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Effect of Horizontal Acceleration and Seat Orientation on Motion Sickness in Passenger Cars

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This paper compares the influence of lateral and longitudinal acceleration manoeuvres as well as forward- and rearward-facing seat orientations on motion sickness (kinetosis) in a passenger car. A study was conducted with 50 individuals in which the subjects were exposed to different driving manoeuvres. External vision and anticipation of the motion trajectory were prevented by an obscured field of view. All participants had a similar kinetosis sensitivity, which was predetermined by a rotating chair experiment. The study showed that longitudinal acceleration manoeuvres cause significantly more kinetosis than those in the lateral direction and that there is no difference between forward- and rearward-facing seat orientation when external vision is prevented.

Topics /Autonomous Driving Systems

1. INTRODUCTION

A negative consequence of the increasing automation of vehicles will be an increased risk of kinetosis. The presumed cause of kinetosis is described by the sensory conflict theory: conflicting motion information is sensed via our visual, vestibular and somatosensory sensing systems to which the individual is not adapted. This results in discomforting symptoms such as pallor, sweating, dizziness, headache, nausea and vomiting [1]. Several advantages of automated driving, such as flexible seating orientations and the possibility of dealing with non-driving-related tasks, may provoke this conflict. This can have a serious negative impact on the acceptance of autonomous driving vehicles.

Salter et al. found that especially rearward-facing passengers are at higher risk for kinetosis under normal viewing conditions [2]. As a possible cause, they indicate the missing anticipation of the future motion trajectory compared to the forward-facing position. Turner and Griffin also pointed out that if passengers cannot see the road ahead, it has a negative effect [3]. Kuiper et al. confirmed this assumption and showed that predictable motion reduces kinetosis [4, 5]. The influence of the viewing condition on kinetosis in passenger cars was also investigated by Irmak et al. [6]. They showed that the kinetosis risk was significantly higher with internal vision compared to external vision. It can be concluded that the visual stimulus has a strong impact on the kinetosis risk. However, it is not yet known whether external vision and anticipation is the only effect which makes a difference between a forward- or rearward-facing position in a passenger car. Vogel et al. found in a study with an ambulance car that there is no difference in the supine position whether the head or feet are facing forward [7]. Due to the construction of ambulance cars and the supine position of the subjects, the view was severely restricted and the influence of the visual stimulus was minimised. The study thus indicates no influence of the seat orientation. However, it is not known whether this result can be transferred to seated persons and passenger cars. Furthermore, there is little knowledge about the impact of horizontal acceleration manoeuvres on kinetosis in a

passenger car. Griffin and Mills investigated the influence of the direction of acceleration using a closed cabin and found no difference [8]. However, Bohrmann and Scholly indicated a negative influence of longitudinal acceleration manoeuvres [9]. Additionally, it is common knowledge that the individual sensibility to kinetosis varies greatly from person to person. Therefore, it is important to consider this influencing factor for the test design and analysis of the results.

Overall, this study aims to investigate the influence of seating orientation and horizontal acceleration direction on kinetosis with unchanged visual stimulus. To control the influence of individual kinetosis sensitivity, subjects will be classified in advance.

2. METHOD

A study with test persons has been conducted on a test track.

2.1 Participants and Classification

The study was approved by the ethics committee of the Charité. Before the test persons were admitted to the experiment, they were screened for disorders of the vestibular system and classified with respect to their kinetosis sensitivity by a rotating chair experiment. Using a modified "Staircase Velocity Motion Test" (SVMT), a vestibular sensory conflict was provoked and gradually increased [10]. Kinetosis sensitivity was classified based on the development of kinetosis symptoms and the total test duration. Subjects with high resistance to kinetosis (test duration > 16 min) were not considered for the car experiment. Furthermore, participants with high sensitivity (test duration < 8 min) were also excluded to avoid very early dropouts. The car experiment was performed at least three days after the rotating chair test to eliminate any possible interferences.

In the car experiment, 50 people (36 females, 14 males) participated with a median age of 29 (range: 18 – 70 yr). The test persons were informed in writing about the goal, procedure and risks of the experiment, and there was no dependency between the participants and the experimenter.

