Head Movements and Physiological Indicators as Predictors of Passenger Motion Sickness

William Emond[1,2] & Mohsen Zare [2]

[1]Mercedes-Benz AG, Germany, [2]ELLIADD-ERCOS, UTBM, France

SUMMARY

Future car transportation is expected to feature automated driving. In such vehicles, drivers will no longer seat behind the wheel but evolve into passengers who may focus on non-driving related activities during the drive. This figure is however expected to increase the incidence and severity of motion sickness while traveling, which motivates the need of an improved understanding of passenger motion sickness and the design of comprehensive mitigation solutions. This research investigated the relationship between passenger motion sickness, physiological parameters and postural activity reflected in head dynamics. In an 18-minute realistic passenger drive scenario, 12 (1 female, 11 male) participants were tested in two separate sessions. Their physiological parameters were recorded using a medical device and their head movements were recorded using motion capturing. Using a Generalized Linear Model, analyses identified changes in peripheral oxygen saturation levels, core temperature and cardiovascular activity as physiological reactions with strong relationships to motion sickness severity. Moreover, the amplitude of head movements in the roll and yaw directions showed significant relationships with motion sickness severity. These findings pave the road for an improved detection of motion sickness depending on passenger individual parameters.

KEYWORDS

Kinetosis, Car Sickness, Human Factors, Motion Comfort, Non-Driving Task

Introduction

Road vehicles are currently undergoing a revolution in their design and use. Future cars are forecasted to feature automated driving with the possibility for the user to quit the driving task and dedicate travel time to Non-Driving Related Activities (NDRA). Passenger comfort will become a key requirement for the design of such vehicles as moving living spaces (Salter et al., 2019). Taking users “out of the loop” for driving the vehicle may result in a greater likeliness to spend travel time on NDRAs. However, focusing on NDRAs devoid of any view of the vehicle surroundings increases the likeliness of experiencing motion sickness (Diels, 2014; Metzulat et al., 2024; Morimoto et al., 2008). Other dimensions inherent to automated vehicles such as the (un)familiarity of the driving style and (lack of) trust in automation may even exacerbate this prevalence (Peng et al., 2024). Experts forecast that, with the introduction of self-driving cars, the occurrence of motion sickness may nearly double in road transportation (Diels et al., 2016; Iskander et al., 2019). A figure which may jeopardize the successful introduction of such vehicles on public roads. Therefore, recent years witnessed consequent research on the design of systems capable of alleviating motion sickness while traveling in a car. This research is mostly driven by automotive manufacturers who target to be the first to market for successfully deploying self-driving cars on the road (Diels, 2014).

Motivation and Objective

For a comprehensive mitigation of motion sickness, there is also a need towards the development of methods for predicting the time course of symptoms. An optimal countermeasure of motion sickness may be able to trigger efficient alleviation methods as soon as a rise in motion sickness severity is increased. Considering the high inter-individual variability in autonomic reactions to motion sickness and wide spectrum of sensitivities, such detection methods should be user-centred and involve the measurement of several parameters. Literature emphasized the combination of physiological measurements as a reliable prediction method (Tan et al., 2022). Furthermore, postural activity, and notably the measurement of head rotations, was documented as another predictor parameter of motion sickness (Wada et al., 2012).

Therefore, two research questions were investigated:

RQ1. How different head movements variables correlate with motion sickness severity?

RQ2. How do changes in physiological parameters correlate with the onset and severity of passenger motion sickness?

The present study addressed these research questions by replicating a realistic passenger drive reproducing fore-aft accelerations, representative of an everyday passenger commute.

Methodology

Twelve (11 male, 1 female) volunteers experienced an 18-minute vehicle drive on the passenger seat of a saloon vehicle (Mercedes-Benz E 400 e) driven six identical laps on a closed test track. Their mean ± SD age was 41 ± 12 years and their mean ± SD motion sickness susceptibility score as assessed by the short version of the Motion Sickness Susceptibility Questionnaire (Golding, 2006) was 17.7 ± 9.5. In a within-subjects design, they tested either an "Upright" or "Reclined" sitting condition in randomized order: in the Upright condition, the backrest position was kept fixed at 28 degrees from the vertical, whereas in the Reclined condition, participants were free to choose a backrest angle superior to 28 degrees, resulting in a mean ± SD angle inclination of 33 ± 3 degrees from the vertical. For each participant, the two experimental sessions were spaced by at least 24 hours.

