. The image in the circle represents a monoscopic screenshot of what the participants saw through the HMD.

Measures

There were used two questionnaires and one verbal rating scale. Questionnaires were used to determine participants' sensitivity to motion sickness and their experienced motion sickness after each trial. Before the experiment, to determine the participants' sensitivity to motion sickness, the shortened version of the Motion Sickness Susceptibility Questionnaire (Golding, 2006) was used. It is divided in two parts, both including 9 items ranging from 0 to 3 (0 = never felt sick, 3 = frequently felt sick), asking about the experience of motion sickness in different scenarios (e.g. in cars, on funfair rides). The first part is concerned with experiences before the age of 12, while the second part inquires the last 10 years. During the experimental trials motion sickness was assessed with the Fast Motion Sickness Scale (FMS; Keshavarz & Hecht, 2011), which ranges from 0 to 20 (0 = not nauseous, 20 = I am about to vomit) and can be applied verbally. After each trial Kennedy, Lane, Berbaum and Lilienthal's (1993) Simulator Sickness Questionnaire (SSQ) was administered to examine the motion sickness participants felt, the SSQ includes 16 4-point scale items (0 = no motion sickness, 3 = severe motion sickness), covering three symptom clusters (nausea, oculomotor impairment and disorientation). All questionnaires were available in English and German.

Procedure

Prior to the actual experiment, participants were to read an information sheet that explained the study's goals and motivation, and gave explicit instructions on the tasks. When participants agreed to participate, they provided written informed consent. All documents were provided in English or German, depending on what the participant preferred.

First, the Motion Sickness Susceptibility Questionnaire was filled out. Then participants were brought to the motion platform, and were given a verbal reiteration of the written instructions. Then they were given the HMD, earplugs to suppress operating noises of the simulator, the headphones and the Xbox controller. When everything was set up and all safety measures were in place, the actual trial started. On each trial a participant experienced the driving simulation along one of the three tracks, in combination with one of the three different visual conditions. The order and combination of visual conditions and tracks was incompletely counterbalanced between participants; each participant experienced each visual condition and track, but the specific combinations differed between participants. During the trials the participants were to report their FMS score. The first time they needed to do this was right after

the start, to establish how sick they felt before actually experiencing any motion. After that, the FMS was reported every two minutes until the end of the trial, if they were to reach a score higher than 15, the trial was aborted in order to prevent sickness. Each trial took approximately 10 minutes and was to be completed on a different day to make sure that the participants had ample time to recuperate in case they showed symptoms of motion sickness, as it is known that these can take multiple hours to disappear (see introduction).

After completion of a trial and being brought back from the motion platform, the participants filled out the SSQ. After completing the final trial of the experiment, participants were debriefed, thanked and compensated for their time.

Data Analysis

For analyzing the sickness scores first an FMS_{max} score was calculated, representing the highest score a participant reached over the course of one trial. Both SSQ and FMS_{max} should represent the same construct, motion sickness, and therefore the scores should be highly correlated. Based on this, the assumption can be made that the two are linearly related. This allows for the use of Pearson correlation, as opposed to other methods like Spearman, which does not require a linear relationship between the two variables. Pearson correlation has also been used by other researchers in the past to investigate the relationship between SSQ and FMS peak scores (cf. Keshavarz & Hecht, 2011; Shahal, Hemmerich, & Hecht, 2016).

To determine whether the experimental manipulations had an effect on motion sickness, and to estimate how large this effect was, a generalized linear mixed-effects model was formulated and the posterior confidence intervals were evaluated. This was done using the ‘rstanarm’ (Gabry, 2018) package in the statistical programming environment ‘R’ (R Core Team, 2017). Before doing so the best fitting model needed to be selected from two conflicting ones for each measurement, the SSQ and the FMS_{max} . Both of them incorporated as fixed effects the experimental manipulation ‘Visual scene’ to check the hypotheses, ‘Trial’ to take possible habituation into account and ‘Participant’ as random effect to compensate for individual variability in motion sickness susceptibility. The difference between the two models was the incorporation of ‘Track’ as an additional fixed effect. Although the tracks the automated vehicle drove on were designed to be equally provocative, it cannot be assumed with certainty that this was the case in reality. The each two models were checked for sensitivity to single measurements

using leave-one-out cross-validation and then compared through means of the expected log pointwise deviance. The R model formula of the four models can be seen in Table 1.

