Driverless public transport
Passenger Acceptance,
Interaction with vulnerable road users
Motion Comfort

Riender Happee, Sina Nordhoff, Tugrul Irmak

Delft University of Technology

Mechanical, Maritime and Materials Engineering (3mE)

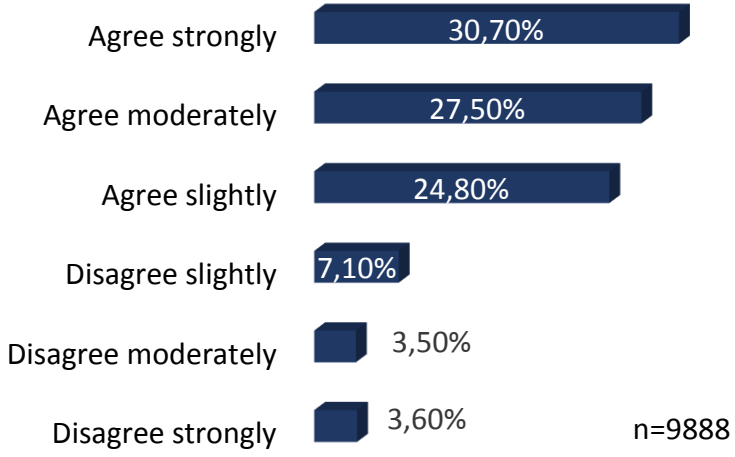
Civil Engineering and Geosciences (CEG)

r.happee@tudelft.nl

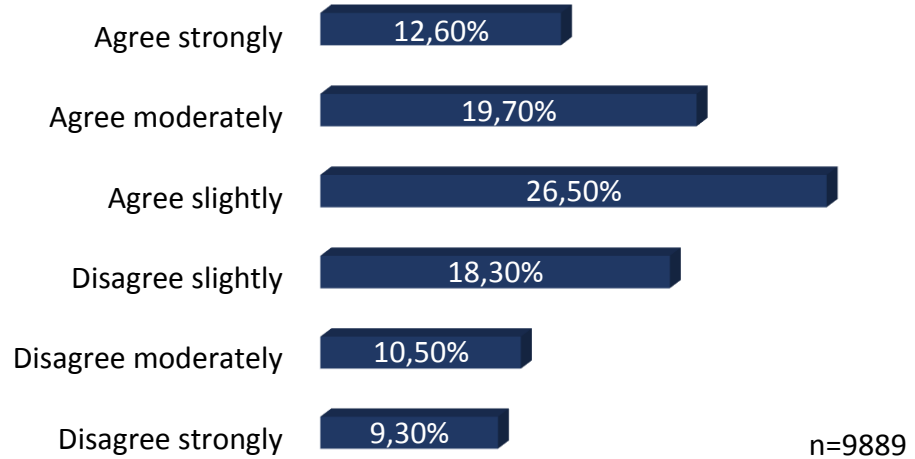
Acceptance driverless shuttles

- Internet surveys indicate a positive attitude towards driverless public transport
- Following slides show attitudes after real test rides

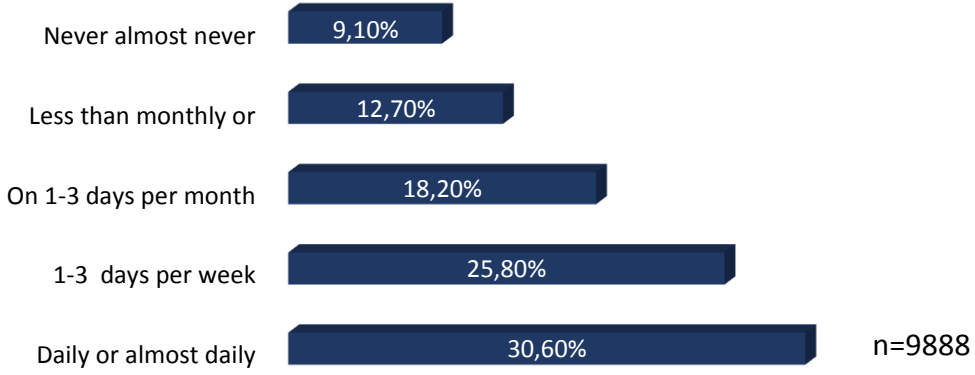
I would use a 100% electric driverless vehicle from the train station or some other public transport stop to my final destination or vice versa.