2.2 Experimental Vehicle

A sedan car (Fig. 1, left) was modified and equipped with a visual setpoint setting method, which enables the driver to perform predefined harmonic driving manoeuvres of given longitudinal and lateral accelerations. This method allows a high degree of repeatability of the manoeuvre's frequencies and amplitudes. Different seat orientations were realised by a modular seating concept. A partition wall between the driver and passenger cabin and darkened windows blocked the view to the outside. A tablet and a camera were mounted in front of the participants. The car was equipped with devices to monitor vital-parameters of the participants, such as gastric motility, heart and respiratory rate (Fig. 1, right).

Fig. 1 Experimental vehicle (left) and passenger cabin with tablet, camera and devices to measure vital-parameters (right)

2.3 Procedure and Measures

The test persons were randomly assigned to sit either forwards or backwards and experience longitudinal or lateral accelerations. This resulted in four different combinations of which each participant experienced only one.

All participants were placed in the passenger cabin and experienced a sequence of sinusoidal acceleration manoeuvres with a frequency of 0.2 Hz. As shown in several previous studies, acceleration frequencies around 0.2 Hz are particularly critical for kinetosis [11, 12, 13]. Each sinusoidal acceleration manoeuvre was followed by an unaccelerated period. Due to test track limitations, a soft turn was performed after four consecutive manoeuvres. To minimise order and habituation effects, the sequence of the amplitudes of the sine acceleration (2, 3 and 4 m/s^2) and the unaccelerated periods (3, 4 and 5 s) were selected using a randomised block design. The lateral acceleration manoeuvres and the unaccelerated periods were driven at a constant velocity of 30 km/h using the car's

cruise control. The initial velocity of the longitudinal acceleration manoeuvres was also 30 km/h.

The test persons were asked to read a text on the tablet and to answer multiple-choice questions related to the text to intensify the sensory conflict. A supervisor outside the car monitored the test person via the camera and tracked the vital-parameters while being able to constantly communicate through the hands-free system with the participant.

During the trials, the current kinetosis level was examined every minute using a smiley scale based on the misery scale (MISC) from Bos et al. [14]. This symptom-based scale is commonly used to measure kinetosis and ranges from 0 to 10 (0: no problems; 1: slight discomfort; 2-5: different symptoms with less psychological strain; 6-9: increasing nausea; 10: vomiting). Additionally, the test persons communicated the occurring symptoms to the supervisor via voice contact. The experiment was terminated after 25 minutes or when the subjects reached a MISC-value of 7 (medium nausea). The test could also be stopped at any time by the participant.

Translational and rotational movements were captured by recording data from the vehicle's CAN bus and inertial measurement units - one fixed to the backrest of the passenger seat and another to the participant's head.

2.4 Data Analysis

For this study, different metrics were used to analyse the effect of seating orientation and horizontal acceleration on kinetosis. Firstly, the mean MISC and the individual MISC rate were calculated. The mean MISC is the average MISC value of all participants for every minute of the test period. If a participant drops out before reaching 25 minutes, a constant kinetosis level of 7 is assumed for every remaining minute. This technique has been used in several previous studies [6, 15]. Due to this conservative approach of assuming a kinetosis level of 7 for the remaining time points, it can be assumed that the calculated effects are actually greater. Therefore, the individual MISC rate, as a measure which is not distorted due to this technique, is additionally calculated. It is a measure of how quickly kinetosis develops and is calculated for each participant by averaging all differences in MISC values between two successive values. The non-parametric Wilcoxon rank-sum test is used to find differences between two independent groups.

In addition, the survival time and number of manoeuvres are analysed. Here, the survival time describes the duration from the start of the experiment (start of exposure) until the test person reaches a certain MISC value. A Cox regression model is used to analyse the association between survival time and several predictor variables. The variables considered in this study were the categorical variables: acceleration direction, seat orientation, sex of participant and the continuous variables: individual kinetosis sensitivity and age. The individual kinetosis sensitivity is the participants' individual test duration in minutes of the rotating chair experiment and therefore a measure of how sensitive a person is to kinetosis. The Cox regression model estimates the relative risks. For the categorical variables, the exponent of the regression coefficient, $\exp(\beta)$, indicates an increase or decrease in the probability of reaching a specific MISC value compared to a reference condition. For continuous variables, the exponent indicates a change in risk for a unit increase in the value of the variable, provided all other variables remain constant. Furthermore, the Cox regression model allows for the inclusion of right-censored data, which is generated when the test persons have not reached the final MISC-value within 25 minutes.

