Hi-Drive

TOPICAL WEBINAR #6

User Comfort & Motion Sickness: Hi-Drive Results

WELCOME !

Co-funded by the European Union under Horizon 2020 programme Grant Agreement No. 101006664

Supported by the European Council for Automotive R&D EUCAR

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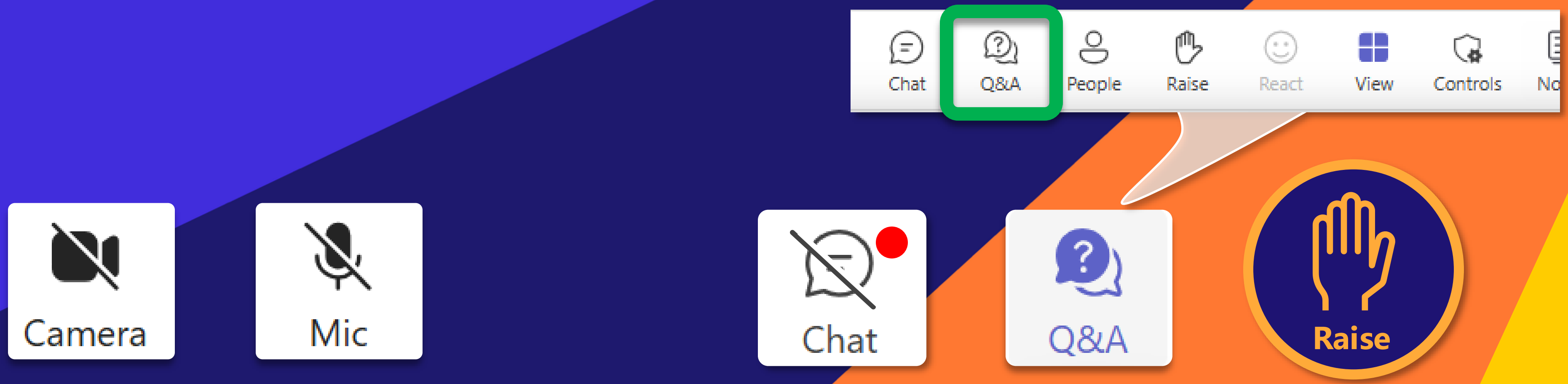

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Introduction: Addressing Challenges Towards the Deployment of Higher Automation

Professor Natasha Merat OBE | University of Leeds

Project Facts

€60 MILLION BUDGET

€30 MILLION FUNDING

48 MONTHS from July 2021 to November 2025

53 PARTNERS among them OEMs, automotive suppliers, research institutes, associations, traffic engineering, deployment organisations and mobility clubs

13 COUNTRIES Belgium, France, Finland, Germany, Greece, Hungary, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom

Supported by the European Council for Automotive R&D

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006664

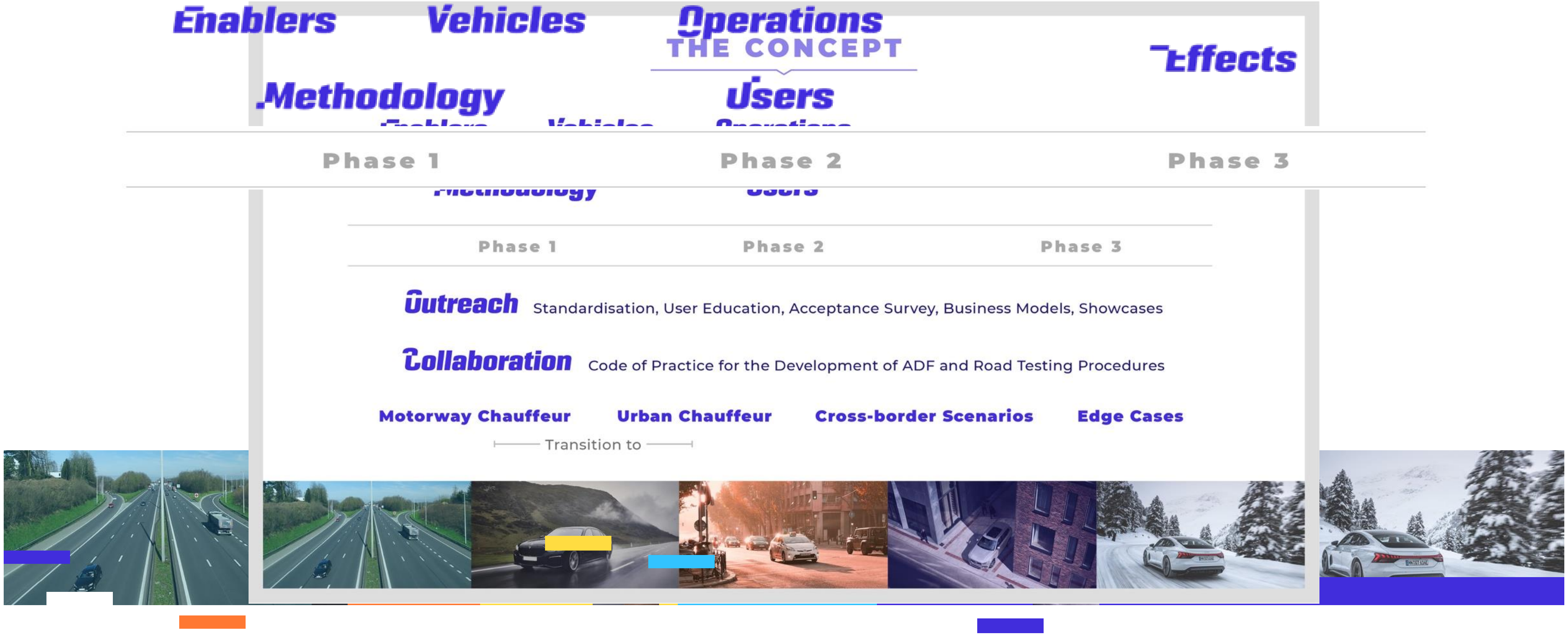
Partners

Hi-Drive
Designing Automation

PUSH TOWARDS HIGHER AUTOMATION

- Robust and reliable automated driving
- Extended and defragmented ODDs
- Interoperability across countries and brands

The Concept


Enablers
Vehicles
Operations
THE CONCEPT
Effects
Methodology
Users
Phase 1
Phase 2
Phase 3
Phase 1
Phase 2
Phase 3
Outreach
Standardisation, User Education, Acceptance Survey, Business Models, Showcases
Collaboration
Code of Practice for the Development of ADF and Road Testing Procedures
Motorway Chauffeur
Urban Chauffeur
Cross-border Scenarios
Edge Cases
Transition to

Hi-Drive

Develop a firm understanding of the **user** when interacting with automated vehicles.

- Acceptance
- Awareness & Expectations
- **User comfort**
- User monitoring & HMIs
- Other road users

Empirical User Studies and Tools

MEANS OF DATA COLLECTION

- Global surveys
- Questionnaires
- Human-in-the-loop simulators
- Test track studies
- Wizard-of-Oz vehicles

Today

Nov 13th 15:00 CET

Stay updated: company/hi-drive

Poll Questions!

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TOPICAL WEBINAR #5

Cyriel Diels | Royal College of Art

Deputy Director, Intelligent Mobility Design Centre (IMDC)

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Motivation

Dr. Stefan Wolter | Ford

Motivation

- Further automation shifts the role of the driver to the role of the passenger.
- As a passenger, people are allowed to engage in **non-driving related tasks** (NDRTs).
  - Increases likelihood of **carsickness**.
- Beyond carsickness itself, automated vehicles' acceptance is largely due to the comfort experienced by its riders.
  - Reduction of carsickness and improvement of comfort as a goal.
- **Measurement** of carsickness and comfort in an efficient and replicable manner is key.
  - **Methodological questions** on research venue, ratings, physiological measures etc.
- When drivers must take over at the end of an Operational Design Domain, it’s crucial to understand how carsickness impacts manual driving and **take-over performance**.
  - **Extension of the Operational Design Domain.**
- High Level RQs:
  - **How can driving with Automated Driving be made a comfortable experience?**
  - **What is the impact of carsickness on the user?**

Research Questions & Partners

Comfort and Human-Like Driving

- U1-2.1 Which guidelines for automated driving behaviour can be derived from manual driving to make driving with AD more comfortable?
- U1-2.2 What is the impact of driving style of AD on driving comfort?
- U1-2.3 What is the impact of driving comfort on acceptance, trust and other related concept?