Even if it were more expensive than my existing form of travel, I would prefer driverless vehicles

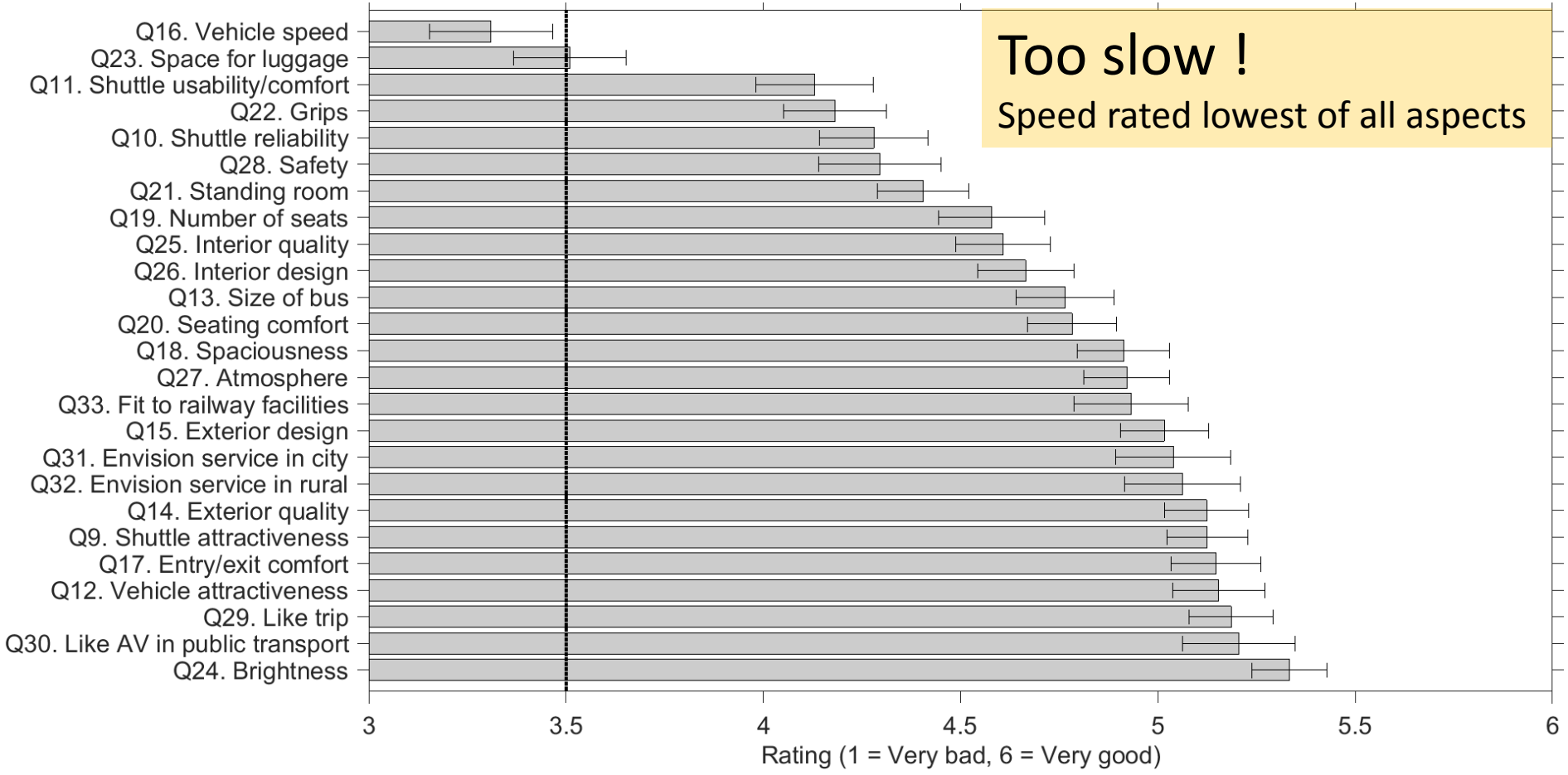


Please indicate how often you intend to use a driverless vehicle when it is on the market.