Table 1. R model formula for the two conflicting models

Model characteristics	R formula
SSQ without ‘Track’	SSQ Total ~ Visual Scene + Trial + (1 Participant)
SSQ with ‘Track’	SSQ Total ~ Visual Scene + Trial + Track (1 Participant)
FMS _{max} without ‘Track’	FMS _{max} ~ Visual Scene + Trial + (1 Participant)
FMS _{max} with ‘Track’	FMS _{max} ~ Visual Scene + Trial + Track + (1 Participant)

Results

From the 19 participants, data of seven was excluded from further analysis, as they did either not meet the selection criterion for the MSSQ (above 50th percentile; cf. Golding, 2006) or did not report any sickness (SSQ below 50th percentile; cf. Kennedy, Lane, Berbaum, & Lilienthal, 1993).

Descriptive Analysis

Figure 4 shows the distribution of the SSQ scores in the three conditions. The overall mean of SSQ total was 43.42 (SD=33.23). The FMS_{max} scores’ mean was 6.64 (SD=3.46) and respectively for the different visual conditions, 6.45 (SD = 6.45) in the control condition ‘Info_{None}’, 6.48 (SD = 3.37) when current information was displayed on interior panels ‘Info_{Current}’ and 6.97 (SD = 3.37) when future motion was displayed ‘Info_{Future}’. The corresponding boxplot can be seen in Figure 5.

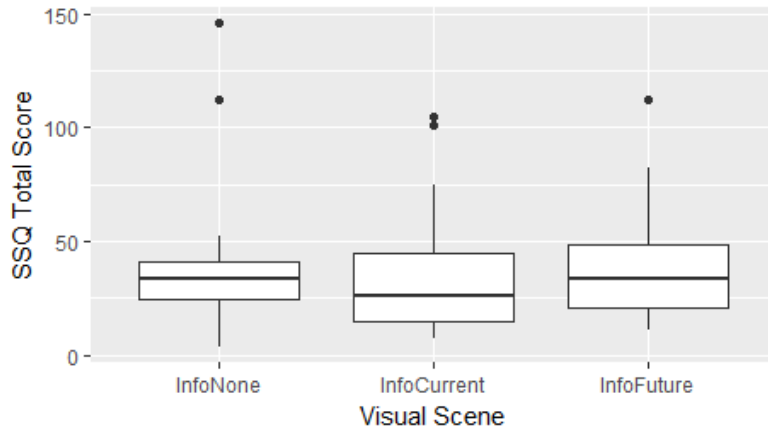


Figure 4. Boxplot of the SSQ total scores for the three experimental conditions.

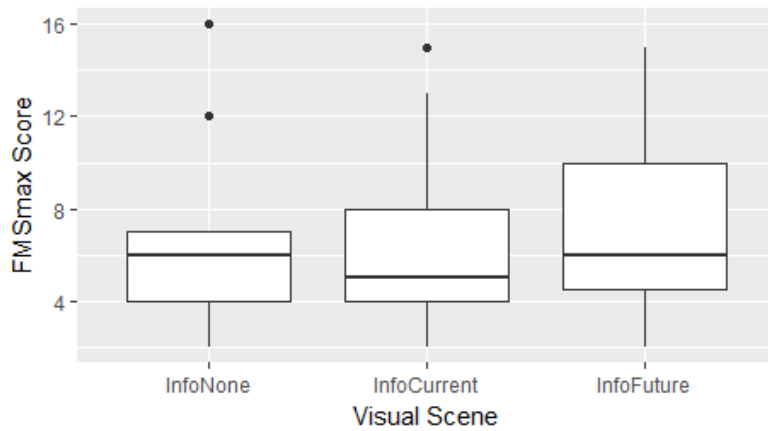


Figure 5. Boxplot of the FMS_{max} scores for the three experimental conditions.

Inferential Analysis

For both measures of motion sickness (i.e., FMS_{max} and SSQ), it was found that the model incorporating ‘Track’ as an additional fixed effect had superior fit. This is indicated by the difference in expected log pointwise deviance. Positive values for the expected log pointwise deviance suggested favoring the more elaborate model over the one not regarding ‘Track’ as a

fixed effect (SSQ: expected pointwise deviance = 25.8, SE = 6.7; FMS_{max}: expected pointwise deviance = 22.6, SE = 6.9; cf. Vehtari, Galman, & Gabry, 2017).

SSQ

The estimates for the intercept and the single effects together with the 5% and 95% confidence intervals are presented in Table 2.

Table 2. Summary statistics of the model using the z-transformed SSQ scores, including the 5% and 95% confidence interval boundaries.