Car Sickness

- U1-2.4 With which methodological approach can car sickness be investigated in an efficient and replicable way?
- U1-2.5 What is the prevalence of car sickness in the European population?
- U1-2.6 How can the occurence of car sickness be predicted?
- U1-2.7 How can car sickness be reduced?
- U1-2.8 How do NDRTs influence the incidence of car sickness?
- U1-2.9 How does car sickness affect manual driving and take-over performance?

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Prevalence and Modulating Factors of Carsickness in the European Population

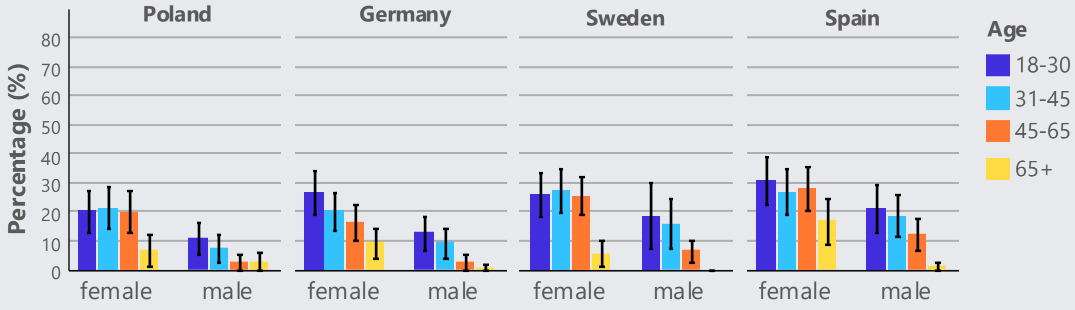
Myriam Metzulat | WIVW

What is the prevalence of carsickness in the European population?

Online-survey with N = 3.999 participants

- **30 %** of participants reported to have already experienced **carsickness** at least once **as adult**

Percentage of people who experience carsickness sometimes to always as a front car passenger



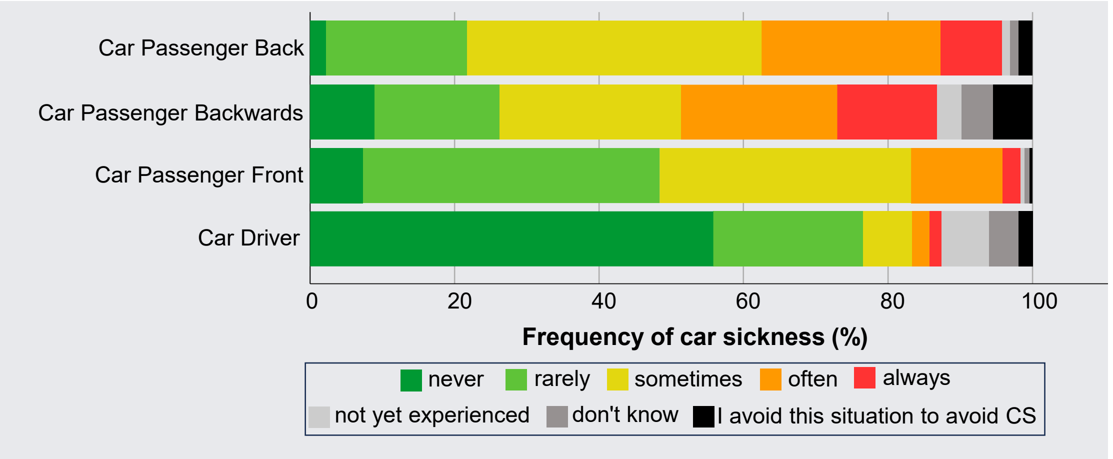
- **15%** experience carsickness **sometimes to always** on the front seat
- gender, age, frequency of being a passenger and country predict the frequency of carsickness experience significantly

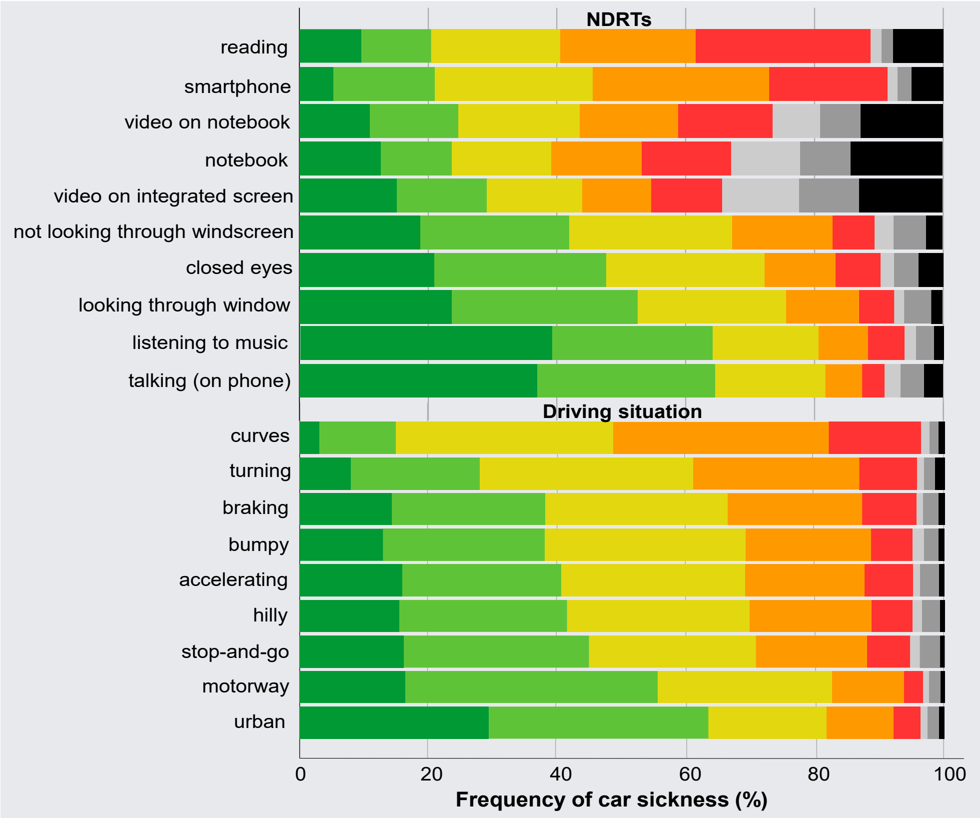
Prediction of frequency of carsickness as front passenger (from never to always)

Predictor	Category	Odds Ratio	Lower 95% CI	Upper 95% CI
Gender	*Male (Ref)*	*1,00*	-	-
	Female	2.76	2.36	3.24
Age	*65+ (Ref)*	*1,00*	-	-
	46 - 65	2.87	2.22	3.76
	31 - 45	4.38	3.39	5.71
	18 - 30	5.08	3.92	6.64
Frequency of being a passenger	*Never (Ref)*	*1,00*	-	-
	1-2 times (year)	1.76	1.11	2.82
	Few times (year)	2.02	1.38	3.03
	1-2 times (Month)	2.67	1.83	4.00
	1-2 times week	2.74	1.90	4.06
	almost every day	2.25	1.48	3.47
Country	*Poland (Ref)*	*1,00*	-	-
	Germany	1.08	0.86	1.35
	Sweden	1.70	1.37	2.11
	Spain	2.36	1.91	2.92

Source: Metzulat, M., Metz, B., Edelmann, A., Neukum, A., & Kunde, W. (2025). Sick of being driven?–Prevalence and modulating factors of carsickness in the European population in context of automated driving. Appl Ergon, 129, 104590.

Which factors influence the occurrence of carsickness?





- **Non-driving related task,** especially those including visual engagement increase carsickness occurrence.
- Driving situation with **strong (lateral) accelerations** induce carsickness most often.
- **Seat direction** and **position** play a crucial role, with backwards and back seats being most provocative.