3. RESULTS

In total, 50 experiments were conducted, with 3 measurements being faulty and filtered out, due to a technical error and two operating errors by the participants. Of the resulting 47 test persons, 22 experienced lateral and 25 longitudinal acceleration manoeuvres, 24 experienced a forward-facing and 23 a rearward-facing seat orientation. The study revealed that the chosen test design specifically induces kinetosis. 44 of 47 participants reached a MISC-value of 5 or higher within the test time of 25 minutes. Only 8 participants did not reach level 7. Of these 8 test persons, 6 experienced

lateral accelerations and 2 longitudinal accelerations, 4 were seated forward and 4 rearward.

The distribution of the experienced number of manoeuvres indicates a lower kinetosis risk of lateral acceleration manoeuvres compared to longitudinal acceleration manoeuvres (Fig. 2). The median value is clearly higher for lateral acceleration manoeuvres (median lateral = 82, median longitudinal = 52). On average, the subjects who experienced lateral acceleration manoeuvres completed almost 30 more manoeuvres before reaching a MISC value of 7. Subsequent Wilcoxon rank-sum test showed a significant difference between these two groups ($Z = 2.54$, $p = 0.01$). The median values and overlapping boxes of the different seat orientations indicate that there is almost no difference between these groups (median forward = 63, median rearward = 69.5). The Wilcoxon rank-sum test showed no statistically significant difference ($Z = -0.12$, $p = 0.91$).

These results are confirmed looking at the mean MISC values over time and the individual MISC rates. Fig. 3 (left) shows the time course of the mean MISC values of different acceleration directions and Fig. 3 (right) depicts the time course for different seat orientations. The values showed a significant difference between the longitudinal and lateral acceleration group ($Z = 2.55$, $p = 0.01$) and no difference between the forward- and rearward-facing group ($Z = 0.49$, $p = 0.63$).

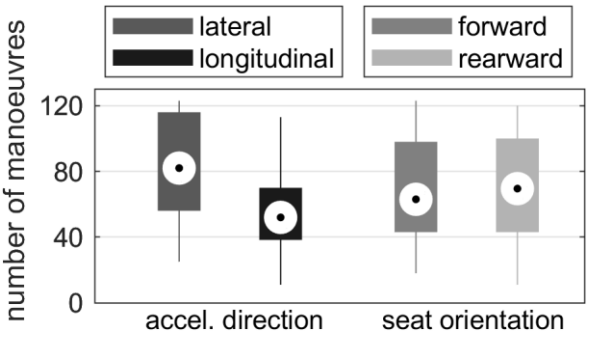

Fig. 2 Number of experienced manoeuvres of different acceleration directions and seat orientations (Boxplot: median, 25th and 75th percentiles, whiskers are 1.5 times the interquartile range)

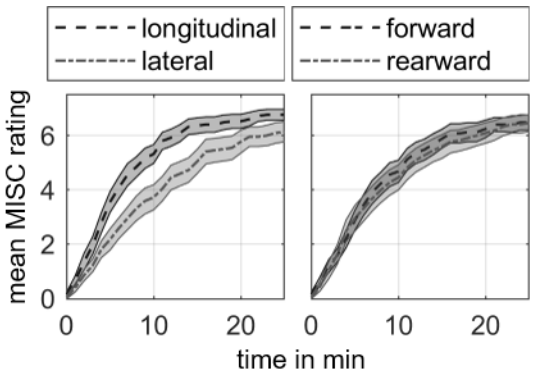

Fig. 3 Mean MISC ratings over time of different acceleration directions (left) and seat orientations (right). Grey band shows standard error of the mean