Parameter	Estimate	5%	95%
Intercept	0.28	-0.15	0.77
Info _{Current}	-0.12	-0.19	-0.06
Info _{Future}	-0.15	-0.21	-0.08
Trial 2	-0.007	-0.07	0.05
Trial 3	-0.01	-2.81	1.38
Track 2	-0.31	-0.38	-0.24
Track 3	-0.20	-0.26	-0.13

FMS

The same analysis was conducted with the FMS_{max} scores, the summary statistics of the model are listed in Table 3.

Table 3. Summary statistics of the model using z-transformed FMS_{max} scores, including the 5% and 95% confidence interval boundaries.

Parameter	Estimate	5%	95%
Intercept	<u>0.171</u> 0.00	<u>-0.380</u> -0.48	<u>1.530</u> 0.73
Info _{Current}	<u>0.091</u> 0	<u>-0.220</u> -0.008	<u>0.412</u> 0
Info _{Future}	<u>0.091</u> 0	<u>-0.220</u> -0.007	<u>0.422</u> 1
Trial 2	<u>0.003</u> 0.002	<u>-0.324</u> 0	<u>0.110</u> 0.30
Trial 3	<u>-0.11</u> -0.13	<u>-0.432</u> 3	<u>-0.030</u> 0.21
Track 2	<u>-0.384</u> 4	<u>-0.715</u> 5	<u>-0.33</u> -0.04
Track 3	<u>-0.332</u> 8	<u>-0.594</u> 3	<u>-0.230</u> 0.04

Post-hoc Correlation Test SSQ and FMS

SSQ total was significantly correlated with the FMS_{max} score (Pearson $\rho = 0.73$, $p < 0.001$), as were all subscales of the SSQ (Nausea: $\rho = 0.79$, $p < 0.001$; Oculomotor: $\rho = 0.61$, $p < 0.001$; Disorientation: $\rho = 0.54$, $p < 0.001$). The scatterplot of the two measurements is depicted in Figure 6. According to Mukaka (2012) Pearson coefficients between 0.70 and 0.90 indicate a high relationship and coefficients between 0.50 and 0.70 a moderate relationship between variables. Following this classification the correlation between the nausea subscale of the SSQ and the FMS_{max} score is considered to be high, while the other two subscales and the total score of the SSQ are moderately correlated with FMS_{max}.

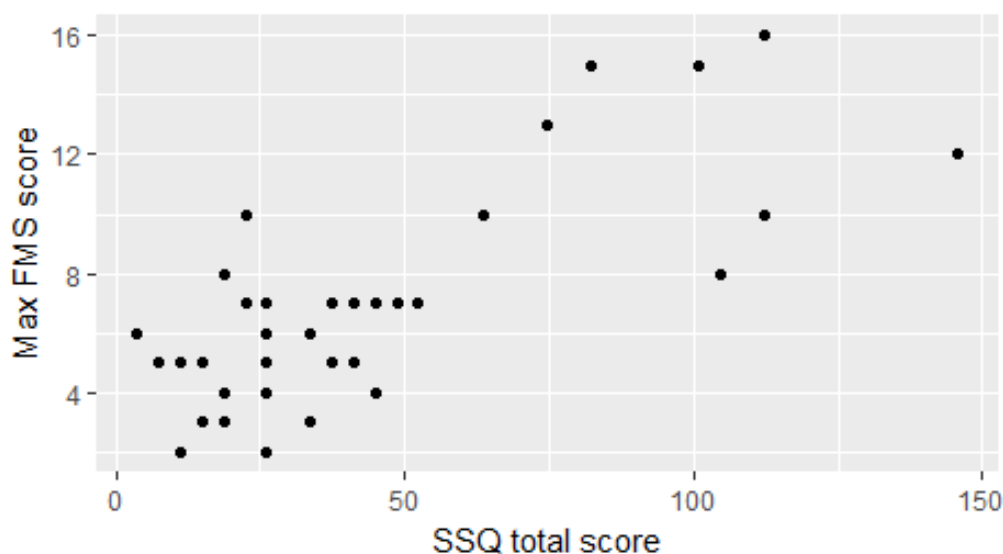


Figure 6. Scatterplot of SSQ total scores and FMS_{max} scores.

Discussion

In the present study, we investigated whether visualizations shown on interior panels of cars can be used to mitigate motion sickness. The visualizations were composed of limited-lifetime random dots that were anchored to the outside world. As the car moved, the dots thus provided information on the direction and velocity of the car. In addition, the color of the dots was made to

change gradually from red to green in proportion to the car's deceleration and acceleration, to communicate the associated meanings of 'stop' and 'go'. This we did in order to mitigate the sensory conflict that is believed to be the underlying cause of motion sickness. We compared three conditions, providing either no information on the car's motion (control), information on current motion, and information on motion 0.5s in the future. Future information was intended to allow for anticipation of the upcoming motion, which has been found to play an important role in the prevention of motion sickness.