Nordhoff, Kyriakidis, van Arem, Happee (2018) Acceptance of Driverless Vehicles: Results from a Large Cross-National Questionnaire Study, JAdvTransp

Acceptance Driverless Shuttles



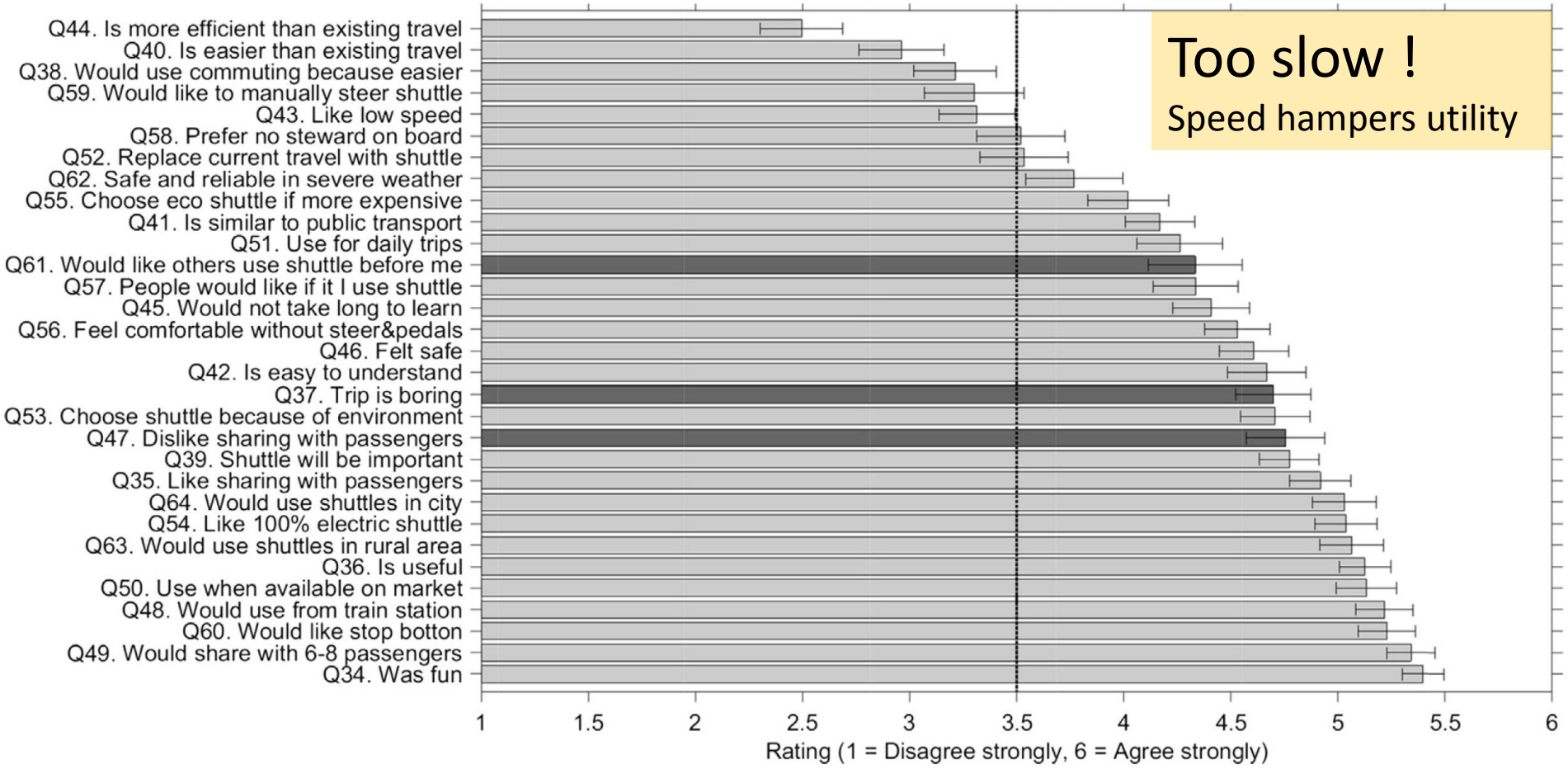
Online questionnaire n=384
Post-drive, Olli, Berlin,
December 2016 – April 2017

Shuttle and service characteristics, mean and 95% confidence intervals, sorted by mean rating.
The vertical line at 3.5 indicates a score in the middle of the range from 1 to 6.

Nordhoff, de Winter, Madigan, Merat, van Arem, Happee (2018). User acceptance of automated shuttles in Berlin Schöneberg: A questionnaire study. TRPF

INTERREG Deutschland Nederland

Acceptance Driverless Shuttles



Online questionnaire n=384
Post-drive, Olli, Berlin,
December 2016 – April 2017

Shuttle and service characteristics, mean and 95% confidence intervals, sorted by mean rating.
The vertical line at 3.5 indicates a score in the middle of the range from 1 to 6.