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Assessment / Testing Environments

Dr. Georgios Papaioannou | TU Delft

Efficient Motion Comfort Assessment - On-Road Scenario Recreation

What if we could squeeze any on-road driving scenario into a small parking lot?

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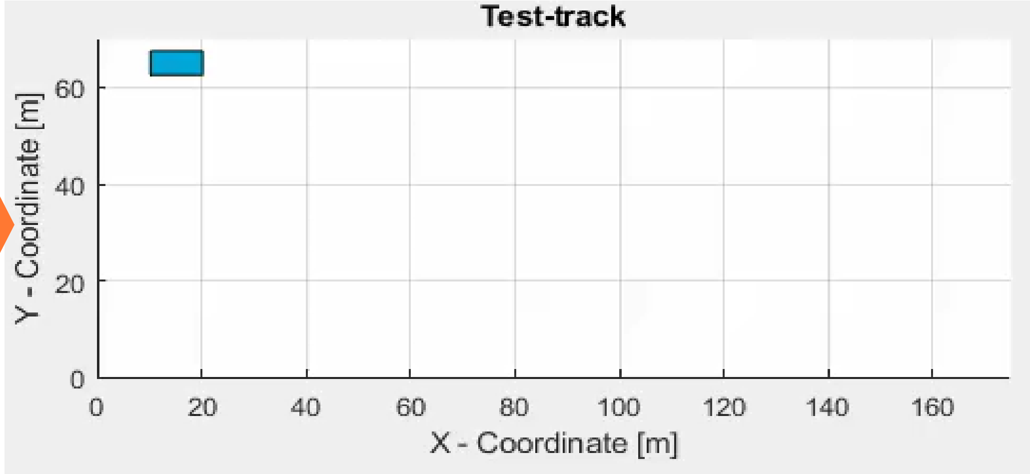
Developed a motion planning algorithm for a vehicle with automated capabilities to replicate the on-road drive



- **47 participants were subjected in both conditions**

A joint study conducted by:

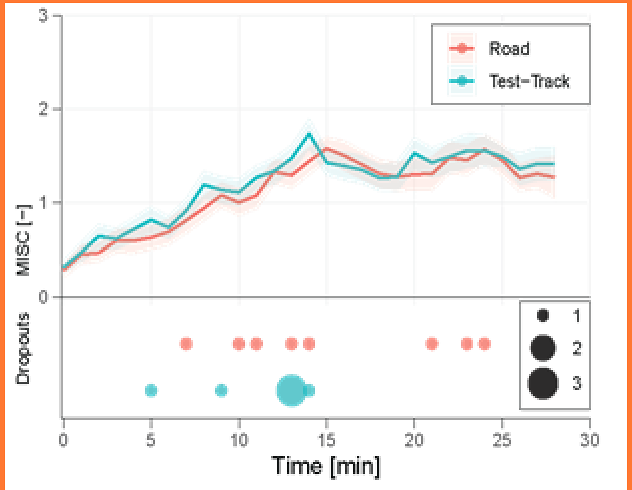
VOLKSWAGEN AKTIENGESELLSCHAFT

TUDelft

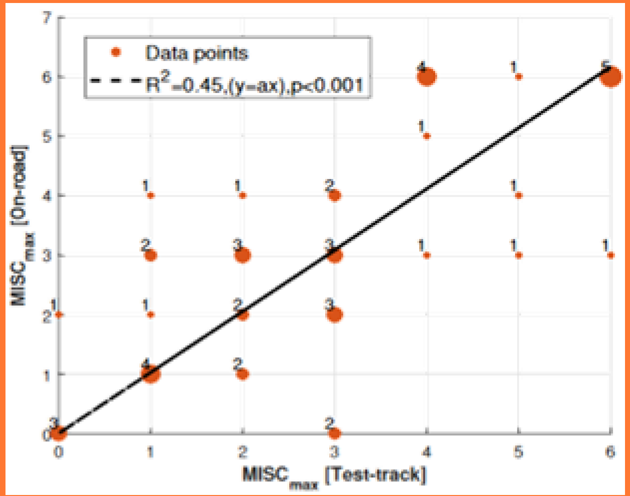
WIVW

Source: Harmankaya, H., Brietzke, A., Xuan, R. P., Shyrokau, B., Happee, R., & Papaioannou, G. (2024). Efficient Motion Sickness Assessment: Recreation of On-Road Driving on a Compact Test Track. IEEE ITS 2025

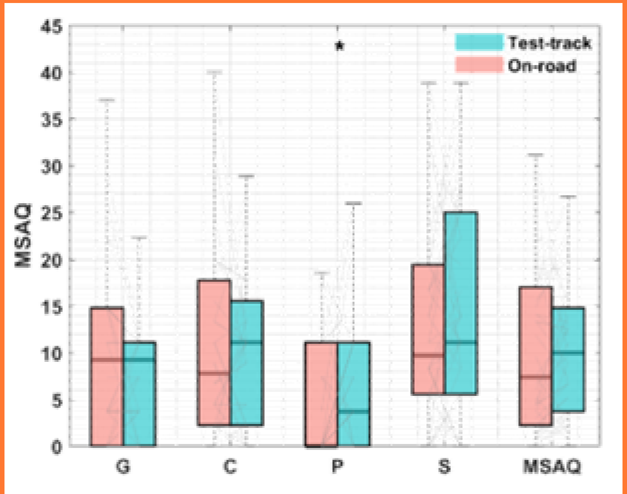
Efficient Motion Comfort Assessment
Recreation of Motion Sickness on Road Exposure



- Average motion sickness **exposure was highly replicated**



- Individual motion sickness **exposure was also replicated**



- Symptoms were not significantly different between conditions, **except the peripheral.**

A joint study conducted by: VOLKSWAGEN AKTIENGESELLSCHAFT, Audi, TU Delft, WIVW

Source: Harmankaya, H., Brietzke, A., Xuan, R. P., Shyrokau, B., Happee, R., & Papaioannou, G. (2024). Efficient Motion Sickness Assessment: Recreation of On-Road Driving on a Compact Test Track. IEEE ITS 2025

TOPICAL WEBINAR #6

Motion Sickness in AVs

Rebecca Pham Xuan | Volkswagen

Observing Passenger Behaviour and Motion Sickness Development in AVs

Research Questions

What do passengers engage in during a car ride?

Does individual susceptibility to motion sickness influence their choice of activities?

Influence of self-selected NDRTs on motion sickness occurrence?

Methods

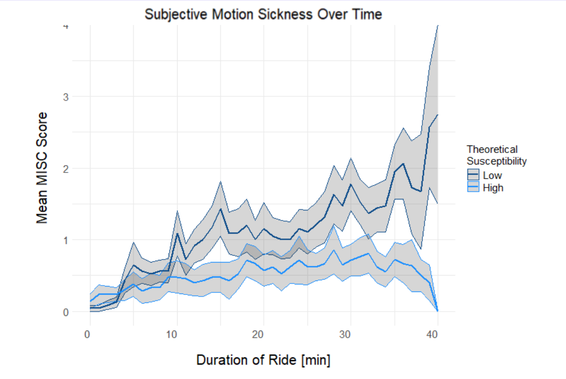
Sample Size n = 44
♂ = 22 ♀ = 22

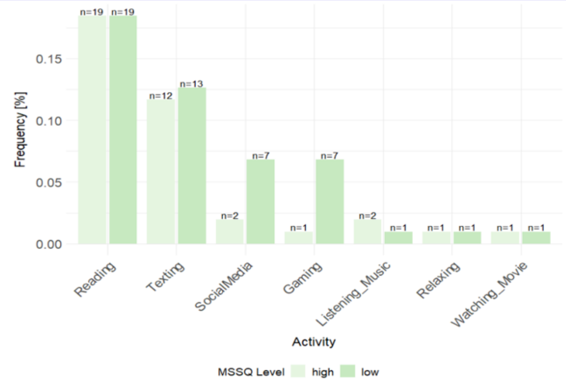
Age M = 41 years (+-16.94)

Susceptibility 21 low 23 high

Participants choose preferred NDRTs and switch between tasks at any time

Results





Conclusion

Method

- Time to carsickness in average 6.9 min (SD = 5.82)
  Trips terminated early
- Self-chosen NDRTs can provoke carsickness
  -> Study design is robust to capture carsickness

Activities

- Participants chose NDRTs (ie on Smartphones) regardless of their susceptibility
- Reading (book or smartphone/ tablet) was the most frequent activity

Participants like to engage in NDRTs regardless of their susceptibility — this highlights the need to focus on the development of countermeasures!

