Occurrence of motion sickness during highway and inner-city drives

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Abstract

Recent concepts for automated vehicles point towards future interior designs that allow passengers to consume media on in-vehicle displays during travel. It is widely accepted that the engagement in non-driving-related tasks, especially those that impede a view of the outside world, can lead to motion sickness. Two field studies were conducted investigating the occurrence of motion sickness while driving in two distinct environments: highway (n_1=296) and inner city (n_2=294). Both studies employed a between-subject-design in which the seating direction and non-driving-related task were varied. Seating direction was varied between forward- and backward-facing. The task varied from watching a movie on a handheld tablet, positioned on the passengers' laps, to watching a movie on a tablet mounted at eye-level in front of the passengers and a baseline condition in which the passengers did not watch a movie. The effect of seating direction, task and driving environment on the occurrence of motion sickness was evaluated using subjective misery scale ratings. Results showed that the occurrence of motion sickness was low across all conditions. Neither seating direction nor driving environment significantly affected the occurrence of motion sickness during both highway and inner city drives. These results indicate that the risk of motion sickness in automated vehicles may be smaller than is often assumed.

Introduction

While the technical developments within autonomous driving are progressing at a fast pace, central questions regarding the man-machine-interaction remain insufficiently addressed. Among these is the question of how severely motion sickness (MS) will affect the wellbeing of passengers. MS has been defined as "a condition characterized by pallor, nausea, and vomiting. It is brought about by exposure to real or apparent, unfamiliar motion to which the individual is not adapted" (Benson, 1992). According to the sensory rearrangement theory by Reason

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and Brand (1975), MS is caused by stimulation that evokes “conflicting position and motion information arriving simultaneously from […] the vestibular system, the eyes and the non-vestibular receptors”. While driving, visual-inertial rearrangements are most likely to cause MS, e.g. when viewing static contents such as text in a book that are in conflict with the sensation of movement by the inertial receptors. In the context of autonomous driving the issue of MS gains importance because it enables settings in which MS is more likely to arise compared to manual driving. First, all vehicle occupants are now in a passenger’s role. Compared to the driver, the passengers are more prone to develop MS because they lack the control over the upcoming driving manoeuvres (Rolnick & Lubow, 1991). Second, automated driving of SAE (Society of Automotive Engineers) levels 3 and higher enables the passenger to engage in non-driving-related tasks (NDRT) because the system carries out the longitudinal and lateral control and monitors the driving environment (SAE, 2014). The engagement in NDRT such as watching a video or reading has been shown to increase MS in previous studies (Schoettle & Sivak, 2009). Third, several concept cars suggest a vis-à-vis seating arrangement in which some passengers are facing backward, which has also been shown to provoke more MS (Turner & Griffin, 1999a).

In order to understand the severity of the problem of MS in the context of automated driving, two on-road studies were conducted that investigated the occurrence of MS under varying conditions in terms of time-on-task, seating direction, NDRT and driving environment.

Related Work

MS has been previously studied both inside and outside the vehicular context. Therefore, insights have been generated in terms of causal factors (Reason & Brand, 1975), symptoms (Benson, 1992) and measurement techniques (Bos et al., 2005; Kennedy, 1975).

Regarding the measurement of MS, subjective and objective methods have been developed. Most important among the subjective measures is the single item 10-point MIsery SCale (MISC) by Bos et al. (2005). Another frequently used measure is the motion sickness questionnaire (MSQ) by Kennedy (1975), in which single symptoms of MS such as headache, stomach awareness, fatigue, blurred vision, nausea, cold sweating and vertigo are assessed. MS susceptibility of individuals can be assessed with the motion sickness history questionnaire (MSHQ) of Griffin and Howarth (2000) which consists of the retrospective report about sickness occurrence in different means of transport.

Previous research suggests that MS affects physiological responses which can therefore serve as objective indicators of MS. The study of Cowings et al. (1986) showed that skin resistance decreased during MS stimulation in people who were highly susceptible to MS. Similarly, Wan et al. (2003) observed a positive correlation between subjective MS ratings and phasic and tonic skin conductance levels. Decreased skin temperature has been found to decrease during MS (Bertin et al., 2005; Min et al., 2004).

In addition to the research on MS indicators, studies have been performed to investigate the occurrence of MS under various vehicular and behavioural conditions. Among the vehicular conditions, display position, seating direction and driving parameters have been shown to affect MS.

