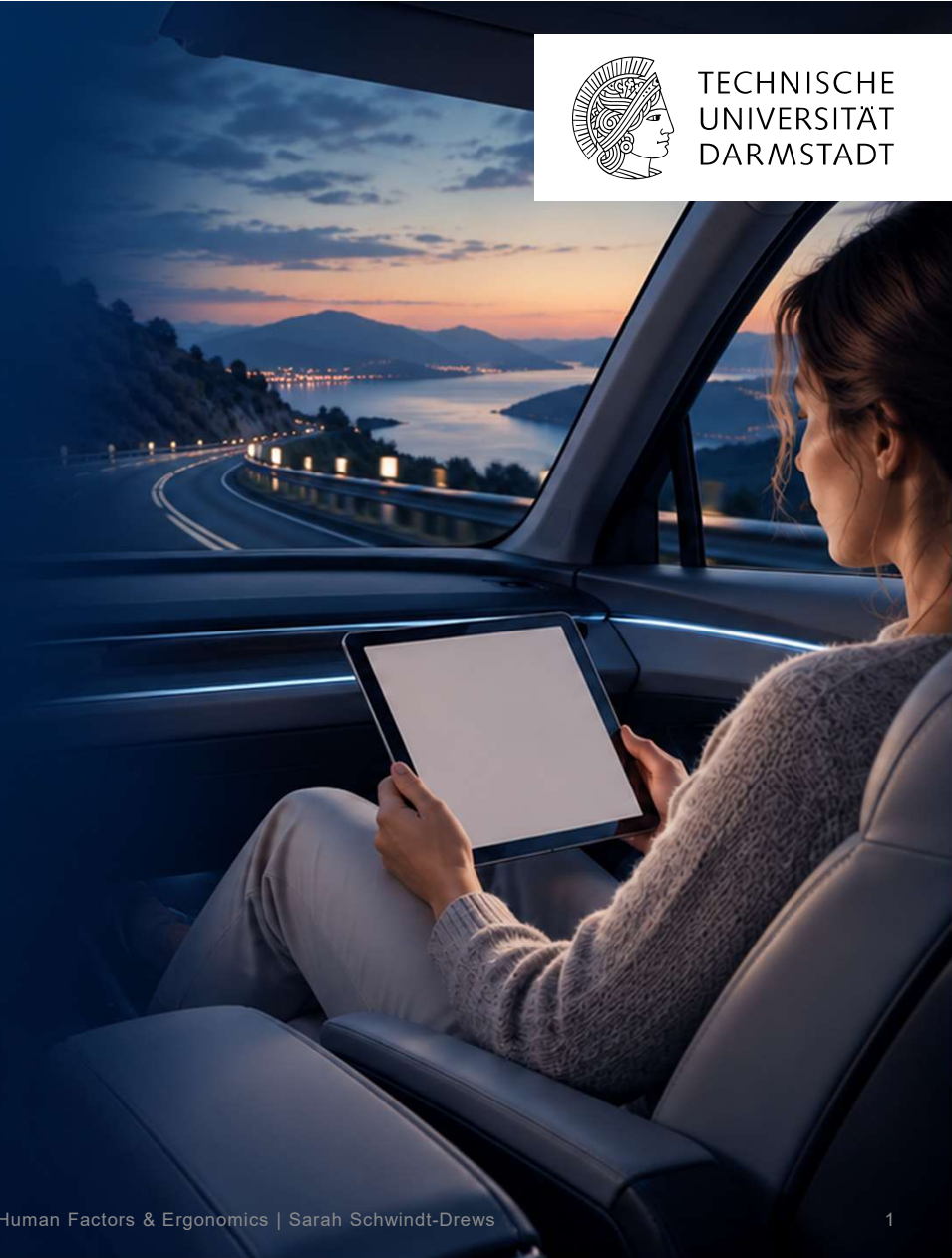




TECHNISCHE  
UNIVERSITÄT  
DARMSTADT

# Effects of Automated Driving Style and Visual Countermeasures on Motion Sickness During Visual NDRT

Sarah Schwindt-Drews, Bettina Abendroth



# Motion Sickness during Automated Driving

- Automated driving enables occupants to engage in non-driving-related tasks (NDRTs), such as reading or watching films.
- Visually demanding NDRTs can increase the risk of motion sickness when visual, vestibular and somatosensory motion cues conflict.  
(Bubb, 2015; Diels & Bos, 2015)
- Restricted external visibility and the absence of active vehicle control can further impair the anticipation of upcoming vehicle movements, potentially contributing to motion sickness.  