Nordhoff, de Winter, Madigan, Merat, van Arem, Happee (2018). User acceptance of automated shuttles in Berlin Schöneberg: A questionnaire study. TRPF

Interview users driverless shuttles

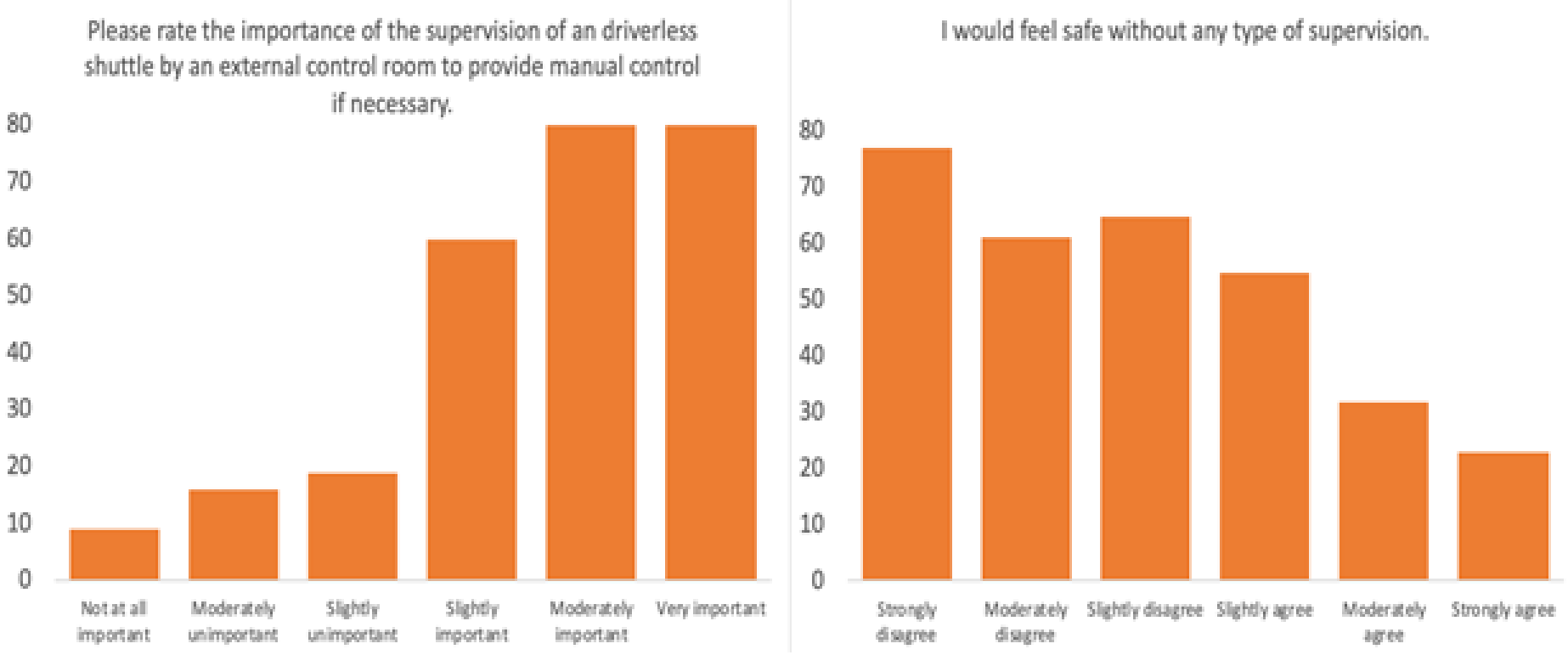
Interviews n=30
Post-drive, Olli, Berlin,
March-July 2017

- 17/30 respondents expected the automated shuttle to be in a more advanced state of technological development.
- They had an idealized idea of the technological capabilities of an automated vehicle that resembled SAE Level 5 or full automation.
- Two interview respondents explained:
  - I find it rather strange that it is defined as automated driving when a steward is onboard who has to tell the shuttle that there is an obstacle on the road. And the shuttle does not know: Do I need to brake, avoid the obstacle now, or is the obstacle moving such as a car or pedestrian?"
  - I was a bit disappointed that the shuttle is not yet as far as I thought. I also found it interesting that the shuttle has to learn the route. I expected it to be much more autonomous

Interview users driverless shuttles

most prefer supervision via an external control room or steward on-board over unsupervised automation

Interviews n=30
Post-drive, Olli, Berlin,
March-July 2017



Nordhoff, de Winter, Payre, van Arem, Happee. What Impressions Do Users Have After a Ride in an Automated Shuttle? An Interview Study, TRPF

Ride with hidden Steward

presented as note maker

- Respondents pressed the emergency button on 28 out of 62 test rides to test the behavior of the automated vehicle.
- Respondents indicated that they worried more about the safety of road users outside the vehicle than about their personal safety as passengers of the automated vehicle.
- Safety concerns related to a lack of knowledge on how the automated vehicle perceives and reacts to other road users.