A display mounted at eye level (head-up) induced less MS than a display mounted below the glove compartment (head-down) (Diels et al., 2016; Kuiper et al., 2018). The reason for this was that the head-up condition allowed the passenger to visually perceive the direction of travel to a larger extent, resulting in smaller sensory conflicts and associated MS. Overall, both studies showed that symptoms of MS occurred after as little as 15 minutes of driving. A backward seating direction has also been shown to increase MS in survey participants because it impedes a forward view (Turner & Griffin, 1999a).

The influence of driving environments has been studied by Turner and Griffin (1999b) who found that nausea was higher with increased exposure to lateral motion at low frequencies (<0.5 Hz) and illness was found to be greater on cross-country routes. In addition, O'Hanlon and McCauley (1973) reported a dependency of MS on vertical acceleration and frequency.

In terms of behavioural conditions, Schoettle and Sivak (2009) found through a survey that NDRTs such as viewing a video or reading a text are related to MS occurrence. Similarly, the severity of MS was found to be lower when viewing a video compared to reading a text. MS was the lowest when passengers neither watched a video nor read a text.

The review of the above literature suggests that MS develops quickly under certain conditions and that vehicular interior arrangements affect the development of MS. The studies investigating the influence of certain vehicular and behavioural conditions have been conducted on test tracks (Kuiper et al., 2018) or using provoking tasks such as reading (Diels et al., 2016) during which MS is likely to arise. Therefore, it remains unknown how severe the problem of MS will be when autonomous driving will first be introduced on the highways and in cities and when passengers are conducting little provocative tasks.

Research question and hypotheses

In order to gain insights on the severity of the problem of MS in autonomous driving, two studies were conducted on real roads. In addition to evaluating the severity of the problem of MS in passengers during driving, the studies were designed to answer the following research question:

> *Which effects do time-on-task, seating direction, NDRT, and driving environment have on subjective indicators of MS?*

The hypotheses were:

> *H1: MS increases with time-on-task.*

H2: MS is higher for backward seated passengers than for forward seated passengers.

H3: MS is higher for watching a movie head-down compared to watching a movie head-up or watching no movie at all (baseline).

H4: MS is higher in the inner city than on the highway.

Method

The two studies were conducted investigating the occurrence of MS while driving in two distinct environments: highway and inner city. The methods of both studies were identical except for minor differences explained in the following.

Participants

In the highway-study 296 people participated of which 50 % were female. The average age of the participants was 43.9 years (SD=15.3 years; range=18-72 years). In the inner city-study 294 people participated and, again, 50 % were female. Here the average age was 43.8 years (SD=15.3 years; range=18-72 years). The participants were recruited by an independent recruitment agency. To avoid self-selection effects, the experiment description used for recruitment neither revealed the experiment's goal, nor included any mentioning of MS, backward seating or NDRT. All participants were compensated financially.

Apparatus

The studies were conducted in a Volkswagen Multivan. The passenger cabin was equipped with four passenger (P) seats, of which the front two seats were rotated to face backwards. A table equipped with four adjustable tablet mounting points was positioned in the middle of the passenger cabin. The seating arrangement is shown in Figure 1. The table, the tablet mounting points, and the seats were positioned such that the tablets were centred with respect to the seats, at an eyepoint distance of approximately 620 mm, at a height of about 450 mm above the passenger's hip joint. During the experiment, the tablets (Surface Pro 4.0, Microsoft Corporation) were used to present the NDRT and questionnaires to the participants. The experiment leader used an additional tablet to control the experiment, e.g., start and stop the measurements, monitor participants and data quality.

Vehicle accelerations, velocities and positions were measured using a 3-Degrees of Freedom Inertial Measurement Unit (Racelogic Ltd.). An ARCOS datalogger (CAETEC GmbH) was used to record obtained data. Physiological data of each participant was recorded using an E4 wristband (Empatica Inc.), which measured galvanic skin response and skin temperature.

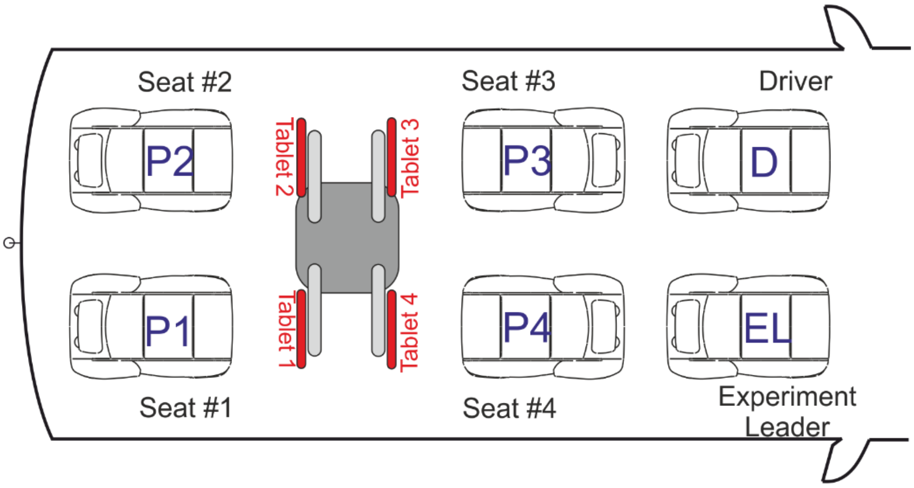

Figure 1. Sketch of vehicle interior.