Effect of Interior Presentations on Motion Sickness

Compared to the control condition, providing participants with motion cueing stimuli was associated with lower levels of motion sickness. Future information decreased the sickness by approximately five points on the SSQ and current information by four. This makes for a reduction of motion sickness by 9% and 8%, respectively. Consequently, it appears that motion cueing stimuli on interior panels in autonomous vehicle can counteract sickness in passengers.

The first hypothesis was confirmed in that motion cues which were in line with the current motion of the vehicle alleviated motion sickness. The second hypothesis was confirmed, too, in that motion cues guided by future motion lessened sickness. The effect of the visual presentation shows that optic flow information and the use of red and green, in the sense of associated population stereotypes of stop and go (Bergum & Bergum, 1981), can be used effectively in an autonomous vehicle as a mean to counteract motion sickness to some extent. In the current study optic flow presented information about velocity and heading direction, while the change of color represented acceleration and deceleration of the vehicle.

Presenting current and future information was not differently effective in alleviating sickness. Although the estimated effect of into the future information was slightly larger, a difference in effectiveness of both 'Visual scenes' was not supported by the findings. A possible explanation for the indifference would be that participants were not able to tell that future information was being shown because the delay of 0.5s was too little to be perceived actively, especially while being occupied with playing a computer game. However, we do not believe this to be the case as literature suggests that stimuli like those used in this study operate mostly at a semantic, unconscious level. Hunt (2002) argues that no conscious awareness at all is necessary in order to process visual stimuli. Optic flow information also is generally believed to be effective at a low, sensory level of perception (Giese & Poggio, 2003) and not require the

involvement of higher-order functions.

A comparable study involving future motion cues found a profoundly larger reduction of sickness symptoms. Feenstra, Bos and van Gent (2011) provided participants with rollercoaster track resembling cues about the upcoming path and found that these visuals mitigated sickness by a factor of approximately four. A possible explanation for this difference is that the roller-coaster like cues showed to participants put them in a position to fully anticipate the upcoming motion for a larger period of time, they were provided information about the whole upcoming path, while in this study only cues for one particular moment in time (0.5s in the future) could be given. Also, the participants were sitting in a backwards facing position and gazing downwards in our study. While realistic user situations in an autonomous vehicle, under these circumstances no observation of the upcoming track was possible, possibly contributing to the large differences in effectiveness of the interventions. Thus although not equally effective, the results obtained in our study are generally in line with those of Feenstra, Bos and van Gent (2011), future motion cues alleviated sickness in passengers.

Morimoto, Isu, Okumura, Araki, Kawai and Masui's (2008) findings, who successfully manipulated visual cues around an infotainment system to lessen sickness, are in line with our research findings. As were those of Jeng-Wee Lin, Parker, Lahav and Furness's (2005) study, reporting that visual motion cues fixed in the outside environment could effectively mitigate sickness symptoms. An advantage of our study was a more ecologically valid context and more realistic interventions. Using a hexapod motion platform, VR and making engage participants in a use-related task make for a more realistic setup when compared to their mock-up car, incorporating no physical motion. Also, presenting visual motion cues in the outside environment, in the way done by them is not feasible in a real world application, projecting moving dot patterns on interior panels are. Our study can thus be seen as an extension and validation of what they report in their paper. In contrast to these studies, McGill, Ng and Brewster (2017) found that participants got sicker when being presented with a landscape in VR, moving coherently with the physical motion of the vehicle they were riding in. However, the authors mentioned some limitations of their study and did recommend retesting with a higher fidelity landmark and abstract motion cues, which was done in our study and led to the hypothesized results. The fact that it did not have the desired effect in their study might have been due to an ineffective implementation of the moving landscape. It is possible that the movement of the landscape and the vestibular perception of motion were not coherent, resulting

in a sensory conflict and causing larger sickness of participants in this condition. We also followed their second recommendation of incorporating future information to allow for anticipation. As hypothesized, this turned out to be an effective mean in reducing motion sickness.

Relation to Motion Sickness Theory

The findings of this study are in line with the Sensory Conflict Theory (Reason, 1978). As expected the conflicting information input from the visual and vestibular system could be mitigated, resulting in less motion sickness. In the control condition the visual system was perceiving stationarity, while the vestibular system was giving respective input when the virtual vehicle accelerated and changed direction. As opposed to both of the conditions containing additional visual information about speed and heading direction in which the visual system's perception was more in line with that of the vestibular system. Also in these conditions the expected sensory input based on the visual information provided by the dot pattern was not conflicting with the actually experienced sensory input. The effects found are thus coherent with the framework of the Sensory Conflict Theory.