During the experimental drive, subjective motion sickness ratings were collected each minute. The order of conditions was not counterbalanced (3 participants were first tested in the Upright condition). Motion sickness severity was assessed every minute (three times per lap) using a 21-point "Fast Motion Sickness (FMS)" scale (0 being very good, 20 being strong nausea) referring to individual wellbeing (Keshavarz & Hecht, 2011). Participants were free in their gazing behaviour and could withdraw from the experimental sessions at any time. Physiological data of participants was monitored and recorded using an in-ear medical device (Cosinuss c-med° alpha) performing continuous measurements of heart rate, RR-intervals at 1 Hz, as well as measurements of core temperature, oxygen saturation level, and perfusion index at 0.1 Hz. An additional quality index signal was generated to help in selecting reliable data for the data analysis. Complementary to physiological measurements, head movements were recorded during the drive using motion capturing techniques: a camera (OptiTrack V:120 Duo) was fixed to the windshield and facing the participants at eye-height. To track head movements, four targets were placed on the face of the participant (one on the upper forehead, one between the eyebrows and one on each zygoma extremity). Both the camera and the in-ear devices were calibrated with participants sitting still in the vehicle before starting the experimental drive.

For data analysis, head movements and physiological measurements were averaged on each time interval between the successive FMS scores of participants. Heart Rate Variability and Low-

Frequency/High-Frequency (LF/HF) ratio were derived from RR-intervals. Using the Matlab (MathWorks, version R2024a) software, the Root Mean Square (RMS), skewness (skw) and kurtosis (kts) of head movement data were calculated in the three directions of rotation and rotation velocity: namely pitch (x-axis) for neck flexion/extension, yaw (y-axis) for head rotation and roll (z-axis) for lateral bending. To attenuate vibration noise related to the drive, signals were processed with a Butterworth filter with cutoff frequency set at 5 Hz and zero-phase filtering. Statistical analyses were performed with R Studio (Version 4.3.3, Posit) with significance level set at $p < .05$. Since FMS scores were not normally distributed, an analysis of FMS scores using a Generalized Linear Model (GLM) was performed.

Results

The free view on the vehicle surroundings and the absence of any restriction to focus on a NDRA resulted in moderate motion sickness severity on average (Figure 1). Seven participants experienced some motion sickness symptoms in both experimental sessions and one male participant did not feel any symptom in both sessions.