The resulting mean MISC value across the entire test period is 5.03 (SD = 2.04) for longitudinal acceleration manoeuvres and 3.98 (SD = 1.92) for lateral acceleration manoeuvres. For forward-facing subjects, the mean MISC values over time is 4.61 (SD = 2) and for rearward-facing subjects 4.46 (SD = 2). When considering the individual MISC rates, a Wilcoxon rank-sum test indicated that the longitudinal acceleration group (median = 0.58) differed from the lateral acceleration group (median = 0.39), which was significant ($Z = 2.12$, $p = 0.03$). A Wilcoxon rank-sum test of seat orientation showed no significant difference between the forward- and rearward-facing group ($Z = -0.02$, 0.98).

The Cox regression analysis was used to estimate the influence of acceleration direction and seat orientation considering several predictor variables simultaneously. Two different models were used: one estimated the influence of the variables on the probability of a subject reaching a MISC value of 5, and one on reaching a MISC value of 7. Therefore, the first model is associated with the risk of experiencing mild symptoms such as headache, sweating and dizziness but no nausea, and the second model is associated with the risk of suffering medium nausea. To simplify the models and exclude variables with a negligible effect, a stepwise algorithm based on the minimisation of the Akaike Information Criteria (AIC) was performed for each analysis. For the first one, the model with the best AIC was the model that included the acceleration direction, individual kinetosis sensitivity and

sex. For the second one, the model with the variable age instead of sex resulted in the best AIC. Table 1 shows significance values and the exponents of the regression coefficients for each variable used in the simplified Cox regression models. In both models, there was a significant effect of acceleration direction and individual kinetosis sensitivity and no significant effects of seat orientation, age and sex. No pairwise interaction showed a significant influence. The non-significant influence of the covariate seat orientation is also illustrated by the two survival time curves in Fig. 4, which represent the probability over time that an individual reaches a MISC-value of 7. The strong overlap and the small distance between the survival curves indicate that there is no significant difference between forward- and rearward-facing seat orientation. In contrast, the survival curves of the acceleration direction show a significant difference (Fig. 5). The relative risk of reaching a MISC value of 5 or 7 was approximately doubled if the participants experienced longitudinal acceleration manoeuvres compared to lateral acceleration manoeuvres. A unit increase in individual kinetosis sensitivity reduced the risk by approximately more than 15 percent. The correlation between the survival time for reaching a MISC value of 7 and the individual kinetosis sensitivity was also tested and confirmed a significant positive relation. ($r = 0.37$, $p = 0.01$, Spearman).

4. DISCUSSION

The results show that there is no difference between forward- and rearward-facing seat orientations on kinetosis in passenger cars when external vision is prevented. These results are in line with findings from Vogel et al. and Bohrmann and Bengler, who found no significant influence of the seat orientation on passengers in supine position under visual standardisation [7, 16]. It can be concluded that a modified vestibular stimulus due to different seat orientations has no significant influence on the risk of kinetosis. Comparing these results with the findings of Salter et al. or Tuner and Griffin, who found a significant difference if vision is unrestricted, it strengthens the assumption that the modified visual stimulus is the only reason why rearward-facing passengers show an increased risk [2, 3]. Hereby, the lack of anticipation in particular is thought to increase the risk of kinetosis for rearward-facing passengers [2]. Further research is now needed to investigate whether additional anticipatory information can compensate the increased risk of kinetosis for rearward-facing passengers.

Analyzing the number of dropouts, the total number of manoeuvres, the MISC ratings and the survival time, all results indicate a significant increased risk of kinetosis for longitudinal acceleration manoeuvres. Bohrmann and Scholly have similar findings, and reported that longitudinal acceleration manoeuvres particularly provoke kinetosis [9].