(Bubb, 2015; Diels & Bos, 2015)
- Automated driving style is another influencing factor, as vehicle acceleration patterns can contribute to motion sickness.  
(Karjanto et al., 2022; O'Hanlon & McCauley, 1974, Vogel et al., 1982)
- These symptoms can limit engagement in NDRTs and adversely affect the acceptance of automated vehicles.  
(Diels & Bos, 2015)

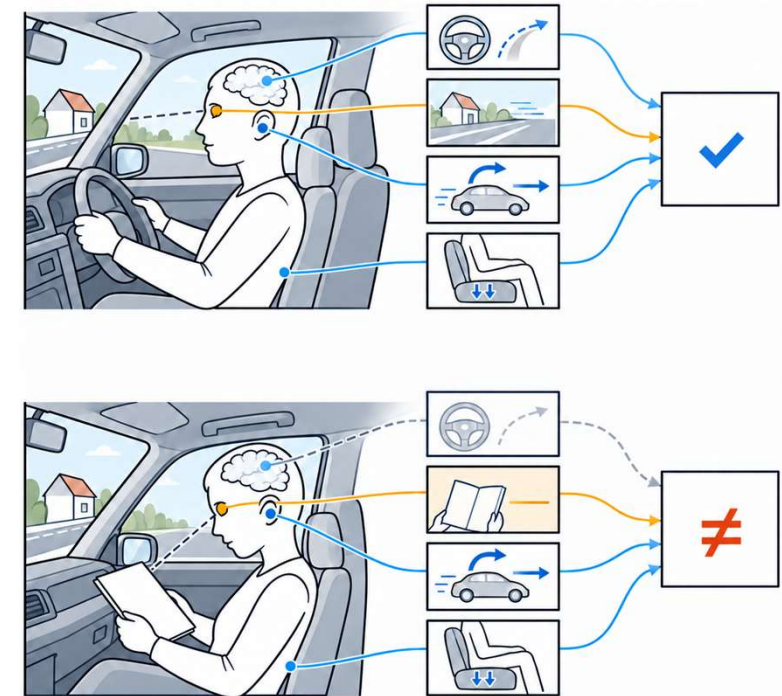


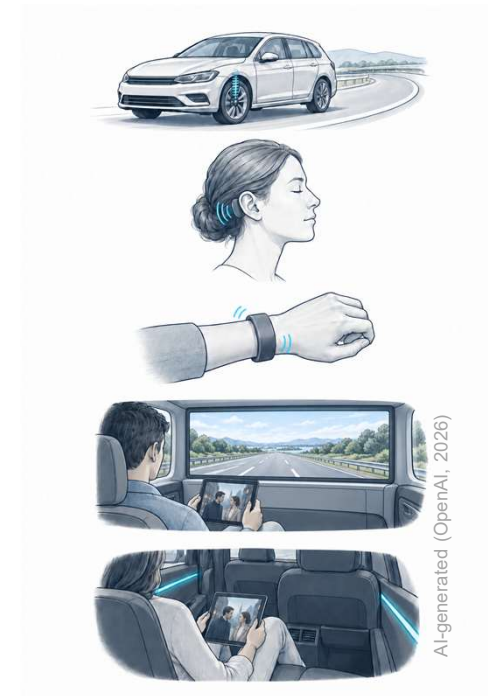
Figure adapted from Bubb (2015)

**How can motion sickness be reduced without restricting engagement in non-driving-related tasks?**

# Countermeasures against Motion Sickness

Various approaches have been investigated or proposed to reduce motion sickness:

- **Reduction of motion provocation**, e.g. defensive driving and adaptive suspension (Karjanto et al., 2022; O'Hanlon & McCauley, 1974; Bär, 2014)
- **Modulation of vestibular input**, e.g. vestibular stimulation through bone-conducted vibration (Dikmen, 2018; Sauter, 2018)
- **Haptic motion cues**, e.g. forearm vibrations indicating upcoming turns (Md. Yusof et al., 2017)
- **Preservation of external visual references**, e.g. an unobstructed forward view and elevated display positioning (Griffin & Newman, 2004; Diels & Bos, 2015)
- **Visual motion cues**, e.g. artificial horizons and motion-adjusted display content (Kato & Kitazaki, 2008; Karjanto et al., 2018; Citroën, 2018)



Peripheral external visual references and favorable display positioning can reduce motion sickness. Evidence for artificial visual motion cues is mixed. (Kuiper et al., 2018, Karjanto et al., 2018, Xie et al., 2023)

**In previous studies, these measures were primarily examined either individually or in conjunction with temporary fixation on NDRTs. Their combined effectiveness during sustained fixation on an NDRT has not yet been sufficiently studied.**

# Research Question and Hypotheses



**How do automated driving style and visual countermeasures affect motion sickness during sustained visual fixation on an NDRT, and does combining the countermeasures provide an additional benefit?**

- H1:** An aggressive driving style leads to higher levels of subjective and objective motion sickness symptoms than a defensive one.
- H2:** LED-based cues in the peripheral field of view that indicate curves reduce subjective and objective motion sickness symptoms during a sustained visual fixation on an NDRT.
- H3:** HUD-level text positioning reduces subjective and objective motion sickness symptoms during sustained visual fixation on an NDRT.
- H4:** The combination of both (LED+HUD) results in the lowest level of subjective and objective motion sickness symptoms.

# Study Design

## Independent Variables:

- Driving Style  
(defensive or aggressive)
- Countermeasures against Motion Sickness  
(none, LED, HUD or LED+HUD)

## Dependent Variables:

- Subjective Motion Sickness:  
Simulator Sickness Questionnaire (SSQ, Kennedy et al., 1993).
- Objective Motion Sickness / psychophysiological measures:  
Skin Conductance Level (SCL)
- Objective Motion Sickness / psychophysiological measures:  
Heart Rate Variability (HRV)

## Within-subjects design

## Dynamic Driving Simulator (Seat Box on Hexapod)



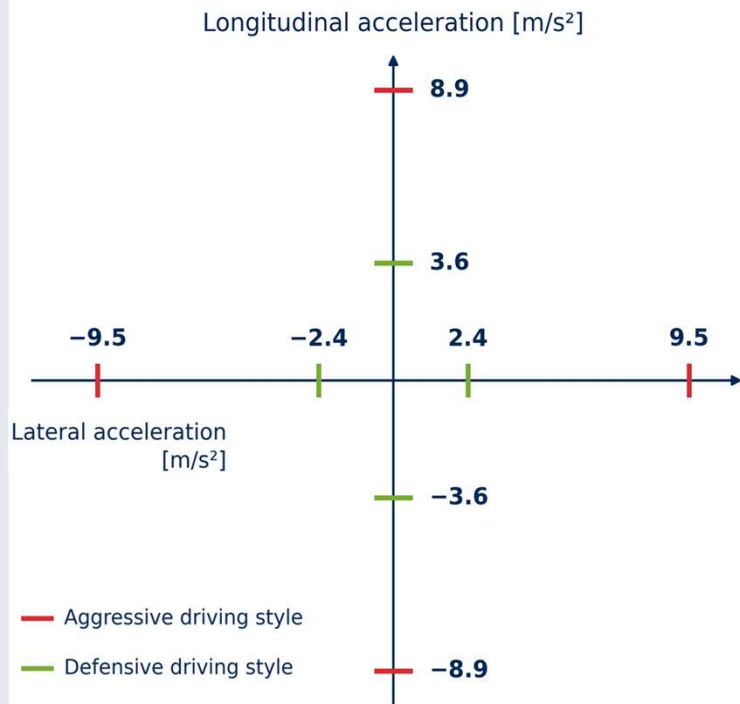
## Non-Driving-Related Task

Reading was used as NDRT because sustained visual fixation is particularly effective at inducing motion sickness according to the sensory conflict theory (Bubb, 2015).