Test routes

The test routes for both studies (highway and inner city) were located in and around Munich, Germany (Figure 2). The start and end of the highway-route were defined to be on the feeder road to the highway and on the exit of the highway, respectively, and served as a landmark at which data collection was started and ended. The route had a length of about 26 km and took about 26 minutes.

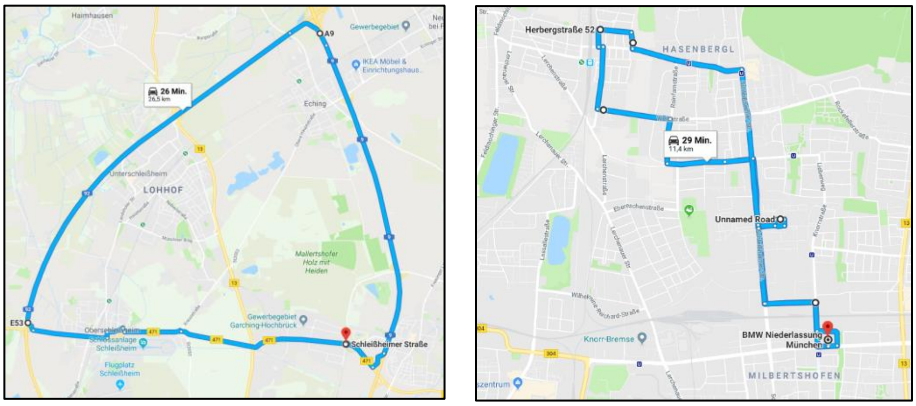

Figure 2. Routes for highway (left) and inner city (right) (Google Maps, 2018a,b).

The inner city-condition included urban streets in Munich. The route had a length of 11 km. Similar to the highway-condition, set landmarks determined the start and end of data collection for each drive. The average commute time to work in Germany is 24 minutes per day (Bach et al., 2007) which led to the decision to perform drives of similar durations.

Experimental design

Both studies employed a 2x3 between-subject-design in which the seating direction and NDRT were varied (Table 1). Seating direction was varied between forward and backward-facing. The NDRT varied from watching a movie (a documentary on the Bahamas) on a handheld tablet, positioned on the passengers' laps (head-down), to watching a movie on a tablet mounted at eye-level in front of the passengers (head-up) and a baseline condition in which the passengers did not watch a movie. Each participant was assigned to only one condition. Figure 3 shows the independent variables.

Table 1. Experimental design showing the number of participants assigned to the different conditions (NDRT=non-driving-related task).

		NDRT							
		Baseline		Head-up		Head-down		Total	
		High-way	Inner city	High-way	Inner city	High-way	Inner city	High-way	Inner city
Seating direction	Forward	49	46	47	56	52	46	148	148
	Backward	51	46	47	56	48	46	146	148
	Total	100	92	94	112	100	92	294	296

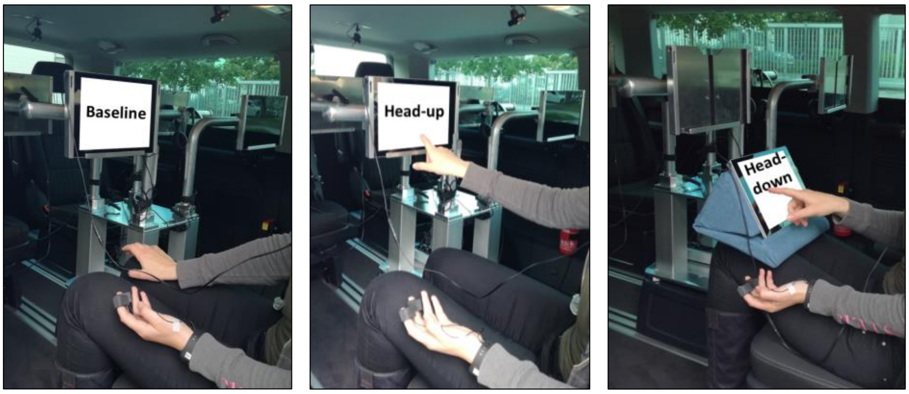

Figure 3. Non-driving-related task "Baseline", "Head-up", "Head-down".