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Non-Driving Related Tasks

Dr. Stefan Wolter | Ford

Impact of different non-driving related tasks

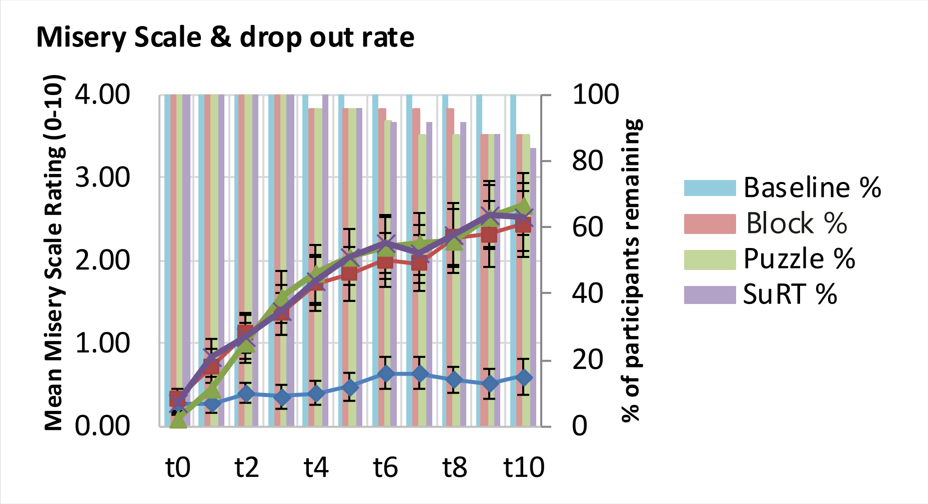
Approach

- On-Road Test with subjects on passenger seat.
- Comparison of task operation (building block task, Puzzle, SuRT) versus outside view (baseline).

Results

- Study shows a successful inducement of carsickness on a standardized on-road test track using several tasks.
- There is no significant difference regarding the tasks on the carsickness scales.
- Difference between tasks and baseline is reflected in physiological measures, also in workload measures.

The **different aspects** of the task (as e.g. physical involvement) did not contribute to a different level of carsickness.



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TOPICAL WEBINAR #1

Psychological Comfort in Automated Driving

Dr. Chen Peng

Assistant Professor | Loughborough University)
Visiting Researcher | University of Leeds)

Why do we look at comfort?

Comfort is crucial for acceptance of Automated Vehicles (AVs)

Potential concerns for user comfort in SAE Level 4+ AVs

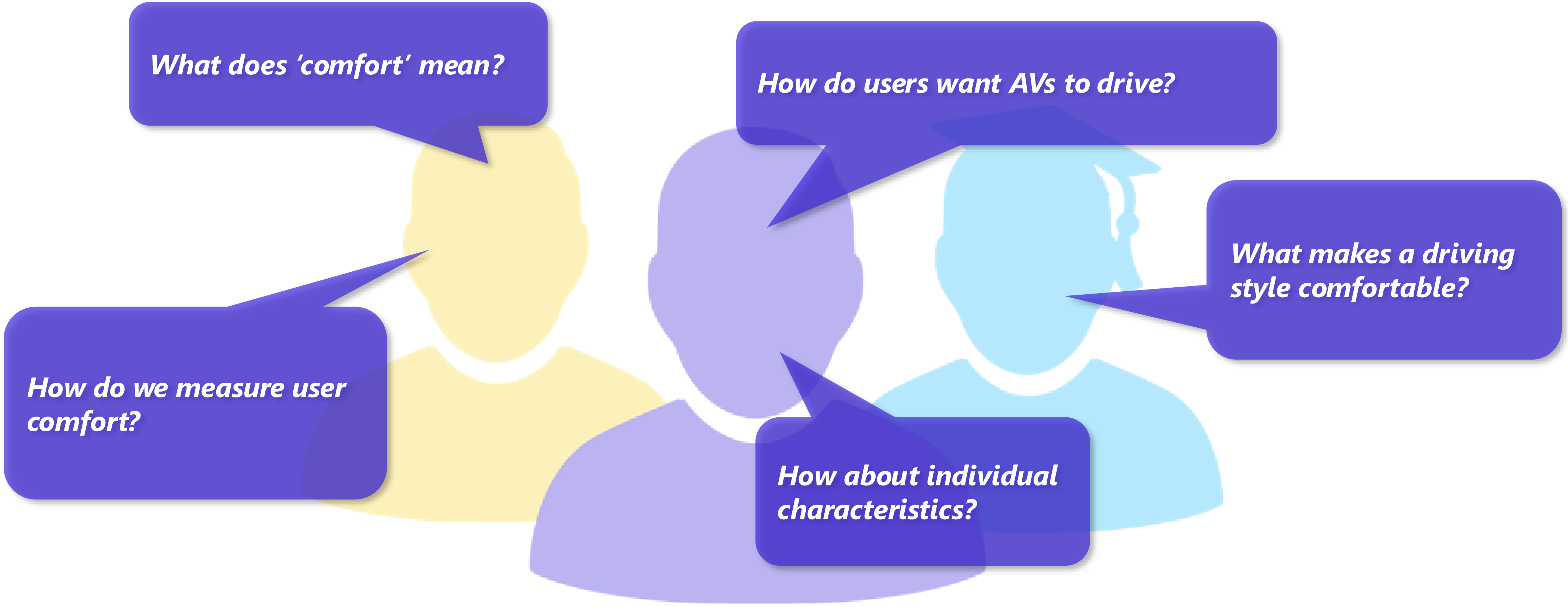
- Role change from driver to passenger
  - “Being driven” by AVs
  - Unable to predict AV’s manoeuvres
- Engagement in non-driving-related tasks (NDRTs)
  - Benefits of Level 4+ AVs
  - Carsickness