# Study Design

## Driving Style



## Countermeasure: HUD



- Tablet mounted at HUD height
- Peripheral view of the driving scene during reading

## Countermeasure: LED



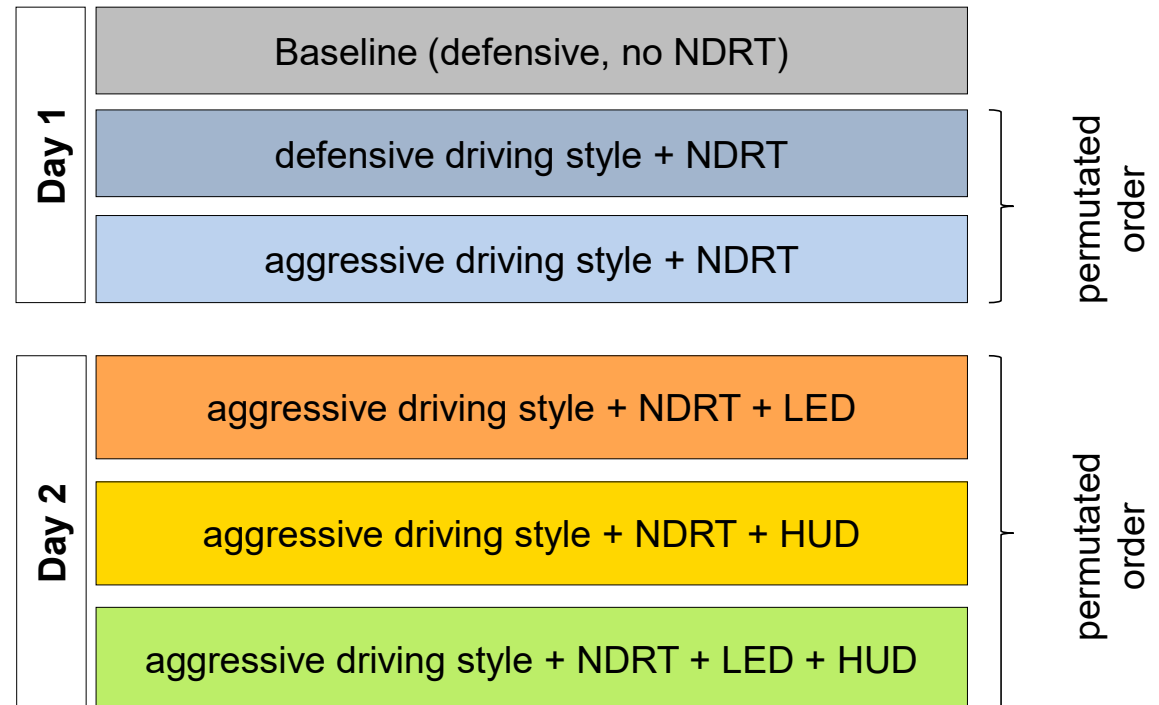
- Blue peripheral LED strips flashing at 0.2 Hz
- Left strip for left curves, right strip for right curves