Procedure

The experiments on the highway and in the inner city took place in September 2017 and January 2018, respectively. The experiment consisted of several drives in which four participants could be tested simultaneously. In each drive, the task was identical for all participants and the four seats were assigned randomly.

Upon arrival, the participants received written instructions, describing the experiment process, tasks and safety instructions (Figure 4). The participants were informed that they can abort the experiment at any time and for any reason without repercussions. If a participant had wished to exit the vehicle, the driver would have stopped at earliest safe location. To motivate the participants in the head-up and head-down condition to direct their attention to the movie, they were told that they would be quizzed on the movie's content after the drive.

The participants wore headphones which were connected to their tablets. Once the experiment leader had taken the passenger seat next to the driver, the experimental drive began. During the experimental drive, an audio cue interrupted the NRDT every three minutes and the MISC was prompted on the screen. In order to avoid extreme symptoms of MS the participants were automatically asked by the programme to contact the experiment leader once their MISC rating reached a value of 6 or higher.

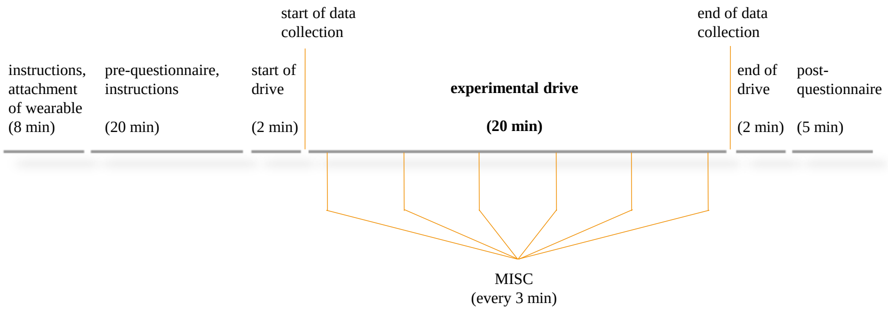

Figure 4. Procedure of experiments.

Table 2. Chronological order of questionnaires (BFI=Big Five Inventory, MSHQ=Motion Sickness History Questionnaire, MISC=Misery Scale, MSQ=Motion Sickness Questionnaire, NDRT=non-driving-related task).

Pre	During the drive	Post
Socio-demographical questionnaire	MISC and checkboxes for symptoms* every three minutes	MISC
Recent/ current illnesses		MSQ
BFI-10		For NDRT head-up & head-down: Questions on the movie's content
MSHQ		
MISC		
MSQ		

**checkboxes for dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation (in case of MISC values from 2-5)*

Questionnaires

To evaluate the subjective feeling of MS, ratings of the MISC and MSQ were taken in pre- and post-experiment-questionnaires (Table 2). The pre-test questionnaire also included questions regarding the participants' socio-demographic information, recent and current illnesses, and the MSHQ. To control for the effects of personality, the Big Five Inventory-10 (BFI-10, Rammstedt et al., 2013) was included. The post-test questionnaire consisted of the MISC, MSQ, and questions about the content of the movie (for NDRT head-up and head-down).

Results

Of the initially N=590 datasets some had to be excluded from analysis due to technical issues with the data recording. The exact number of datasets considered will be reported for each procedure. To ensure comparability between the data recorded on highway and inner city, the first six measurements of MISC during the experimental drive were considered for the statistical analysis. This is because the duration of the experimental drive was shorter in case of low traffic density, leading to missing data in some of the drives after 18 minutes.

Descriptive analysis

Table 3 shows the percentage of participants experiencing different degrees of MS. MISC-values equal or higher than 6 were only reported by 0.25 % of all participants. The majority (about 90.39 %) neither had problems nor felt uneasy (MISC-rating between 0 and 1). The remainder of the participants (9.36 %) reported vague to severe symptoms of MS (MISC-rating between 2 and 5).

Table 3. Distribution of MS across factors for pre-rating, rating between minutes 0 to 18, and post-rating (MISC=Misery Scale).