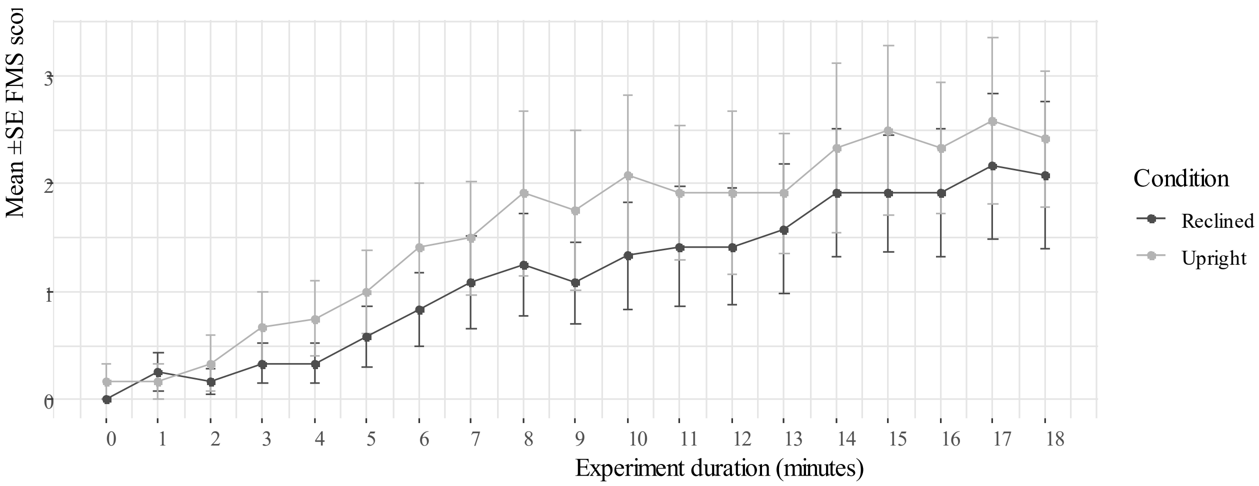

Figure 1: Time course of FMS scores in each experimental condition, n = 12 participants, within-subjects design.

The GLM analysis (Table 1) revealed that the duration of the drive and the individual susceptibility (measured with the MSSQ-Short) had strong relationship with motion sickness severity. No significant effect of the backrest angle could be identified (t = 0.747, p = .456). However, several physiological parameters were identified to correlate with the time course of FMS scores, notably increases in perfusion index (t = 6.139, p < .001), decreases in peripheral oxygen saturation (t = -4.217, p < .001), decreases in core body temperature (t = -3.317, p = .001) and increases in heart rate (t = 2.423, p = .016). Heart Rate Variability and LF/HF ratio had no significant relationship with FMS scores.

The GLM analysis of FMS scores identified two characteristics of head dynamics as related to increases in motion sickness severity: namely increases in the amplitude of head roll rotations (t = 3.442, p < .001) and decreases of the amplitude of head yaw angle rotations (t = -3.201, p = .002). No effect of skewness or kurtosis of head rotation could be identified. Additionally, the analysis did not identify any relationship between FMS scores and characteristics of the head rotation velocity.

Table 1: Results from the Generalized Linear Model on the time course of FMS scores, n = 12 participants.

	Estimate	Std. Error	t value	p value	odds ratio*	VIF**
(Intercept)	6.82e+01	1.26e+01	5.405	2.24e-07	4.27e+29	-
Drive duration (min)	1.42e-01	2.19e-02	6.499	9.15e-10	1.15e+00	1.60e+00
MSSQ score (-)	1.77e-01	1.89e-02	9.360	5.28e-17	1.19e+00	2.98e+00
Backrest angle (deg)	3.32e-02	4.45e-02	0.747	4.56e-01	1.03e+00	1.89e+00
Heart rate (min^{-1})	2.77e-02	1.15e-02	2.423	1.65e-02	1.03e+00	3.89e+00
Core temperature (°C)	-1.34e+00	4.03e-01	-3.317	1.12e-03	7.57e-01	5.12e+00
Peripheral oxygen saturation (%)	-2.78e-01	6.60e-02	-4.217	4.07e-05	2.62e-01	2.21e+00
Perfusion index (-)	2.55e+00	4.15e-01	6.139	5.96e-09	1.28e+01	2.58e+00
Heart Rate Variability (ms)	-7.19e-05	1.54e-03	-0.047	9.63e-01	1.00e+00	1.49e+00
LF/HF ratio (-)	4.14e-02	7.77e-02	0.533	5.95e-01	1.04e+00	1.38e+00
RMS pitch angle (deg)	1.90e-02	1.73e-02	1.099	2.73e-01	1.02e+00	1.83e+00
RMS yaw angle (deg)	-1.22e-01	3.82e-02	-3.201	1.64e-03	8.85e-01	1.78e+00
RMS roll angle (deg)	5.00e-02	1.45e-02	3.442	7.31e-04	1.05e+00	2.02e+00
Skewness of pitch angle (-)	-8.39e-02	1.41e-01	-0.595	5.52e-01	9.20e-01	2.15e+00
Skewness of yaw angle (-)	3.14e-01	1.73e-01	1.814	7.15e-02	1.37e+00	1.43e+00
Skewness of roll angle (-)	6.66e-02	1.05e-01	0.637	5.25e-01	1.07e+00	1.43e+00
Kurtosis of pitch angle (-)	-2.20e-02	3.90e-02	-0.565	5.73e-01	9.78e-01	2.27e+00
Kurtosis of yaw angle (-)	-1.45e-02	8.48e-02	-0.171	8.64e-01	9.86e-01	1.75e+00
Kurtosis of roll angle (-)	-1.40e-02	3.20e-02	-0.437	6.63e-01	9.86e-01	1.88e+00
RMS pitch angle velocity ($deg.s^{-1}$)	-6.27e-01	1.69e+00	-0.372	7.11e-01	5.34e-01	3.39e+00
RMS yaw angle velocity ($deg.s^{-1}$)	2.25e-01	1.74e+00	0.129	8.97e-01	1.25e+00	1.33e+00
RMS roll angle velocity ($deg.s^{-1}$)	5.39e-01	5.43e-01	-0.993	3.22e-01	5.83e-01	3.48e+00
Skewness of pitch angle velocity (-)	7.48e-01	1.17e-01	0.638	5.25e-01	1.08e+00	2.03e+00
Skewness of yaw angle velocity (-)	1.30e-02	1.86e-01	0.699	4.85e-01	1.14e+00	1.59e+00
Skewness of roll angle velocity (-)	9.44e-02	1.15e-01	0.820	4.14e-01	1.10e+00	1.84e+00
Kurtosis of pitch angle velocity (-)	1.17e-02	1.15e-02	1.019	3.10e-01	1.01e+00	3.10e+00
Kurtosis of yaw angle velocity (-)	6.18e-03	2.70e-02	0.229	8.19e-01	1.01e+00	1.99e+00
Kurtosis of roll angle velocity (-)	-8.45e-03	1.86e-02	-0.454	6.50e-01	9.92e-01	3.02e+00