## Countermeasure: HUD+LED



# Study Procedure

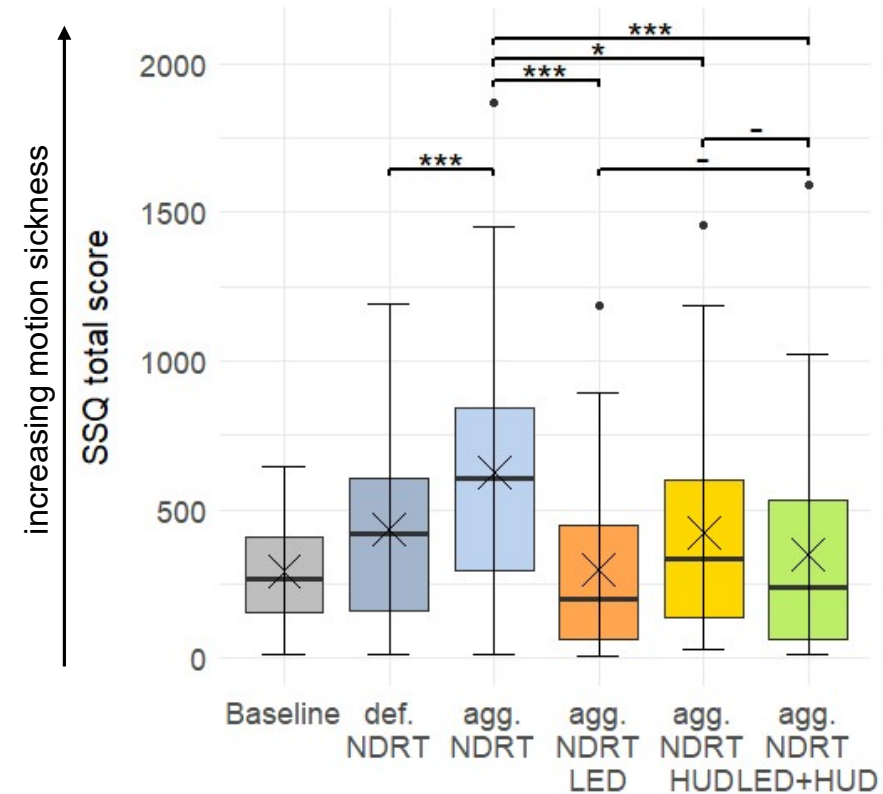
- Six 15-minute experimental drives were conducted across two days.
- Breaks between drives were adjusted to ensure symptoms had subsided before the next drive.
- After written informed consent was obtained, demographic data were collected.
- The SSQ was completed before and after each drive.
- SCL and HRV were recorded continuously during the drives.



28 of 31 participants were included: 15 women and 13 men aged between 20 and 63 years ( $M = 32.96$ ,  $SD = 13.07$ )  
Exclusions due to severe symptoms under defensive driving, or insufficient symptom induction under aggressive driving.

# Results - subjective Motion Sickness (SSQ)

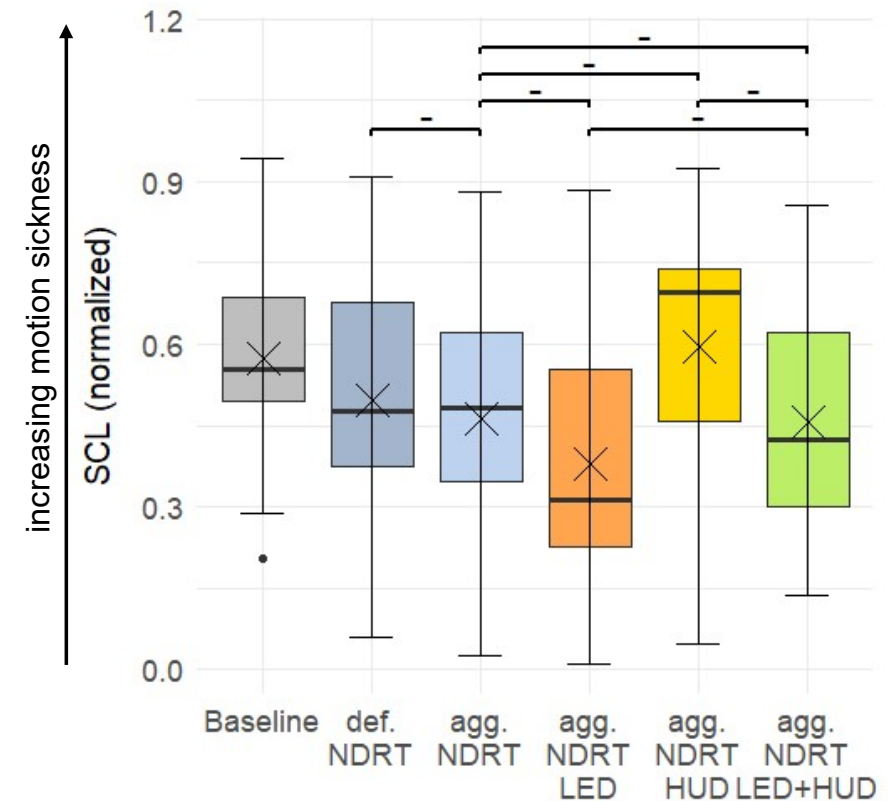
- **H1:** Aggressive driving increased SSQ scores compared with defensive driving (aggressive M = 623.0 vs. defensive M = 432.5,  $t(27) = 6.19$ ,  $p < .001$ ,  $d = 1.17$ ).
- **H2:** LED cues reduced SSQ scores compared with aggressive driving without countermeasures (LED M = 299.1 vs. no countermeasures M = 623.0,  $V = 31$ ,  $p < .001$ ,  $r = -.84$ ).
- **H3:** HUD-level positioning reduced SSQ scores compared with aggressive driving without countermeasures (HUD M = 422.0 vs. no countermeasures M = 623.0,  $V = 74$ ,  $p = .017$ ,  $r = -.64$ ).
- **H4:** The combined condition reduced subjective motion sickness compared with no countermeasure but provided no additional benefit over the individual measures (M = 350.0 for LED + HUD, M = 623.0 without countermeasures,  $V = 29$ ,  $p < .001$ ,  $r = -.85$ ).