Interestingly, in our study there was no effect of 'Trial' on motion sickness, meaning that during subsequent trials of the experiment no habituation occurred. Based on the Sensory Conflict Theory we would expect motion sickness to decrease proportional to past exposure to the experimental setup. A more prolific mental representation should have been formed of what to expect, which should lead to lower levels of motion sickness. A possible explanation for the absence of habituation could be the use of different tracks for each trial, especially since analysis suggests that each of them differed in provocativeness. Another reason might simply be the short exposure time of approximately ten minutes per trial. Although we cannot say this with certainty, it should be considered that this period of time might not be sufficient to allow for habituation to occur. So we did not find habituation in our study, but for the mentioned reasons this does not necessarily mean that our findings stand in conflict with Reason's theory.

Comparison FMS and SSQ

An issue with the data is that sickness scores as assessed by the two employed measurements are not entirely coherent and subsequently suggest the existence of different effects. Surprisingly so, as they are both intended to give an indication of motion sickness. The FMS was constructed with

the intention of providing a subjective measure of how sick an individual feels (Keshavarz & Hecht, 2011). Subjectively, sickness is more reflected by nausea than by symptoms like eye strain or difficulty focusing. This is demonstrated by the high correlation of the SSQ subscale ‘nausea’ and the FMS scores. The argument can be made that the SSQ provides a more sophisticated assessment of motion sickness, as it incorporates the additional dimensions ‘oculomotor symptoms’ and ‘disorientation’, as well as covering the FMS scores by means of the nausea subscale. The SSQ has been labeled the gold standard for this kind of research (Johnson, 2007). Following this line of reasoning the discussion of the results primarily refers to the SSQ scores. Note that the FMS rating was also employed to have a set criterion on when to stop a trial to prevent inadvertent levels of sickness in the participants, focusing on the SSQ does not mean that administering the FMS becomes obsolete.

Limitations and Generalizability

Some limitations of the study merit to be mentioned and commented on. A major one was the small amount of data available for the final analysis. The scarceness of data, especially in interplay with the large individual differences in motion sickness susceptibility, poses the threat of having masked effects or not indicating their size correctly. Especially whether there is a difference between current and future visual motion cues could not be shown by analyzing the gathered data.

Another limitation was the setup of the study. Although using a hexapod motion platform and a virtual environment in VR is a comparatively advanced simulation when considering similar studies, it still is remains a simulation with the accompanying disadvantages. The motion cueing algorithm, steering the motion of the simulator, might not have been ideal and could have led to an increase in sickness if it did not fit the apparent motion of the visual environment. Simulators have natural boundaries that potentially form a threat to generalizability. However, testing the effectiveness of the visualizations we employed in this study was not feasible as a real-world implementation using a physical autonomous vehicle. Altering the properties of a virtual, computer generated, environment on the other hand could be done and together with the motion platform made for a comparable user situation.

A final limitation is that the change of red and green of the visualizations would not work for individuals suffering from red-green colorblindness.

Recommendations for Future Research

Although the findings of the present study provide valuable insights on possibilities to alleviate motion sickness for passengers in autonomous vehicles, they also raise new questions that ask for further investigation. First, looking into the found effects using a larger and more carefully chosen sample of participants should be focused on, this would provide more insight in the magnitude and persistence of the effects. Second, if feasible, the suggested visualizations should be implemented and evaluated in a more realistic context. Preferably in a real autonomous vehicle, when not available simulating the situation with a conventionally driven vehicle is recommendable. Third, since the present design did not allow us to draw conclusions whether velocity or acceleration information were the main reason for the effectiveness of the interventions, this should be looked into more thoroughly. Fourth, we could not disentangle whether present or future information have differently strong effects on the alleviation of motion sickness, so further investigating this relationship might be a fruitful endeavor. Also it is recommended to consider different delays for the presentation of anticipatory information. Arguments can be made for choosing different onset times, for example following the theory that the P300 event related component is responsible for context updating (Hansenne, 2000), effectiveness of presenting 300ms into the future motion could be explored. The delay can also be enlarged, providing a larger time window. This, however, bears the risk of introducing another conflict, if the presentation on the interior panels cannot be associated with the corresponding motion, but seems off, motion sickness might increase. Additionally, a prolonged delay could make it necessary to consciously process the provided information at a higher cognitive level to be able to make use of it, which would not allow the passenger to engage in side-activities. Finally, past research has elaborated on the role of distraction on motion sickness. Bos (2015) reported a decrease of 19% in participants who were mentally engaged in a task. In our study all experimental conditions involved playing the video game, therefore future research could focus on investigating the effectiveness of the visualizations in a non-distracting use situation. Regarding the game, in retrospective it appears that recording the score of participants would have been valuable information. It might be an indication of workload, directly influenced by motion sickness and could have provided an additional indication of motion sickness.