Table 1 Cox regression model

		MISC 5 AIC: 256.37 global p-value (Log-Rank): p< 0.01**		**MISC 7** AIC: 243.84 global p-value (Log-Rank): p< 0.01**	
Variable	**Reference**	**Exp(β)**	**p**	**Exp(β)**	**p**
acceleration direction	lateral	2.11	0.02*	1.97	0.048*
individual kinetosis sensitivity	-	0.83	0.01*	0.85	0.04*
sex	female	0.57	0.10	-	-
age	-	-	-	1.03	0.06

Note: simplified Cox regression models for reaching a MISC value of 5 (mild symptoms) and a MISC value of 7 (medium nausea); significance levels: * = $p < 0.05$, ** = $p < 0.01$

In contrast, Griffin and Mills found no difference between horizontal accelerations [8]. Their study was conducted in a simulator cabin and did not produce tilts and rotational movements, typically occurring in a car. Therefore, the occurrence of these complex movements and their impact on the human body (vestibular system) could be an important reason for the difference in kinetosis risk between longitudinal and lateral acceleration manoeuvres.

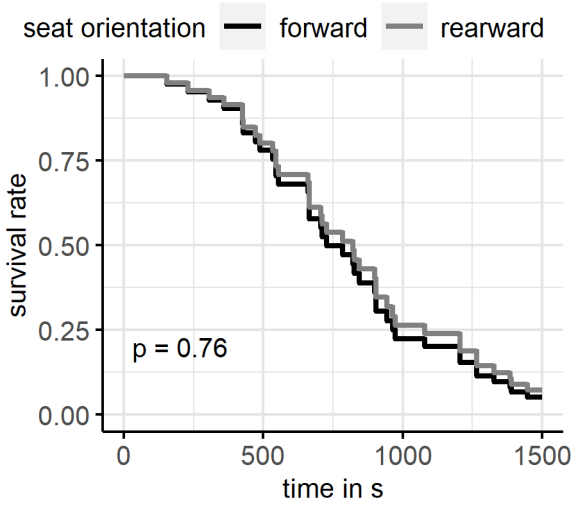

Fig. 4 Estimated survival curves of different seat orientations. Model uses mean age (32 yr), mean individual kinetosis sensitivity (12 min) and longitudinal acceleration direction to calculate curves

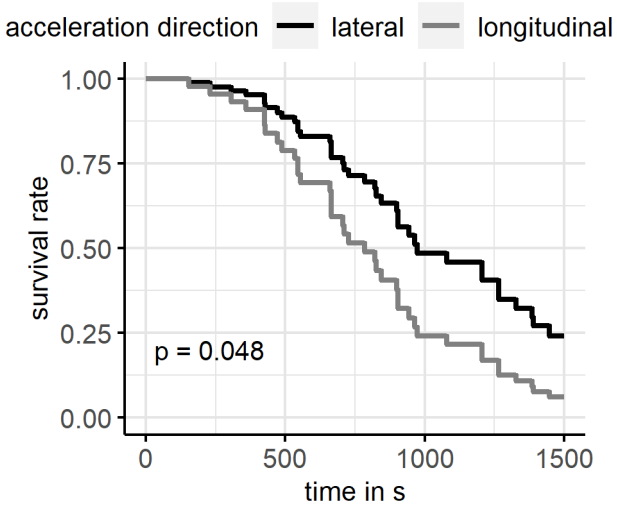

Fig. 5 Estimated survival curves of different acceleration directions. Model uses mean age (32 yr) and mean individual kinetosis sensitivity (12 min) to calculate curves

Several studies indicated that women are more likely to develop kinetosis than men and that age has a significant influence [17, 18, 19]. In this study, none of these factors showed a significant influence. A possible reason could be that factors such as age and gender mainly influence the individual kinetosis sensitivity. Due to the test design and the associated classification and pre-selection of the test persons concerning their individual sensitivity, this influence is strongly weakened.

In this study, the selected group of participants does not represent the general population, hence the number of female participants was approximately 2.6 times higher than the number of male participants. Furthermore, participants with too low or too high individual kinetosis sensitivity were excluded. However, the latter made it possible to achieve less scattering of the data in the subgroups, which increased the validity of the results.

5. CONCLUSION

Findings clearly show that longitudinal accelerations significantly increase the kinetosis risk compared to lateral accelerations in passenger cars. Furthermore, there is no difference between forward- and rearward-facing seat orientations if the passenger cannot see the environment outside the car, suggesting that anticipation is the main effect that makes a difference between these two seat positions.

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