* Odds ratio quantifies the change in odds of the dependent event occurring for a one-unit increase in the predictor variable

** Variance Inflation factor (VIF) is a measure of the extent of multicollinearity in the set of multiple regression variables

Discussion

Results from motion capturing data support an influence of postural activity on the development of passenger motion sickness. The contributing effect of head roll movements to the severity of symptoms aligns with observations from other studies replicated in vehicular environments (Papaioannou et al., 2024; Wada et al., 2012; Wada & Yoshida, 2016). However, the inversely proportional effect of head yaw amplitude of rotation is quite novel and might reflect an orientation behaviour while gazing at specific visual cues from the vehicle surroundings. This attitude might also reflect distraction, which is reported as a protective behaviour against the development of symptoms (Bos, 2015). Referring to the first research question (RQ1), head movements stood out as correlates of motion sickness severity and could be considered for the development of camera-based motion sickness prediction models in vehicles.

The significant relationship between perfusion index and FMS scores suggests that a rise in motion sickness severity would be accompanied by an increase in blood pressure or volume. This finding aligns with similar observations of an increased blood volume as a reaction to passenger motion sickness (Pham Xuan et al., 2019). Yet, other findings from empirical research suggest no relationship (Graybiel & Lackner, 1980) or a negative relationship between blood pressure and motion sickness severity (Steele, 1968; Tan et al., 2022). This increase in cardiovascular activity is also reflected into a slight heart rate increase correlating with motion sickness, which aligns with findings from motion sickness studies (Cowings et al., 1986; Henry et al., 2023; Irmak et al., 2021).

No experimental research investigated oxygen saturation levels respective to motion sickness, the negative relationship identified aligns with findings from genetic research identifying a correlation between motion sickness susceptibility and sensitivity to hypoxia (Hromatka et al., 2015). Whether this body reaction is a cause or a consequence of motion sickness is however unclear. A physiological reaction consequent to motion sickness is hypothermia (Nalivaiko et al., 2014; Nobel et al., 2006), which could be identified by the negative relation ship between FMS scores and core temperature. Similar findings were reported in a similar stop-and-go passenger ride experiment (Pham Xuan et al., 2019). Referring to the second research question (RQ2), the significant relationships identified between many physiological parameters and FMS scores support the development of motion sickness detection methods based on the real-time monitoring of such parameters.