Aggressive driving increased subjective motion sickness, while both visual countermeasures reduced it. Combining the countermeasures provided no additional benefit.

# Results - objective Motion Sickness (SCL)

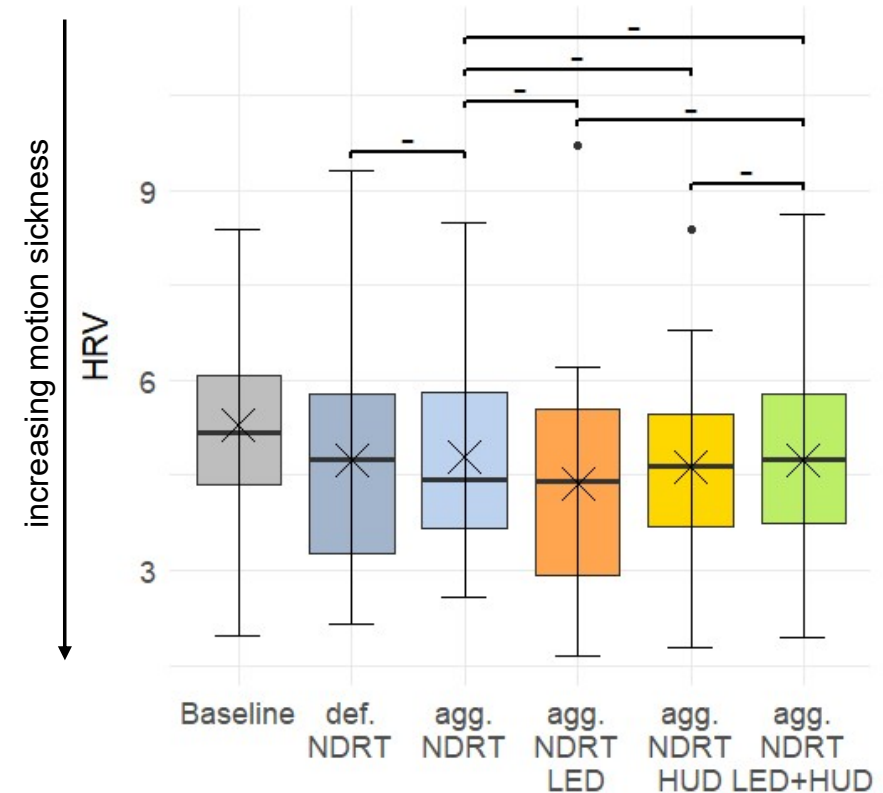
- **H1:** SCL did not differ significantly between defensive and aggressive driving (defensive M = 0.5 vs. aggressive M = 0.5).
- **H2:** SCL did not differ significantly between LED cues and aggressive driving without countermeasures (LED M = 0.4 vs. no countermeasures M = 0.5).
- **H3:** SCL did not differ significantly between HUD-level positioning and aggressive driving without countermeasures (HUD M = 0.6 vs. no countermeasures M = 0.5).
- **H4:** SCL did not differ significantly between the combination and LED cues alone (LED+HUD M = 0.5 vs. LED M = 0.4).
- SCL differed across countermeasure conditions ( $F(2.79, 75.32) = 5.11$ ,  $p = .004$ ,  $\eta^2 = .16$ ), but no comparison with the condition without countermeasures was significant after Bonferroni correction.