	No problems / uneasiness (MISC 0-1)	Vague to severe symptoms (MISC 2-5)	Slight to severe nausea, retching, vomiting (MISC 6-10)
All (N=583)	90.39 %	9.36 %	0.25 %
Foward (n=291)	90.41 %	9.20 %	0.39 %
Backward (n=292)	89.61 %	10.35 %	0.04 %
Head-up (n=205)	88.75 %	10.95 %	0.31 %
Head-down (n=187)	87.87 %	11.79 %	0.34 %
Baseline (n=191)	93.47 %	6.53 %	0 %
Highway (n=289)	88.61 %	11.26 %	0.13 %
Inner city (n=294)	92.12 %	7.58 %	0.30 %

Statistical procedure

A multivariate (6x3x2x2; time of measurement, NDRT, seating direction, driving environment) repeated-measures MANOVA was conducted with N=565 participants with the first factor being the repeated measure. In the following, univariate results are reported to answer the respective hypotheses. If interactions were found, they are reported. All analyses assume multivariate significance.

Hypothesis 1: Motion sickness and time

It was hypothesised that MS changes across the duration of the experimental drive. As visualized in Figure 5, hypothesis 1 is confirmed ($F(6,546)=12.135$, $p<.000$; Hotelling's $T^2=0.133$, partial $\eta^2=.118$): MS significantly differs between each time point, except time point 1 to 2. However, on the 10-point MISC, mean MS was very low ($M=0.42$). Therefore, based on the results of this study, the occurrence of MS can be deemed negligible for practical application. Nevertheless, participants occasionally experienced higher levels of MS (Table 3).

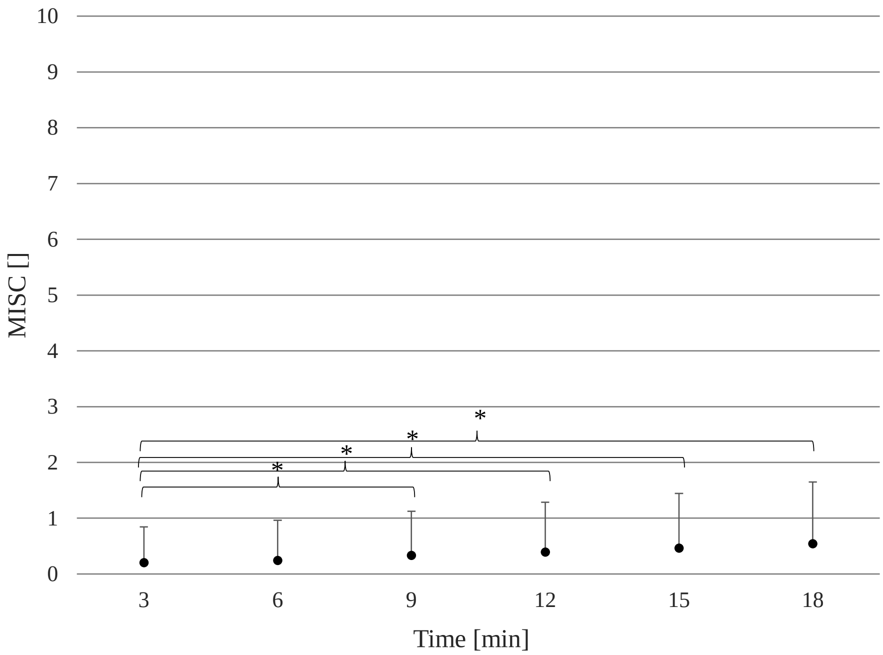

*Figure 5. MISC-rating (=Misery Scale) (M, SD) over time. (*p<.05)*

Hypothesis 2: Motion sickness and seating direction

Hypothesis 2 assumed that the experience of MS is influenced by the seating direction of the participants. However, no significant difference (Figure 6) can be found between the conditions ($F(1,553)=0.783$, $p>.05$, partial $\eta^2=.001$). Thus, the occurrence of MS cannot be explained by the direction the participants are facing while the vehicle is moving.