Roads can be challenging for AVs

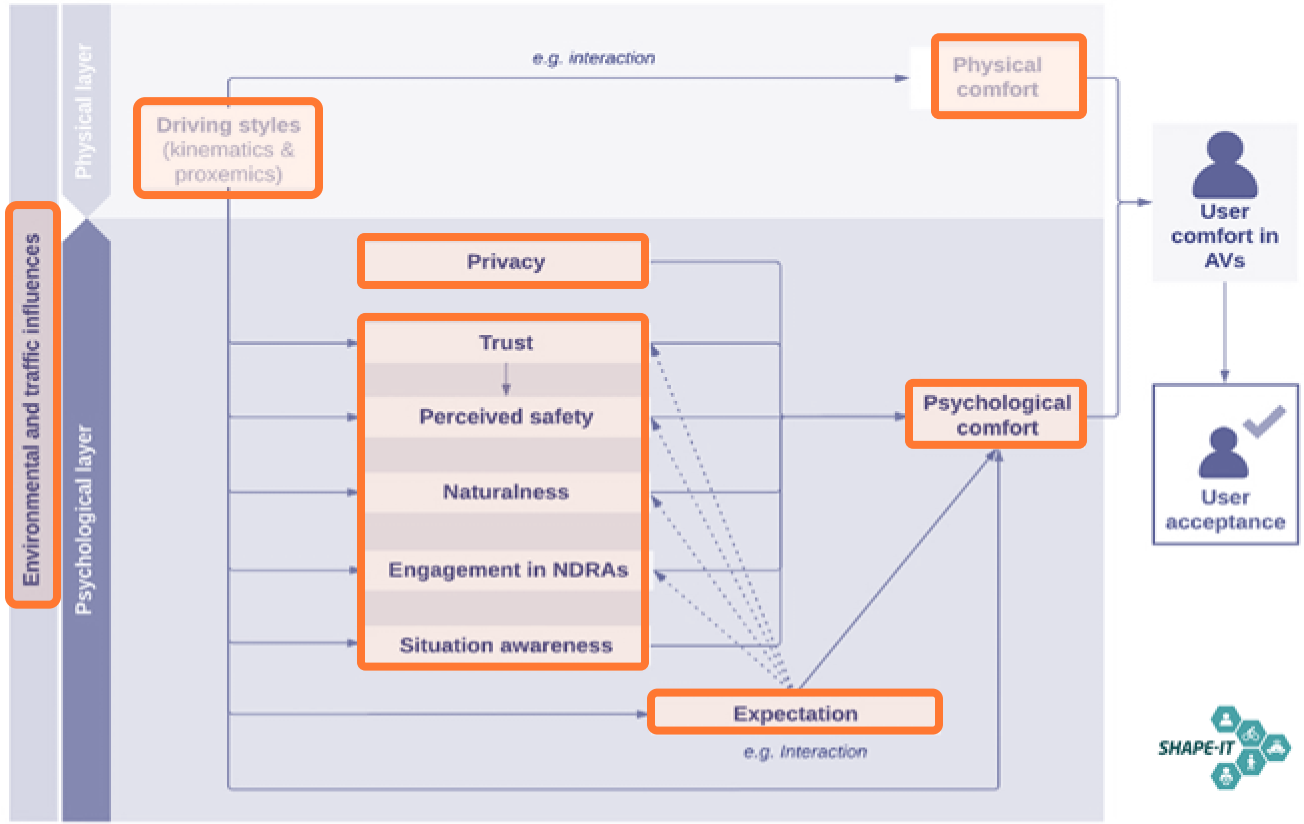
- How does it speed up, slow down, take a turn, and stop for traffic lights…?
- Driving style: kinematics, proxemics, how the vehicle negotiates road

Enhancing user comfort via AV’s driving styles

What remains unclear?



What is comfort? A conceptual framework



Transportation Research Interdisciplinary Perspectives
Volume 24, March 2024, 101070

Conceptualising user comfort in automated driving: Findings from an expert group workshop

Chen Peng, Stefanie Carlowitz, Ruth Madigan, Claus Marberger, John D. Lee, Josef Krems, Matthias Beggiato, Richard Romano, Chongfeng Wei, Ellie Wooldridge, Riender Happee, Marjan Hagenzieker, Natasha Merat

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https://doi.org/10.1016/j.trip.2024.101070

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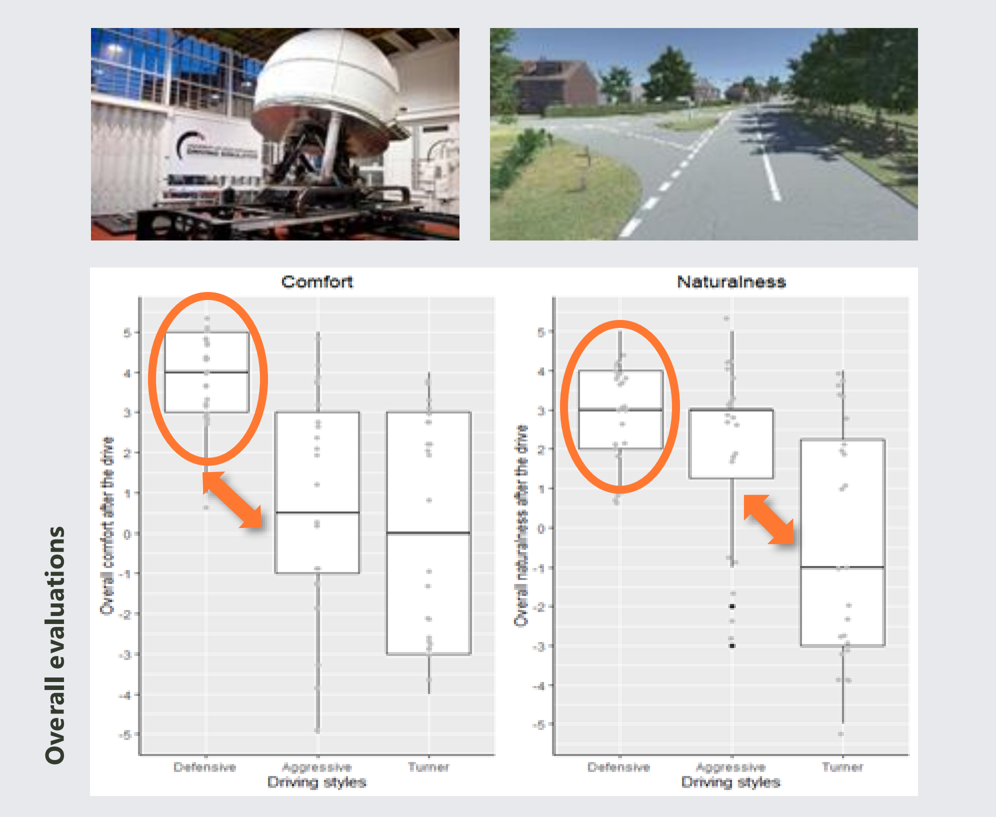
Abstract

The driving style of an automated vehicle (AV) needs to be comfortable to encourage the broad acceptance and use of this newly emerging transport mode. However, current research provides limited knowledge about what influences comfort … described, and how it is measured. This knowledge is espec… linked to the AV's driving styles. This paper present… with nine experts, all with hands-on experie… …h in this context. Using onli…

Improving comfort: Overall driving styles



Overall AV driving styles

- Users would like AVs to drive like a **human**, rather than a machine (Comfort)
- Challenging **road environments** demand more careful manoeuvres
- A natural driving style is **not** necessarily perceived as comfortable, especially by **high sensation seekers**

SHAPE-IT

HUMAN DRIVE

Source:
Peng, C., Merat, N., Romano, R., Hajiseyedjavadi, F., Paschalidis, E., Wei, C., Radhakrishnan, V., Solernou, A., Forster, D., & Boer, E. (2022).
Drivers' Evaluation of Different Automated Driving Styles: Is It both Comfortable and Natural?. *Human Factors*.

Improving comfort: Longitudinal and lateral acceleration

Longitudinal deceleration

- **Lower** deceleration rates (-1.5 m/s^2 and -2.5 m/s^2) are preferred, while **higher** deceleration (-3.5 m/s^2) is only rated as quite comfortable in certain situations, such as sudden pedestrian appearances
- At **blind intersections**, the deceleration rate impacts comfort more than the presence of other vehicles

Lateral acceleration

- **2 m/s^2** was often rated “too slow”, especially in **L1 driving** or in **L4 without NDRAs**, while **4 m/s^2** was frequently rated “too fast”
- **3 m/s^2** was a more **balanced option**
- **Gentler curves** led to a preference for **lower** accelerations
- **NDRA engagement** and **L4 automation** both led to fewer “too slow” ratings for lower accelerations

Sources: Carlowitz, S., Madigan, R., Goodridge, C., Marberger, C., Alt, P., Schulz, M., Osswalt, S., Engeln, A., & Merat, N.
Balancing Comfort: Deceleration Rate and Environmental Impact at Crosswalks and Intersections in Automated Driving. Under Review
Peng, C., Carlowitz, S., Madigan, R., Marberger, C., Schulz, M., Osswalt, S., Schultz, A., & Merat, N.
Optimal Lateral Acceleration for Different Levels of Automated Driving: A Test Track Study of Passenger Evaluation for Curve Negotiation. Under Review

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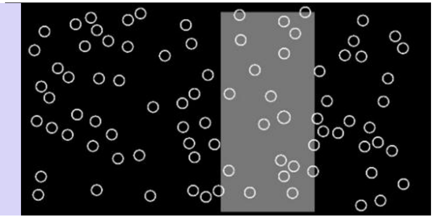
Effect of Carsickness on Cognitive Performance as well as Driving and Takeover Performance

Myriam Metzulat | WIVW

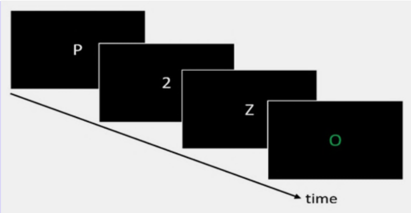
How does carsickness affect cognitive performance relevant to driving?