The relatively low duration of the passenger ride, the restriction of manoeuvres to fore-aft accelerations, and the limited sample size constitute strong limitations to the generalizability of findings. Replicating a design to elicit more severe forms of motion sickness (e.g restricting forward vision of participants) might yield greater differences in FMS scores across participants for a more generalizable analysis but would limit the real representativeness of the drive scenario. Increasing the duration of testing may be judged by volunteering participants as too time-consuming. The sample was also biased by unequal gender and age repartition, which are not representative of a general population. Further research should consider samples that are more representative of car passengers, with all ages, gender and susceptibilities represented to better understand the effect of these independent variables.

Conclusion

The present study aimed investigating the development of motion sickness over a duration of 18 minutes in a realistic passenger drive scenario replicating fore-aft vehicle accelerations. Despite moderate motion sickness severity, some significant correlation could be identified. Oxygen saturation, core temperature and cardiovascular activity stood out as indicators of a rise in cardinal motion sickness symptoms. Moreover, the significant relationships identified between motion sickness severity and head movements suggest a contributing effect of postural activity while riding as a vehicle passenger with free gazing behaviour. Despite limited generalizability, these findings can guide the development of systems capable of early detection of motion sickness to prevent the symptoms from exacerbating.

Acknowledgement

The authors would like to thank the participants of the study and are pleased to acknowledge Josef Ghebru (University of Stuttgart) as second experimenter.

References

Bohrmann, D., Bruder, A., & Bengler, K. (2022). Effects of Dynamic Visual Stimuli on the Development of Carsickness in Real Driving. *IEEE Transactions on Intelligent Transportation Systems*, 1–10. IEEE Transactions on Intelligent Transportation Systems. https://doi.org/10.1109/TITS.2021.3128834

Bohrmann, D., Koch, T., Maier, C., Just, W., & Bengler, K. (2020). *Motion Comfort – Human Factors of Automated Driving*. 1697–1708. https://www.researchgate.net/profile/Dominique-Bohrmann/publication/346647590_Motion_Comfort_-_Human_Factors_of_Automated_Driving/links/5fcc0619299bf188d4f96833/Motion-Comfort-Human-Factors-of-Automated-Driving.pdf

Bos, J. E. (2015). Less sickness with more motion and/or mental distraction. *Journal of Vestibular Research*, *25*(1), 23–33. https://doi.org/10.3233/VES-150541

Cowings, P. S., Suter, S., Toscano, W. B., Kamiya, J., & Naifeh, K. (1986). General Autonomic Components of Motion Sickness. *Psychophysiology*, *23*(5), 542–551. https://doi.org/10.1111/j.1469-8986.1986.tb00671.x

D'Amour, S., Bos, J. E., & Keshavarz, B. (2017). The efficacy of airflow and seat vibration on reducing visually induced motion sickness. *Experimental Brain Research*, *235*(9), Article 9. https://doi.org/10.1007/s00221-017-5009-1

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.), *Contemporary Ergonomics and Human Factors 2014* (pp. 301–307). Taylor and Francis. https://doi.org/10.13140/RG.2.1.1461.0087

Diels, C., & Bos, J. (2021). Great Expectations: On the Design of Predictive Motion Cues to Alleviate Carsickness. In H. Krömker (Ed.), *HCI in Mobility, Transport, and Automotive Systems* (Vol. 12791, pp. 240–251). Springer International Publishing. https://doi.org/10.1007/978-3-030-78358-7_16

Diels, C., Bos, J. E., Hottelart, K., & Reilhac, P. (2016). Motion Sickness in Automated Vehicles: The Elephant in the Room. In G. Meyer & S. Beiker (Eds.), *Road Vehicle Automation 3* (pp. 121–129). Springer International Publishing. https://doi.org/10.1007/978-3-319-40503-2_10

Emond, W., & Zare, M. (2024). *Motion Sickness Mitigation in Road Vehicles with a Triad of Focus on Safety and Sustainability.* 8. https://hal.science/hal-04538188/document

Golding, J. F. (2006). Predicting individual differences in motion sickness susceptibility by questionnaire. *Personality and Individual Differences*, *41*(2), Article 2. https://doi.org/10.1016/j.paid.2006.01.012

Graybiel, A., & Lackner, J. R. (1980). Evaluation of the relationship between motion sickness symptomatology and blood pressure, heart rate, and body temperature. *Aviation, Space, and Environmental Medicine*, *51*(3), 211–214.