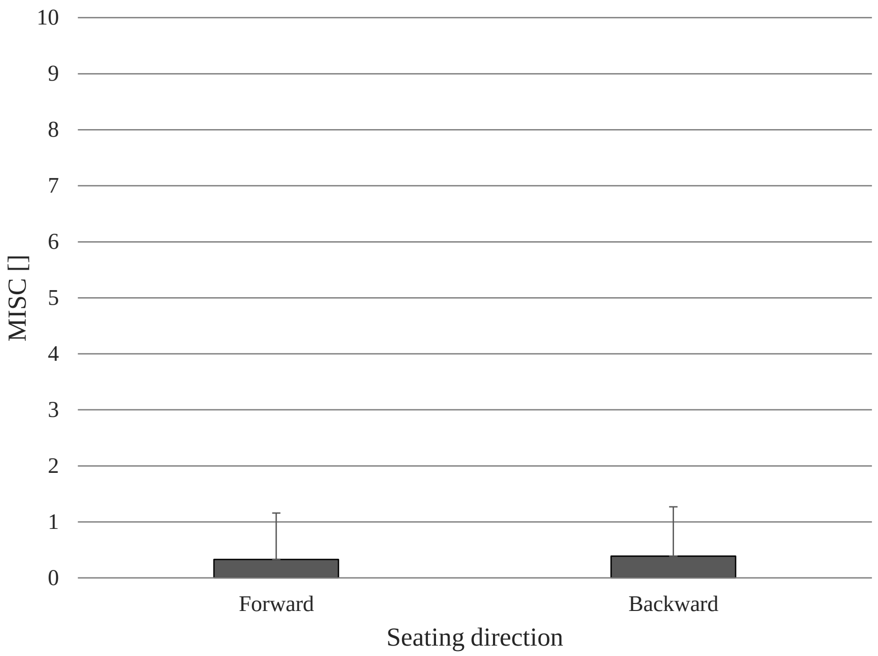

Figure 6. MISC-rating (=Misery Scale) (M, SD) for different seating directions.

Hypothesis 3: Motion sickness and non-driving-related task

Evaluating Hypothesis 3, the difference in MS due to the NDRT is examined. As visualized in Figure 7, a significant difference between BL (M=0.22; SD=0.672), head-down (M=0.42; SD=0.909) and head-up (M=0.43; SD=0.125) was found ($F(2,553)=4.579$, $p<.05$, partial $\eta^2=.016$). Subsequent Bonferroni-corrected post-hoc analysis revealed that the identified difference lies between the baseline and the head-down condition (-0.23, 95% - CI[-0.43, -0.03], $p<.05$) and between the baseline and head-up condition (-2.40, 95% - CI[-0.43, -0.05], $p<.01$).

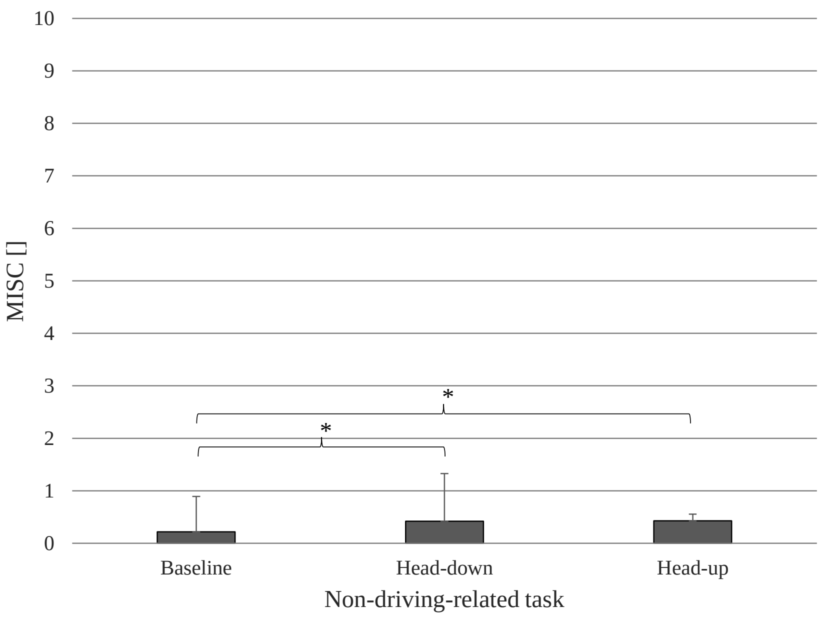

*Figure 7. MISC-rating (=Misery Scale) (M, SD) for different NDRT. (*p<.05)*

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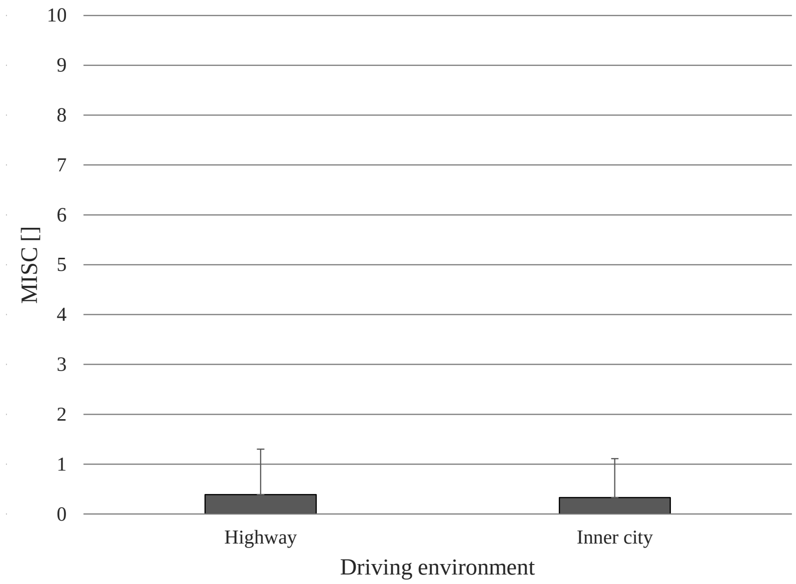

Figure 8. MISC-rating (=Misery Scale) (M, SD) for different driving environments.