Conclusion

Despite the limitations of the present experiment, the data on motion sickness provide empirical evidence that visualizations can indeed mitigate motion sickness. Consequently, we conclude that the implementation of such visualizations in autonomous vehicles is a promising intervention to alleviate symptoms of motion sickness, warranting further research in the recommended directions.

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Appendix

R script for analyzing the data

[library\(plyr\)](#)

[library\(dplyr\)](#)

[library\(tidyr\)](#)

[library\(haven\)](#)

[library\(readr\)](#)

[library\(ggplot2\)](#)

[library\(rstanarm\)](#)

[library\(printr\)](#)

[library\(nlme\)](#)

[library\(lme4\)](#)

[library\(lmerTest\)](#)

[library\(memisc\)](#)

[library\(ggthemes\)](#)

[library\(reshape2\)](#)

[library\(effects\)](#)

[Sys.setenv\(LANG = "eng"\)](#)

[update.packages\(checkBuilt = TRUE\)](#)

```

D1 <- read.csv(choose.files(), header = T, sep = ";")

summary(D1)

str(D1)

###Data manipulation and transformation

#Turn int into factors

D1$Trial <- factor(D1$Trial)

D1$Track <- factor(D1$Track)

D1$Condition <- factor(D1$Condition)

#Make FMS scores long format

head(D1)

#change FMS names in how many minutes after the start the measurement was taken

colnames(D1)[5] <- "0"

colnames(D1)[6] <- "2"

colnames(D1)[7] <- "4"

colnames(D1)[8] <- "6"

colnames(D1)[9] <- "8"

colnames(D1)[10] <- "10"


#using melt function from reshape2 package to make it long format

D1 <- melt(D1, id.vars = c('Part ID', 'Trial', 'Track', 'Condition', 'MSSQ', 'SSQ_N', 'SSQ_O',
'SSQ_D', 'SSQ_total'),
_____ variable.name = 'Min after start',

```

```

      value.name = 'FMS_score')

#reorder according to participant ID

D1 <- arrange(D1, Part_ID)

#make 'Min_after_start' and 'FMS_score' numerical, first to char otherwise they would be internal
#factor numbers, not labels

D1$Min_after_start <- as.numeric(as.character(D1$Min_after_start))

D1$FMS_score <- as.numeric(as.character(D1$FMS_score))


#Filter out participants who were below the 50th percentile of the MSSQ (<11.3 Combined
#score)

D1 <- filter(D1, MSSQ > 11.3)


#Filter out those individuals who did not get sick in the experiment according to SSQ (<3.7) in
#either of the conditions

#This cannot be done as easily as with the MSSQ, as it differs per Condition, so filter(D1, >3.7)
#won't work

#Visually inspect data and omit participants with one or more SSQ scores <3.7

#Those are: 2, 3, 9, 15, 20)

D1 <- filter(D1, Part_ID != 2, Part_ID != 3, Part_ID != 9, Part_ID != 15, Part_ID != 20)


##### FMS MAX#####

D1 <- na.omit(D1)

```

```
D1$MaxScore <- ave(D1$FMS_score, D1$Part_ID, D1$Trial, D1$Track, D1$Condition,  
FUN=max)
```

```
#create a separate dataframe containing only one FMSmax score per Trial, use this for building  
models
```

```
#related to the FMS max scores
```

```
D1max <- filter(D1, D1$Min_after_start == 0)
```

```
##### Z transformation#####
```

```
D1 <- D1 %>%
```

```
mutate(SSQz = scale(SSQ_total), FMSz = (scale(FMS_score)))
```

```
D1max <- D1max %>%
```

```
mutate(FMSz = (scale(MaxScore)))
```

```
##### Pearson Correlation #####
```

```
#Correlation FMS SSQ
```

```
cor.test(D1$SSQ_total, D1$MaxScore, method = 'pearson')#-> .734
```

```
#Correlation of FMS and Nausea subscale
```

```
cor.test(D1$SSQ_N, D1$MaxScore, method = 'pearson')#->.788
```

```
#Oculomotor
```

```
cor.test(D1$SSQ_O, D1$MaxScore, method = 'pearson')#->.612
```

```
#Disorientation
```

```
cor.test(D1$SSQ_D, D1$MaxScore, method = 'pearson')#->.537
```