Henry, E. H., Bougard, C., Bourdin, C., & Bringoux, L. (2023). Car sickness in real driving conditions: Effect of lateral acceleration and predictability reflected by physiological changes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *97*, 123–139. https://doi.org/10.1016/j.trf.2023.06.018

Hromatka, B. S., Tung, J. Y., Kiefer, A. K., Do, C. B., Hinds, D. A., & Eriksson, N. (2015). Genetic variants associated with motion sickness point to roles for inner ear development, neurological processes and glucose homeostasis. *Human Molecular Genetics*, *24*(9), 2700–2708. https://doi.org/10.1093/hmg/ddv028

Htike, Z., Papaioannou, G., Siampis, E., Velenis, E., & Longo, S. (2022). Fundamentals of Motion Planning for Mitigating Motion Sickness in Automated Vehicles. *IEEE Transactions on Vehicular Technology*, *71*(3), 2375–2384. IEEE Transactions on Vehicular Technology. https://doi.org/10.1109/TVT.2021.3138722

Irmak, T., Pool, D. M., & Happee, R. (2021). Objective and subjective responses to motion sickness: The group and the individual. *Experimental Brain Research*, *239*(2), 515–531. https://doi.org/10.1007/s00221-020-05986-6

Iskander, J., Attia, M., Saleh, K., Nahavandi, D., Abobakr, A., Mohamed, S., Asadi, H., Khosravi, A., Lim, C. P., & Hossny, M. (2019). From car sickness to autonomous car sickness: A review. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 716–726. https://doi.org/10.1016/j.trf.2019.02.020

Jurisch, M., Holzapfel, C., & Buck, C. (2020). The influence of active suspension systems on motion sickness of vehicle occupants. *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)*, 1–6. https://doi.org/10.1109/ITSC45102.2020.9294311

Keshavarz, B., & Hecht, H. (2011). Validating an Efficient Method to Quantify Motion Sickness. *Human Factors*, *53*(4), Article 4. https://doi.org/10.1177/0018720811403736

Kuiper, O. X., Bos, J. E., Diels, C., & Schmidt, E. A. (2020). Knowing what's coming: Anticipatory audio cues can mitigate motion sickness. *Applied Ergonomics*, *85*, 103068. https://doi.org/10.1016/j.apergo.2020.103068

Metzulat, M., Metz, B., Landau, A., Neukum, A., & Kunde, W. (2024). Does the visual input matter? Influence of non-driving related tasks on car sickness in an open road setting. *Transportation Research Part F: Traffic Psychology and Behaviour*, *104*, 234–248. https://doi.org/10.1016/j.trf.2024.06.002

Morimoto, A., Isu, N., Asano, H., Kawai, A., & Masui, F. (2008). *Effects of reading books and watching movies on inducement of car sickness.* 14–19. https://www.researchgate.net/profile/Fumito-Masui/publication/264843228_Effects_of_Reading_Books_and_Watching_Movies_on_Inducement_of_Car_Sickness/links/542eb6fd0cf27e39fa963cb6/Effects-of-Reading-Books-and-Watching-Movies-on-Inducement-of-Car-Sickness.pdf

Nalivaiko, E., Rudd, J. A., & So, R. H. (2014). Motion sickness, nausea and thermoregulation: The "toxic" hypothesis. *Temperature*, *1*(3), Article 3. https://doi.org/10.4161/23328940.2014.982047