The results indicate that the occurrence of MS is affected by whether the passengers watched a movie or not. However, if the participant's attention was allocated towards the movie, the magnitude of MS was not influenced by the vertical positioning of the tablet

Hypothesis 4: Motion sickness and driving environment

Hypotheses 4 assumed a difference in MS in dependence of the driving environment, inner city or highway. Statistical analysis showed no significant difference in the occurrence of MS ($F(1,563)=0.200$, $p>.05$) between the driving environments (highway and inner city) (Figure 8). However, a difference in the MS for the course of the experimental drive between highway and inner city can be observed: While participants in inner city reported lower levels of MS than the participants in highway, this tendency turned after about 12 to 15 minutes. This might be explained by the different driving characteristics of inner city which cause MS after a certain time in traffic.

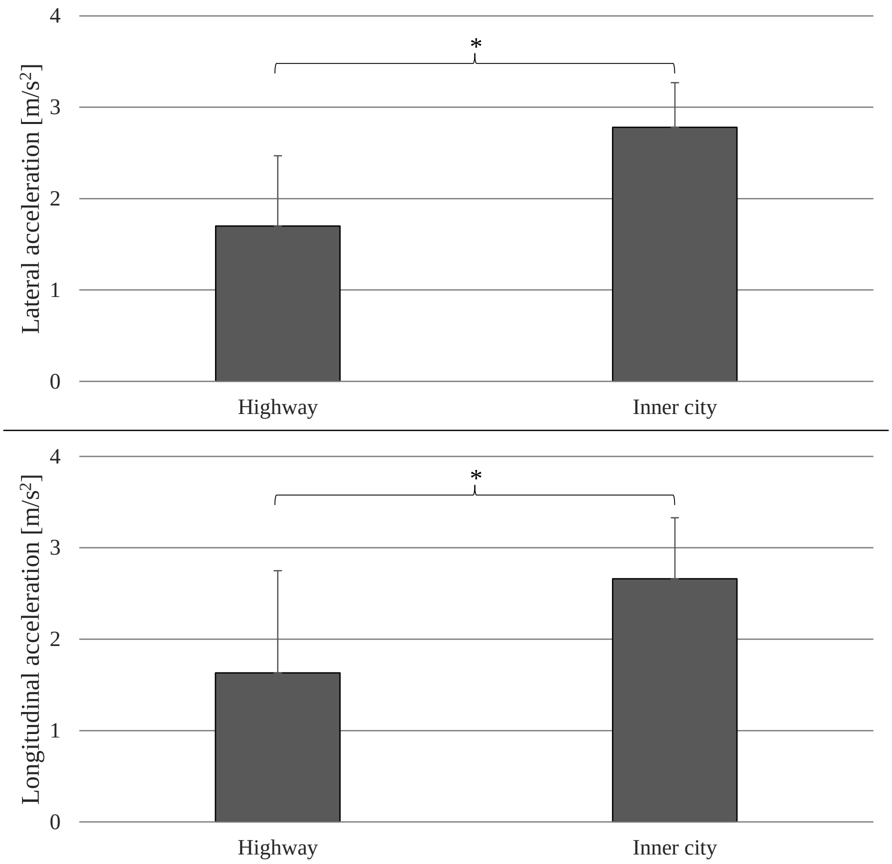

*Figure 9. Mean absolute lateral and longitudinal accelerations for different driving environments (M, SD). (*p<.05)*

Additionally, a comparison of the driving characteristics of inner city and highway revealed significant differences in longitudinal and lateral acceleration confirming that the inner city-drive was associated with higher average vehicular accelerations (F(4,1900)=591.424, p<.05, partial η^2=.555) (Figure 9).

Results from the other questionnaires, like BFI, MSQ and MSHQ and the physiological measurements are not reported in this paper due to constraints of length.

Discussion

The most striking result of this research was that only little degrees of MS (M=0.42) were measured and that a very small percentage of participants experienced nausea (percentage of people with MISC of 6 or higher <1 %). This could be due to the selected NDRTs which were watching a movie (head-up and head-down) and no task (baseline). Based on the observations of Schoettle and Sivak (2009), higher MS is likely to occur when reading a text. While watching a movie, the visual input is not as static compared to reading a text. This might have caused a lower discrepancy between the visual and inertial system and hence low levels of MS.