Plotting of data

D1 %>%

ggplot(aes(x=Condition,
y=SSQ_total))+
geom_boxplot()+
ylab('SSQ Total Score')+
scale_x_discrete('Visual Scene', labels = c('InfoNone', 'InfoCurrent', 'InfoFuture'))

D1 %>%

ggplot(aes(x=Condition,
y=MaxScore))+
geom_boxplot()+
ylab('FMSmax Score')+
scale_x_discrete('Visual Scene', labels = c('InfoNone', 'InfoCurrent', 'InfoFuture'))

D1 %>% #possible, but because of habituation and different Tracks not valuable

ggplot(aes(x=Condition,
col=Condition,
y=SSQ_total))+
geom_point()+
facet_wrap(~Part_ID)

```
#correlation FMS SSQ
```

```
D1 %>%
```

```
ggplot(aes(x=SSQ_total,
```

```
          y=MaxScore))+
```

```
geom_point()+
```

```
xlab('SSQ total score')+
```

```
ylab('Max FMS score')
```

```
##### Compare two models, one with Track included and one without it#####
```

```
MB1 <- stan_glmer(SSQ_total ~ Condition + Trial + (1|Part_ID), data = D1)
```

```
fixef(MB1)
```

```
posterior_interval(MB1)
```

```
MB2 <- stan_glmer(SSQ_total ~ Condition + Trial + Track + (1|Part_ID), data = D1)
```

```
fixef(MB2)
```

```
posterior_interval(MB2)
```

```
loo_MB1 <- loo(MB1)
```

```
loo_MB2 <- loo(MB2)
```

loo_MB1

loo_MB2

both models have good pareto k diagnostics <.5

plot(loo_MB1)

plot(loo_MB2)

compare_models(loo_MB1,loo_MB2)

according to the recommendation the second model (with Track included) has a better fit

####FMS####

MB3 <- stan_glmer(MaxScore ~ Condition + Trial + (1|Part_ID), data = D1max)

fixef(MB3)

posterior_interval(MB3)

MB4 <- stan_glmer(MaxScore ~ Condition + Trial + Track + (1|Part_ID), data = D1max)

fixef(MB4)

posterior_interval(MB4)

loo_MB3 <- loo(MB3)

loo_MB4 <- loo(MB4)

loo_MB3

loo_MB4

```
compare_models(loo_MB3, loo_MB4)
```

```
#### Do again, now with Z transformed values to make scales comparable
```

```
MB5 <- stan_glmer(SSQz ~ Condition + Trial + Track + (1|Part_ID), data = D1)
```

```
fixef(MB5)
```

```
posterior_interval(MB5)
```

```
MB6 <- stan_glmer(FMSz ~ Condition + Trial + Track + (1|Part_ID), data = D1max)
```

```
fixef(MB6)
```

```
posterior_interval(MB6)library(plyr)
```

```
library(dplyr)
```

```
library(tidyr)
```

```
library(haven)
```

```
library(readr)
```

```
library(ggplot2)
```

```
library(rstanarm)
```

```
library(printr)
```

```
library(nlme)
```

```
library(lme4)
```

```
library(lmerTest)
```

```
library(memisc)
```

```
library(ggthemes)
```

```
library(reshape2)
```

```

library(effects)

Sys.setenv(LANG="eng")

update.packages(checkBuilt=TRUE)

D1 <- read.csv(choose.files(), header = T, sep = ";")
summary(D1)
str(D1)
###Data manipulation and transformation
#Turn int into factors
D1$Trial <- factor(D1$Trial)
D1$Track <- factor(D1$Track)
D1$Condition <- factor(D1$Condition)
#Make FMS scores long format
head(D1)
#change FMS names in how many minutes after the start the measurement was taken
colnames(D1)[5] <- "0"
colnames(D1)[6] <- "2"
colnames(D1)[7] <- "4"
colnames(D1)[8] <- "6"
colnames(D1)[9] <- "8"
colnames(D1)[10] <- "10"

#using melt function from reshape2 package to make it long format
D1 <- melt(D1, id.vars = c('Part_ID', 'Trial', 'Track', 'Condition', 'MSSQ', 'SSQ_N', 'SSQ_O',
'SSQ_D', 'SSQ_total'),
  variable.name = 'Min_after_start',