LED cues had the lowest mean SCL, but no statistically significant reduction compared with the condition without countermeasures was demonstrated. The SCL results therefore do not establish a clearly superior countermeasure.

# Results - objective Motion Sickness (HRV)

- **H1:** HRV did not differ significantly between defensive and aggressive driving (defensive M = 4.7 vs. aggressive M = 4.8).
- **H2:** HRV did not differ significantly between LED cues and aggressive driving without countermeasures (LED M = 4.4 vs. no countermeasures M = 4.8).
- **H3:** HRV did not differ significantly between HUD-level positioning and aggressive driving without countermeasures (HUD M = 4.6 vs. no countermeasures M = 4.8).
- **H4:** HRV did not differ significantly between the combination and either individual countermeasure (LED+HUD M = 4.7, LED M = 4.4, HUD M = 4.6).
- No overall effect of countermeasures on HRV was detected ( $\chi^2(3) = 2.91$ ,  $p = .405$ , Kendall's  $W = .03$ ).



Neither driving style nor the visual countermeasures significantly affected HRV. The HRV results do not establish a superior countermeasure.

# Discussion and Limitations

- **Aggressive driving** increased subjective symptoms relative to defensive driving, consistent with acceleration effects (O'Hanlon & McCauley, 1974, Karjanto et al., 2022).
- **LED cues that indicate curves** reduced symptoms, consistent with positive findings for peripheral visual information. (Karjanto et al., 2018).
- **HUD-level positioning of the NDRT** reduced symptoms, consistent with improved peripheral external visibility (Kuiper et al., 2018).
- **Combining both measures** provided no additional benefit. Visibility of the stationary laboratory surroundings may have introduced additional visual conflicts. Another possible explanation is that the LED cues were less noticeable against the simulated driving scene and may therefore have gone unnoticed in the combined condition. Both explanations require further investigation.
- **The absence of a significant physiological effect** is consistent with Mullen et al. (1998), who found no change in autonomic heart rate control during motion sickness under their experimental conditions.

## Limitations

- **Simulator setting** with N = 28 and 15-minute drives limits generalization to real vehicles and longer journeys.
- **SCL and HRV** are nonspecific stress indicators. Low symptom intensity may have limited their sensitivity.
- **Limited motion realism** and **different test days** may affect comparisons through day, order or carryover effects.

# Conclusion and Future Work

## Conclusion

- **Defensive driving and visual countermeasures** reduced subjective motion sickness during continuous reading.
- **LED-based curve cues** offer a promising approach to reduce motion sickness. Combining them with HUD-level positioning added no subjective benefit.
- **Subjective ratings** remain essential. SCL and HRV did not consistently reflect subjective effects.



## Future Work

- **Improve simulator realism** by shielding laboratory surroundings and refining motion cues. Counterbalance test order across days.
- **Validate the countermeasures** in real vehicles and during longer journeys, accounting for individual susceptibility.
- **Extend LED cues** to announce braking and acceleration.
- **Evaluate alternative LED positions** and reassess the combined condition with the NDRT display positioned to preserve a peripheral view of road traffic.