The study provided several insights with regard to the research question and the four hypotheses of which only one could be confirmed. As expected, MS increased with travel time. This result has been observed in previous studies (Kuiper et al., 2018) and McCauley et al. (1976) once described MS to increase monotonically under constant motion.

In contrast with results of the survey of Turner and Griffin (1999a), this study showed that MS was not affected by the seating direction. One reason for this difference could be that the seating direction in their survey came along with different impediments of the outside view. In this study, however, the view was impeded similarly in both forward and backward seating because of the armatures for the tablets and the NDRT. This is an important difference between this study and the one of Turner and Griffin (1999a), however, the lack of effect of seating direction on MS is still surprising and should be further investigated.

In alignment with the study of Schoettle and Sivak (2009), this study found that the NDRT affected the occurrence of MS. Like in their study, MS was higher when passengers watched a video (head-up and head-down) compared to no task (baseline). The result on the effect of display position of Diels et al. (2016) and Kuiper et al. (2018), however, could not be reproduced in this study because there was no difference between the head-up and head-down condition. The reason for this could be that in the previous studies, the display in the head-up condition was mounted directly behind the windscreen and the participant sat in the passenger's seat of the car, thus, allowing peripheral view to the road ahead. In our study, the view in the head-up condition was obstructed to a larger extent, because of the vis-à-vis seating arrangement in the back of a van. This larger obstruction in the head-up condition could have played an important role for the rejection of the hypothesis.

Contrary to the results of Turner and Griffin (1999b) who found increased MS on cross-country routes compared to highways, the driving environment did not affect MS in this study. Even though the analysis of driving data could confirm larger lateral and longitudinal accelerations in the inner city, the MS occurrence was not significantly higher compared to the highway. An explanation for the lack of the effect could be that the MISC-ratings were very low in general, suggesting that in both environments, the motion was not sufficiently provocative for most of the study participants. Another reason for the lack of alignment of this study to the one of Turner and Griffin (1999b) could be that their cross-country routes were associated with higher lateral and longitudinal accelerations than the inner city-route of this study, and hence leading to significant differences compared to highways.

The study came along with several limitations. The first limitation is that the study was conducted in different seasons, and hence the ambient air temperature varied between the highway and inner city-study. Additionally, naturally occurring changes in temperature were observed within the studies which were not sufficiently compensated by the vehicle's air conditioning which was permanently set at 20 °C. According to Turner and Griffin (1999a), though, ambient temperature was not found to influence MS occurrence.

Another limitation was found to lie in the subjective assessment of MS using the MISC. Whereas the MISC-values were increased significantly over the duration of the experiment, the measurement taken before the experimental drive showed a higher average MISC-rating among the participants. Likely, this did not occur from MS itself but rather as a relic of nervousness and heightened attention towards the participant's own wellbeing, or, as the participants were seated in the experimental vehicle shortly before the questionnaire was taken, anticipated MS as a reaction to the experimental setup. Accordingly, it is suggested that the MISC does not only measure symptoms related to MS in the lower range of the scale.

Conclusion

The key finding of the study was that – contrary to the often made assumption of MS in automated vehicles – the magnitude of MS has been shown to be fairly low. Descriptive analyses showed that only 9% of the n=583 participants felt distinctive symptoms of MS and less than 1% reported nausea. The mean rating of 0.42 on a scale from 0 to 10 indicated that on average almost no MS was experienced during the course of the study.

The studies further showed that even drives in the inner city, associated with higher lateral and longitudinal accelerations compared to highway drives, did not provoke a significant increase in MS. Similarly, the seating direction did not affect MS. Based on the findings of this study, new concepts of interior design do not need to be restricted to the classical seating arrangements of current vehicles but can comprise more divergent options including backward seating. Even when occupied with NDRTs passengers who were faced backwards experienced close to no symptoms of MS.

However, the ratings of MS were found to be significantly influenced by the factors manipulated in the experiment: time-on-task and NDRT. In both cases, the effects were very small. Long driving durations could still bear the risk of increased MS. While the chosen duration of approximately 26 minutes in the studies reflected the average commute time to work in Germany (Bach et al., 2007), it remains unknown how MS would develop when driving longer in these environments.

As discussed above, different NDRTs associated with more static visual input will probably lead to higher MS. Therefore, it is worthwhile to investigate on the one hand longer times-on-task and on the other hand more provoking NDRTs in future studies.

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