Nobel, G., Eiken, O., Tribukait, A., Kölegård, R., & Mekjavic, I. B. (2006). Motion sickness increases the risk of accidental hypothermia. *European Journal of Applied Physiology*, *98*(1), 48–55. https://doi.org/10.1007/s00421-006-0217-6

Papaioannou, G., Desai, R., & Happee, R. (2024). The Impact of Body and Head Dynamics on Motion Comfort Assessment. In W. Huang & M. Ahmadian (Eds.), *Advances in Dynamics of Vehicles on Roads and Tracks III* (pp. 54–63). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-66968-2_6

Peng, C., Horn, S., Madigan, R., Marberger, C., Lee, J. D., Krems, J., Beggiato, M., Romano, R., Chongfeng, W., Wooldridge, E., Happee, R., Hagenzieker, M., & Merat, N. (2024). Conceptualising user comfort in automated driving: Findings from an expert group workshop. *Transportation Research Interdisciplinary Perspectives*, *24*, 101070. https://doi.org/10.13140/RG.2.2.14206.87369

Pham Xuan, R., Brietzke, A., & Marker, S. (2019). *Evaluation of physiological responses due to car sickness with a zero-inflated regression approach*. 147–160. https://www.hfes-europe.org/wp-content/uploads/2019/10/PhamXuan2019.pdf

Salter, S., Diels, C., Herriotts, P., Kanarachos, S., & Thake, D. (2019). Motion sickness in automated vehicles with forward and rearward facing seating orientations. *Applied Ergonomics*, *78*, 54–61. https://doi.org/10.1016/j.apergo.2019.02.001

Schartmüller, C., & Riener, A. (2020). Sick of Scents: Investigating Non-invasive Olfactory Motion Sickness Mitigation in Automated Driving. *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 30–39. https://doi.org/10.1145/3409120.3410650

Steele, J. E. (1968). *The symptomatology of motion sickness* (AMRL-TR-70-86; Fourth Symposium on The Role of the Vestibular Organs in Space Exploration, pp. 89–96). Naval Aerospace Medical Institute, Pensacola, Florida.

Stelling, D., Hermes, M., Huelmann, G., Mittelstädt, J. M., Niedermeier, D., Schudlik, K., & Duda, H. (2021). Individual differences in the temporal progression of motion sickness and anxiety:

The role of passengers' trait anxiety and motion sickness history. *Ergonomics*, *64*(8), 1062–1071. https://doi.org/10.1080/00140139.2021.1886334

Tan, R., Li, W., Hu, F., Xiao, X., Li, S., Xing, Y., Wang, H., & Cao, D. (2022). Motion Sickness Detection for Intelligent Vehicles: A Wearable-Device-Based Approach. *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)*, 4355–4362. https://doi.org/10.1109/ITSC55140.2022.9922392

Wada, T., Konno, H., Fujisawa, S., & Doi, S. (2012). Can Passengers' Active Head Tilt Decrease the Severity of Carsickness?: Effect of Head Tilt on Severity of Motion Sickness in a Lateral Acceleration Environment. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *54*(2), 226–234. https://doi.org/10.1177/0018720812436584

Wada, T., & Yoshida, K. (2016). Effect of passengers' active head tilt and opening/closure of eyes on motion sickness in lateral acceleration environment of cars. *Ergonomics*, *59*(8), 1050–1059. https://doi.org/10.1080/00140139.2015.1109713

Yen Pik Sang, F. D., Billar, J. P., Golding, J. F., & Gresty, M. A. (2003). Behavioral Methods of Alleviating Motion Sickness: Effectiveness of Controlled Breathing and a Music Audiotape. *Journal of Travel Medicine*, *10*(2), 108–111. https://doi.org/10.2310/7060.2003.31768

Yusof, N. Md., Karjanto, J., Terken, J. M. B., Delbressine, F. L. M., & Rauterberg, G. W. M. (2020). Gaining Situation Awareness through a Vibrotactile Display to Mitigate Motion Sickness in Fully-Automated Driving Cars. *International Journal of Automotive and Mechanical Engineering*, *17*(1), 7771–7783. https://doi.org/10.15282/ijame.17.1.2020.23.0578