```

```

———value.name = 'FMS_score')

#reorder according to participant ID
D1 <- arrange(D1, Part_ID)

#make 'Min_after_start' and 'FMS_score' numerical, first to char otherwise they would be internal
factor numbers, not labels
D1$Min_after_start <- as.numeric(as.character(D1$Min_after_start))
D1$FMS_score <- as.numeric(as.character(D1$FMS_score))

#Filter out participants who were below the 50th percentile of the MSSQ (<11.3 Combined
score)
D1 <- filter(D1, MSSQ > 11.3)

#Filter out those individuals who did not get sick in the experiment according to SSQ (<3.7) in
either of the conditions
#This cannot be done as easily as with the MSSQ, as it differs per Condition, so filter(D1, >3.7)
won't work
#Visually inspect data and omit participants with one or more SSQ scores <3.7
#Those are: 2, 3, 9, 15, 20)

D1 <- filter(D1, Part_ID != 2, Part_ID != 3, Part_ID != 9, Part_ID != 15, Part_ID != 20)

##### FMS MAX#####
D1 <- na.omit(D1)
D1$MaxScore <- ave(D1$FMS_score, D1$Part_ID, D1$Trial, D1$Track, D1$Condition,
FUN=max)

##### Z transformation#####
D1 <- D1 %>%

```

```

-mutate(SSQz = scale(SSQ_total), FMSz = (scale(FMS_score)))
D1$MaxScoreZ <- ave(D1$FMSz, D1$Part_ID, D1$Trial, D1$Track, D1$Condition, FUN=max)

##### Pearson Correlation #####
#Correlation FMS-SSQ
cor.test(D1$SSQ_total, D1$MaxScore, method='pearson')#>.734
#Correlation of FMS and Nausea subscale
cor.test(D1$SSQ_N, D1$MaxScore, method='pearson')#>.788
#Oculomotor
cor.test(D1$SSQ_O, D1$MaxScore, method='pearson')#>.612
#Disorientation
cor.test(D1$SSQ_D, D1$MaxScore, method='pearson')#>.537

##### Plotting of data #####
D1 %>%
  -ggplot(aes(x=Condition,
  -y=SSQ_total))+
  -geom_boxplot()+
  -ylab('SSQ Total Score')+
  -scale_x_discrete('Visual Scene', labels=c('InfoNone', 'InfoCurrent', 'InfoFuture'))

D1 %>%
  -ggplot(aes(x=Condition,
  -y=MaxScore))+
  -geom_boxplot()+
  -ylab('FMSmax Score')+
  -scale_x_discrete('Visual Scene', labels=c('InfoNone', 'InfoCurrent', 'InfoFuture'))

```

```

D1 %>% #possible, but because of habituation and different Tracks not valuable
  ggplot(aes(x=Condition,
  col=Condition,
  y=SSQ_total))+
  geom_point()+
  facet_wrap(~Part_ID)

#correlation FMS SSQ
D1 %>%
  ggplot(aes(x=SSQ_total,
  y=MaxScore))+
  geom_point()+
  xlab("SSQ total score")+
  ylab("Max FMS score")

##### Compare two models, one with Track included and one without it#####
MB1 <- stan_glmmer(SSQ_total ~ Condition + Trial + (1|Part_ID), data = D1)
fixef(MB1)
posterior_interval(MB1)

MB2 <- stan_glmmer(SSQ_total ~ Condition + Trial + Track + (1|Part_ID), data = D1)
fixef(MB2)
posterior_interval(MB2)

loo_MB1 <- loo(MB1)

```

```

loo_MB2 <- loo(MB2)

loo_MB1
loo_MB2
# both models have good pareto k diagnostics < .5
plot(loo_MB1)
plot(loo_MB2)

compare_models(loo_MB1, loo_MB2)
# according to the recommendation the second model (with Track included) has a better fit

####FMS####
MB3 <- stan_glmer(MaxScore ~ Condition + Trial + (1|Part_ID), data = D1)
fixef(MB3)
posterior_interval(MB3)

MB4 <- stan_glmer(MaxScore ~ Condition + Trial + Track + (1|Part_ID), data = D1)
fixef(MB4)
posterior_interval(MB4)

loo_MB3 <- loo(MB3)
loo_MB4 <- loo(MB4)

loo_MB3
loo_MB4

compare_models(loo_MB3, loo_MB4)

```

```
#### Do again, now with Z-transformed values to make scales comparable
```

```
MB5 <- stan_glmer(SSQz ~ Condition + Trial + Track + (1|Part_ID), data = D1)
```

```
fixef(MB5)
```

```
posterior_interval(MB5)
```

```
MB6 <- stan_glmer(MaxScoreZ ~ Condition + Trial + Track + (1|Part_ID), data = D1)
```

```
fixef(MB6)
```

```
posterior_interval(MB6)
```

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