- Previous studies on other types of motion sickness show **performance decreases due to motion sickness** in different areas, such as reaction times, visual performance, memory task etc. (Metzulat et al. 2025)
- On-road study with **N = 20 participants**, who performed four **tasks** that represent different requirements for driving **with and without carsickness** (before and after sickness inducing ride with NDRT engagement)

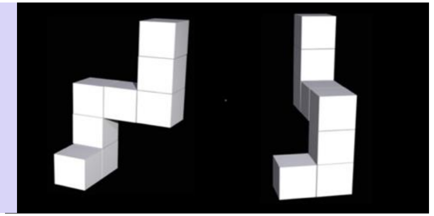
Visual Search



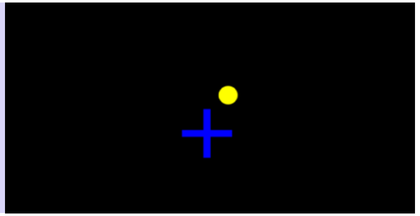
Simple Reaction Task



Mental Rotation



Hand-eye-coordination



With increasing carsickness…

… performance in visual search did not change

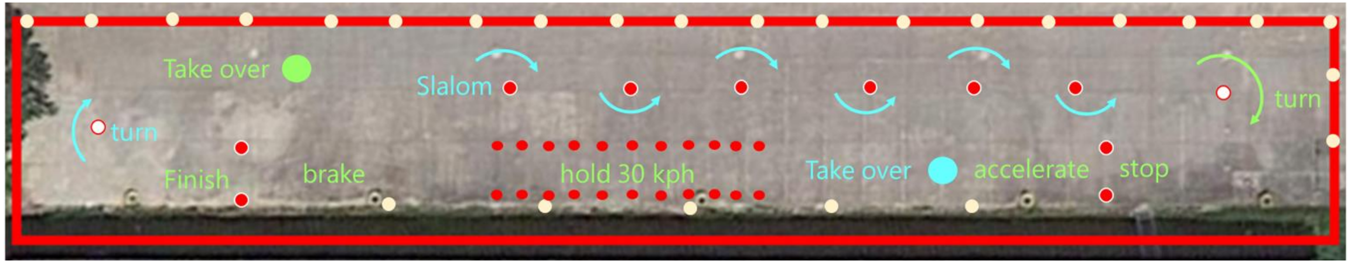
… **reaction times** to sudden stimuli **increased** ($p = .002$)

… **visuo-spatial ability** measured with mental rotation task **tended to decrease** ($p = .059$)

… **hand-eye-coordination deteriorated** ($p < .001$)

Source: Metzulat, M., Metz, B., Landau, A., Neukum, A., & Kunde, W. (2025).
Too sick to take over?– Impact of car sickness on cognitive performance related to driving in the context of automated driving. *Transportation research part F: traffic psychology and behaviour*, *109*, 480-500.

How does carsickness affect driving and takeover performance?



- Test-track study with Wizard-of-Oz vehicle and N = 33 participants
- 4 simulated automated rides with 4 takeovers and 4 subsequent driving tasks:
  - Slalom with free speed, slalom with 25 km/h, target braking, emergency braking
- Two within-subject conditions on different days: carsickness vs. baseline (no carsickness)

Source: Metzulat, M., Metz, B., Landau, A., Edelmann, A., Neukum, A., & Kunde, W. (2025).
Still fit to drive? Effect of car sickness on takeover and driving performance–A test-track study. Transportation research part F: traffic psychology and behaviour, 114, 1223-1240.

Subjective Experience of driving with carsickness

- The **subjective fitness to drive decreased** as the subjective carsickness level increased. [*rmCorr*elation(2455) = .601, p < .001]
- 73% felt **impaired** and 70% stated that they had **adapted their driving** behavior due to carsickness. (lower speeds, defensive)
- The subjective **criticality of takeover** was assessed significantly higher with carsickness than without [F(1, 30)= 26.991, p < .001], as was the **mental workload** (NASA-TLX; [F(1, 30) = 29.361, p < .001]).

How does carsickness affect driving and takeover performance?

Objective Driving and Takeover Performance

- There is a tendency for the **takeover time** to be slightly slower with carsickness (M = 2.61s ; SD = 0.70s) than without car sickness (p = .074).
- The distance to the target line in target braking, reactions time in emergency braking and number of hit pylons in both slaloms did not differ significantly between the carsickness and baseline conditions.

- **Variation** in speed and maximum lateral accelerations were significantly **higher with carsickness**
- Only when they can choose speed, participants **drove significantly faster and more dynamic** with carsickness.

	Condition			Slalom			Condition*Slalom		
Measure	*F*	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*
Mean speed	3.838	(1,26)	.061	57.912	(1,26)	**<.001**	6.931	(1,26)	**.014**
Variation in speed (*SD*)	5.577	(1,26)	**.026**	22.487	(1,26)	**<.001**	0.044	(1,26)	.835
Max lat. Acceleration (*M*)	2.825	(1,28)	.104	42.361	(1,28)	**<.001**	7.857	(1,28)	**.009**
Variation lat. Acceleration (*SD*)	9.471	(1,28)	**.005**	20.590	(1,28)	**<.001**	0.962	(1,28)	.335

Conclusion

- Impairments in cognitive performance were not reflected in impaired driving performance.
- Subjectively, carsickness did impair driving and made it more demanding, but objectively no performance decreases found.
- Regarding driving style, subjective experience contradicts the objective finding of a more dynamic driving style.

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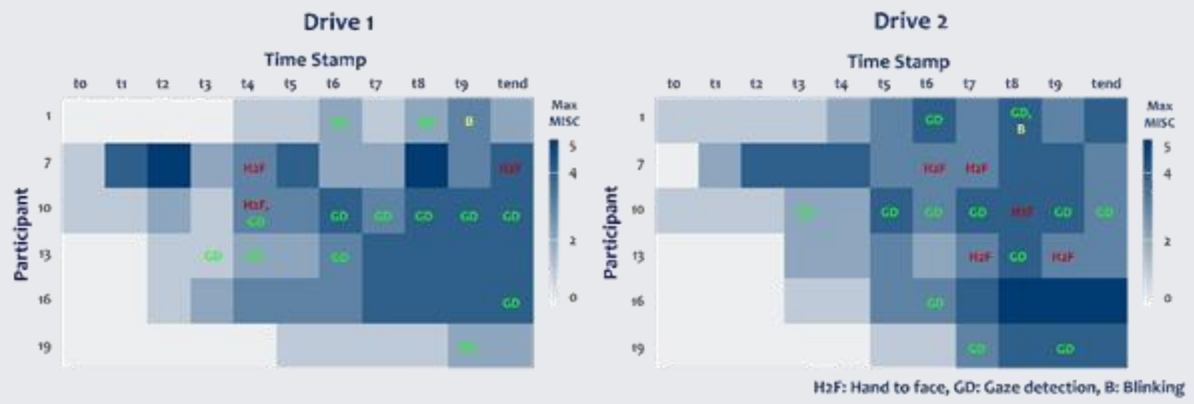
User Monitoring

Dr. Stefan Wolter | Ford

Camera-based measurement

Camera based measures might provide an unobtrusive way to assess the level of carsickness.

- 1st **Study** on proving ground was used to exploratively extract promising video-based markers indicating carsickness.
- 2nd **Study** on public road was used to train a classification model based on camera and physiological data.