# REFERENCES

- Bär, M. (2014). *Vorausschauende Fahrwerkregelung zur Reduktion der auf die Insassen wirkenden Querschleunigung* [Dissertation, RWTH Aachen]. Forschungsgesellschaft Kraftfahrwesen mbH Aachen.
- Bubb, H. (2015). Gestaltung der Konditionssicherheit. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Hrsg.), *Automobilergonomie* (S. 471-523). Springer Vieweg. [https://doi.org/10.1007/978-3-8348-2297-0\\_8](https://doi.org/10.1007/978-3-8348-2297-0_8)
- Citroën. (2018, 5. Juli). *SEETROËN: Citroën bringt Brille gegen Reisekrankheit auf den Markt* [Pressemitteilung]. Stellantis Media. <https://www.media.stellantis.com/de-de/citroen/press/seetroen-citroen-bringt-brille-gegen-reisekrankheit-auf-den-markt>
- Diels, C., & Bos, J. E. (2015). User interface considerations to prevent self-driving carsickness. In *Adjunct proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (S. 14-19). Association for Computing Machinery. <https://doi.org/10.1145/2809730.2809754>
- Dikmen, M. (2018, 27. Dezember). *Vibrierendes Stirnband hilft gegen Schwindel & die Reisekrankheit*. TURNON. <https://www.turn-on.de/smart-living/news/vibrierendes-stirnband-hilft-gegen-schwindel-die-reisekrankheit-449402>
- Griffin, M. J., & Newman, M. M. (2004). Visual field effects on motion sickness in cars. *Aviation, Space, and Environmental Medicine*, 75(9), 739-748.
- Karjanto, J., Md. Yusof, N., Wang, C., Terken, J., Delbressine, F., & Rauterberg, M. (2018). The effect of peripheral visual feedforward system in enhancing situation awareness and mitigating motion sickness in fully automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 58, 678-692. <https://doi.org/10.1016/j.trf.2018.06.046>
- Karjanto, J., Wils, H., Md. Yusof, N., Terken, J., Delbressine, F., & Rauterberg, M. (2022). Measuring the perception of comfort in acceleration variation using electrocardiogram and self-rating measurement for the passengers of the automated vehicle. *Journal of Engineering Science and Technology*, 17(1), 180-196. [https://jestec.taylors.edu.my/Vol%2017%20Issue%201%20February%20%202022/17\\_1\\_14.pdf](https://jestec.taylors.edu.my/Vol%2017%20Issue%201%20February%20%202022/17_1_14.pdf)
- Kato, K., & Kitazaki, S. (2008). *Improvement of ease of viewing images on an in-vehicle display and reduction of carsickness* (SAE Technical Paper No. 2008-01-0565). SAE International. <https://doi.org/10.4271/2008-01-0565>
- Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3(3), 203-220. [https://doi.org/10.1207/s15327108ijap0303\\_3](https://doi.org/10.1207/s15327108ijap0303_3)

# REFERENCES

- Kuiper, O. X., Bos, J. E., & Diels, C. (2018). Looking forward: In-vehicle auxiliary display positioning affects carsickness. *Applied Ergonomics*, 68, 169-175. <https://doi.org/10.1016/j.apergo.2017.11.002>
- Md. Yusof, N., Karjanto, J., Kapoor, S., Terken, J., Delbressine, F., & Rauterberg, M. (2017). Experimental setup of motion sickness and situation awareness in automated vehicle riding experience. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (S. 104-109). Association for Computing Machinery. <https://doi.org/10.1145/3131726.3131761>
- Mullen, T. J., Berger, R. D., Oman, C. M., & Cohen, R. J. (1998). Human heart rate variability relation is unchanged during motion sickness. *Journal of Vestibular Research*, 8(1), 95-105. <https://doi.org/10.3233/VES-1998-8113>
- O'Hanlon, J. F., & McCauley, M. E. (1974). Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. *Aerospace Medicine*, 45(4), 366-369.
- Sauter, M. (2018, 26. November). *AntVR: Stirnband soll Motion Sickness in VR verhindern*. Golem.de. <https://www.golem.de/news/antvr-stirnband-soll-motion-sickness-in-vr-verhindern-1811-137901.html>
- Vogel, H., Kohlhaas, R., & von Baumgarten, R. J. (1982). Dependence of motion sickness in automobiles on the direction of linear acceleration. *European Journal of Applied Physiology and Occupational Physiology*, 48(3), 399-405. <https://doi.org/10.1007/BF00430230>
- Xie, W., He, D., & Wu, G. (2023). Inducers of motion sickness in vehicles: A systematic review of experimental evidence and meta-analysis. *Transportation Research Part F: Traffic Psychology and Behaviour*, 99, 167-188. <https://doi.org/10.1016/j.trf.2023.10.013>

# THANK YOU!



**M.Sc. Sarah Schwindt-Drews**

Research Associate

[sarah\\_selina.schwindt@tu-darmstadt.de](mailto:sarah_selina.schwindt@tu-darmstadt.de)

**Technical University of Darmstadt**

**Institute of Automotive Engineering | Research Group Human Factors & Ergonomics**

Otto-Berndt-Straße 2, 64287 Darmstadt, Germany

[www.fzd.tu-darmstadt.de](http://www.fzd.tu-darmstadt.de)