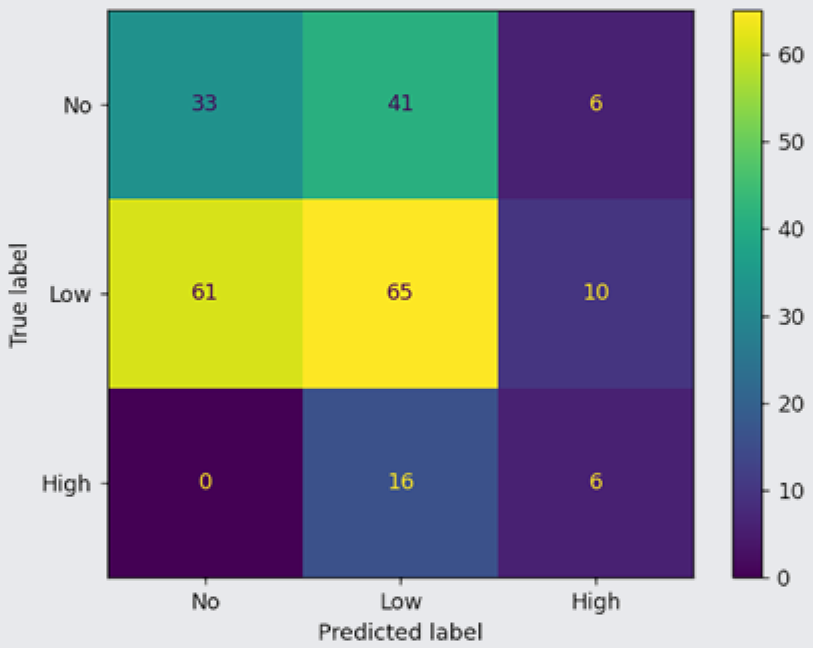


Extracted markers:
Gaze Detection,
Blinking, Hand to Face/Neck

Classification model

- Classification model based on data from 2nd study was deployed on data from 3rd study on public roads.
- An average weighted **F1-score of .44** was achieved using the classification model.
  - Due to the small and imbalanced nature of the dataset, i.e. lack of datapoints representing MISC > 3, there is an inability of the model to distinguish between Low and High True labels.
  - Categorical predictor of timestamp as drive duration representing exposure time is not considered.

Tested markers show a high potential for measuring carsickness in an unobtrusive way.



Confusion matrix for Misery Scale (MISC) prediction;
No (MISC: 0), Low (MISC: 1-3) and High (MISC: > 3)

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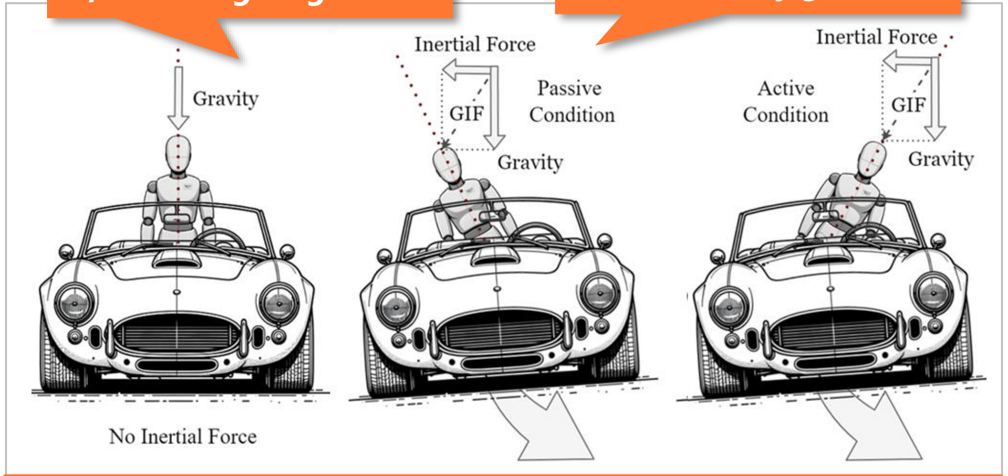
Countermeasures

Dr. Georgios Papaioannou | TU Delft

Seat comfort & Carsickness
Explore smart seat suspension designs with negative stiffness elements

2/3 Passengers get sick!

Drivers rarely get sick!



What if we developed a **serious game in VR** to **train occupants to such posture while being driven** self-enhance motion comfort?

2 x experiments with ~20 participants each

Developed **MATE-AV** *(Motion anticipation training environment for AVs)* in VR with the objective to **train occupants to adopt comfort-oriented postural control**

A joint study conducted by: TU Delft VOLKSWAGEN AKTIENGESELLSCHAFT

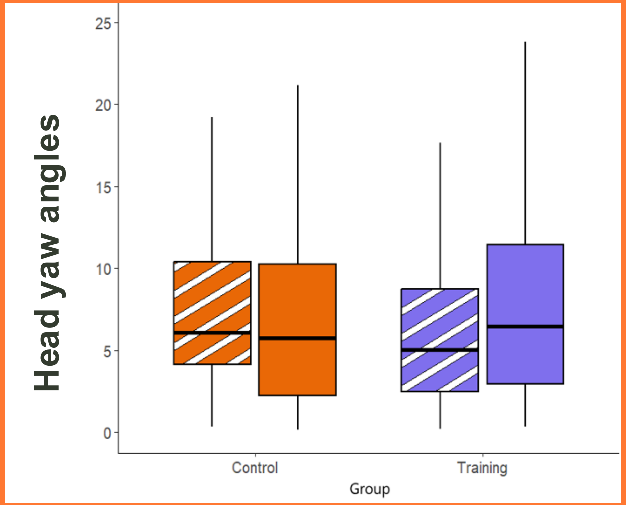
Floris Pauwels
MSc Student

Charlotte Croucher
Researcher

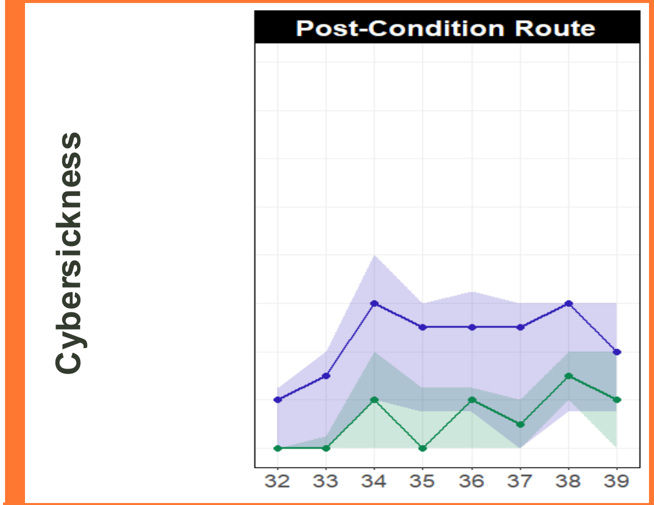
Source: Croucher, C., Pauwels, F., Xuan, R. P., Brietzke, A., Marchal-Crespo, L., & Papaioannou, G. (2025). MATE-AV: A VR-based training environment to teach occupants' how to adopt a comfort-oriented postural control in a vehicle.

Immersive technologies -
How to exploit their use towards enhancing motion comfort?

- Participants moved **their trunk roll more after training session!**



- Participants moved **their head yaw more** after training session!



- Misalignment of trunk and the trajectory **increases the odds of higher cybersickness by 14%.**

A joint study conducted by: TU Delft VOLKSWAGEN AKTIENGESELLSCHAFT

Floris Pauwels
MSc Student

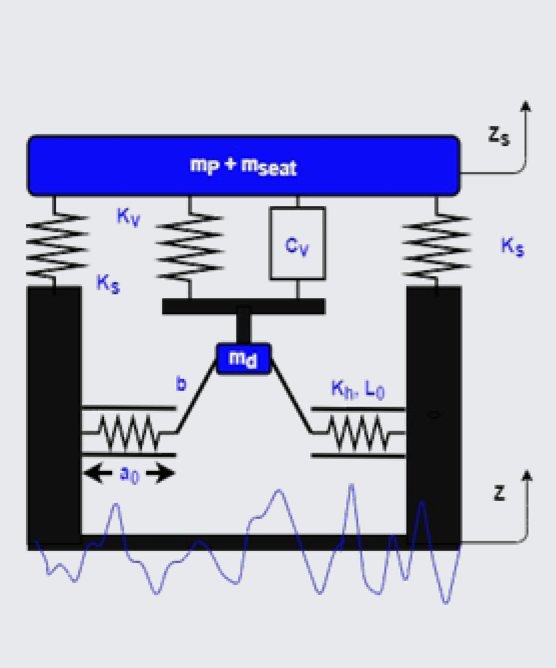
Charlotte Croucher
Researcher

Source: Croucher, C., Pauwels, F., Xuan, R. P., Brietzke, A., Marchal-Crespo, L., & Papaioannou, G. (2025). MATE-AV: A VR-based training environment to teach occupants' how to adopt a comfort-oriented postural control in a vehicle.

Seat comfort & Carsickness
Explore smart seat suspension designs with negative stiffness elements

The interior of AVs is under transformation to accommodate engagement non driving activities and increase productivity

Can we design a seat to mitigate motion sickness and enhance comfort while being driven ?



We redesigned **a novel seat** from the literature, which can **isolate low-frequency vibrations**, the **most provocative for motion sickness**

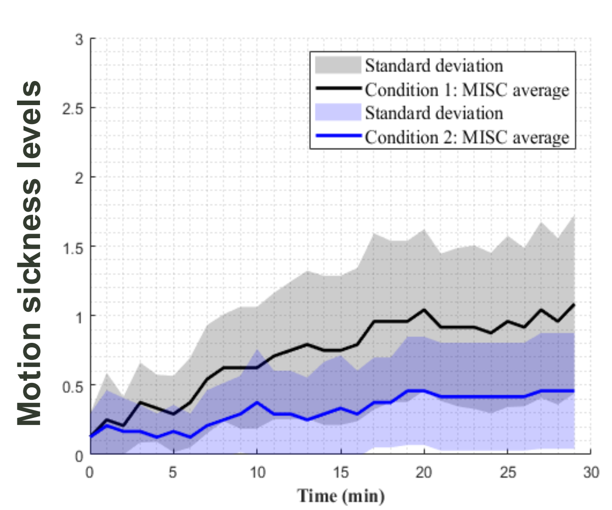
A joint study conducted by: TU Delft VOLKSWAGEN AKTIENGESELLSCHAFT

Chrysovalanto Messiou
PhD Candidate

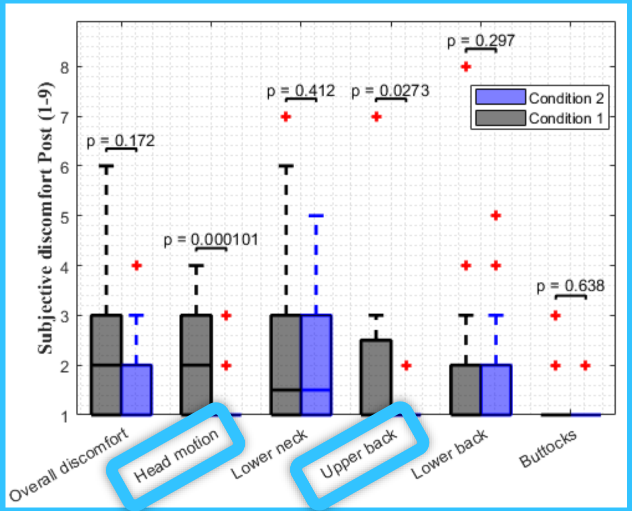
Farjam Tajdari
Researcher

Source: Papaioannou G, Voutsinas A, Koulocheris D, Antoniadis I, Dynamic performance analysis of vehicle seats with embedded negative stiffness elements. Vehicle System Dynamics. 2020;58(2):307-337.

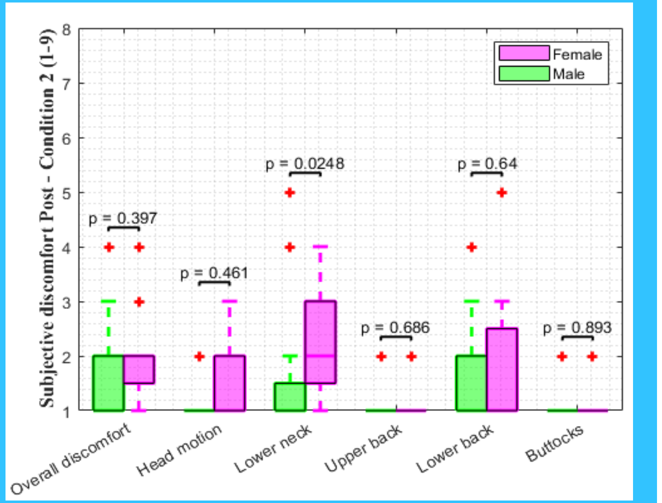
Immersive technologies -
How to exploit their use towards enhancing motion comfort?



- We designed a seat that could decrease average MISC **by almost 50%.**



- **KSeat was experienced significantly more comfortable** on head and upper back.



- Females experienced **significant more discomfort** in the lower neck region.

A joint study conducted by: TU Delft VOLKSWAGEN AKTIENGESELLSCHAFT

Chrysovalanto Messiou
PhD Candidate

Farjam Tajdari
Researcher

Source: Tajdari, F., Messiou, C., Happee, R., & Papaioannou, G. (2025). Exploring the Impact of Seat Suspension With Negative Stiffness Elements on Occupants' Motion Comfort.

Hi-Drive

TOPICAL WEBINAR #5

Panel Discussion

Hi-Drive

TOPICAL WEBINAR #6

Cyriel Diels | Royal College of Art

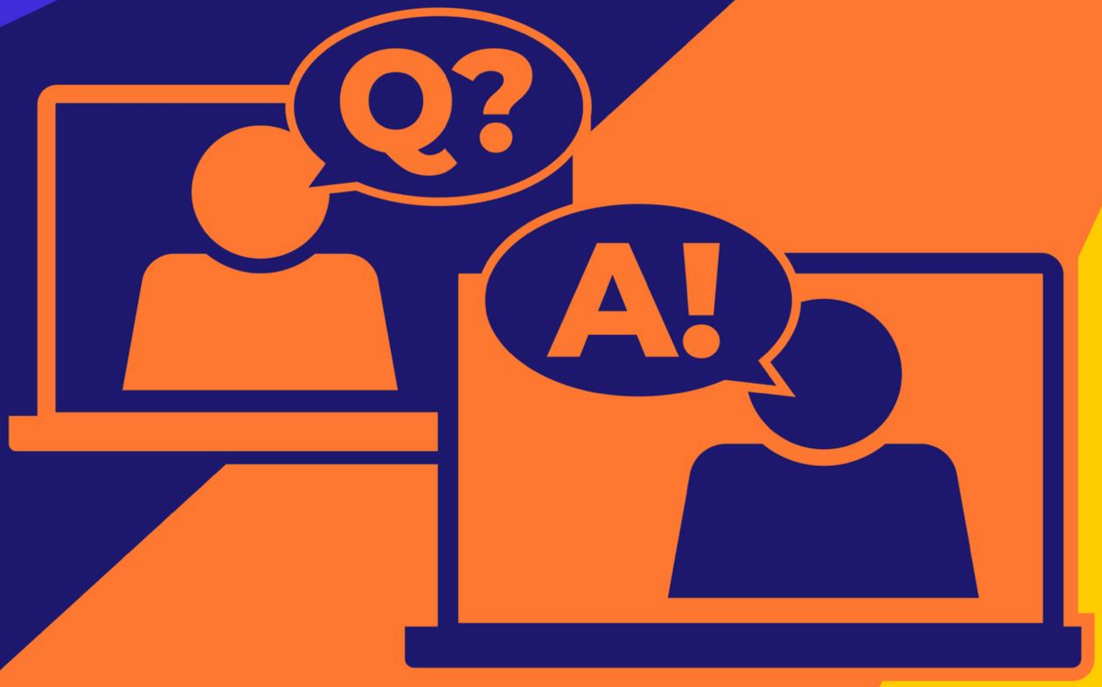
Rebecca Pham Xuan | Volkswagen

Chen Peng | Leeds

Myriam Metzulat | WIVW

Georgios Papaioannou | TU Delft

Stefan Wolter | Ford



Hi-Drive
Designing Automation

THANK YOU FOR YOUR ATTENTION

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Supported by the European Council for Automotive R&D EUCAR

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We look forward to welcoming you

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