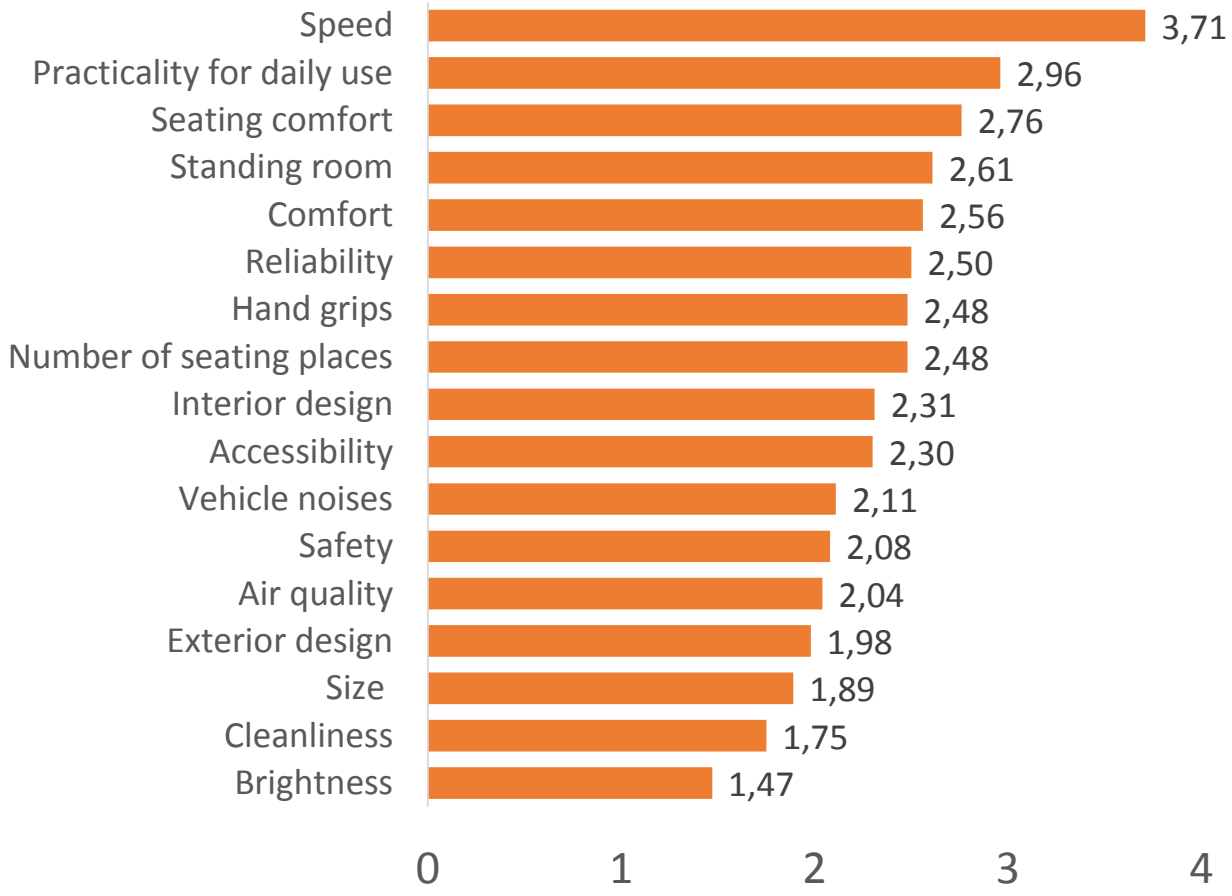
Interviews during drive
& survey post-drive, n=119,
Easymile EZ10, Berlin,
March-December 2018

INTERREG Deutschland Nederland

Nordhoff, S., Stapel, J., Van Arem, B., & Happee, R. (under revision).
Passenger opinions of interactions with an automated vehicle: An accompanied test ride study.

Ride with hidden Steward

presented as note maker



Too slow !

Speed hampers practicality

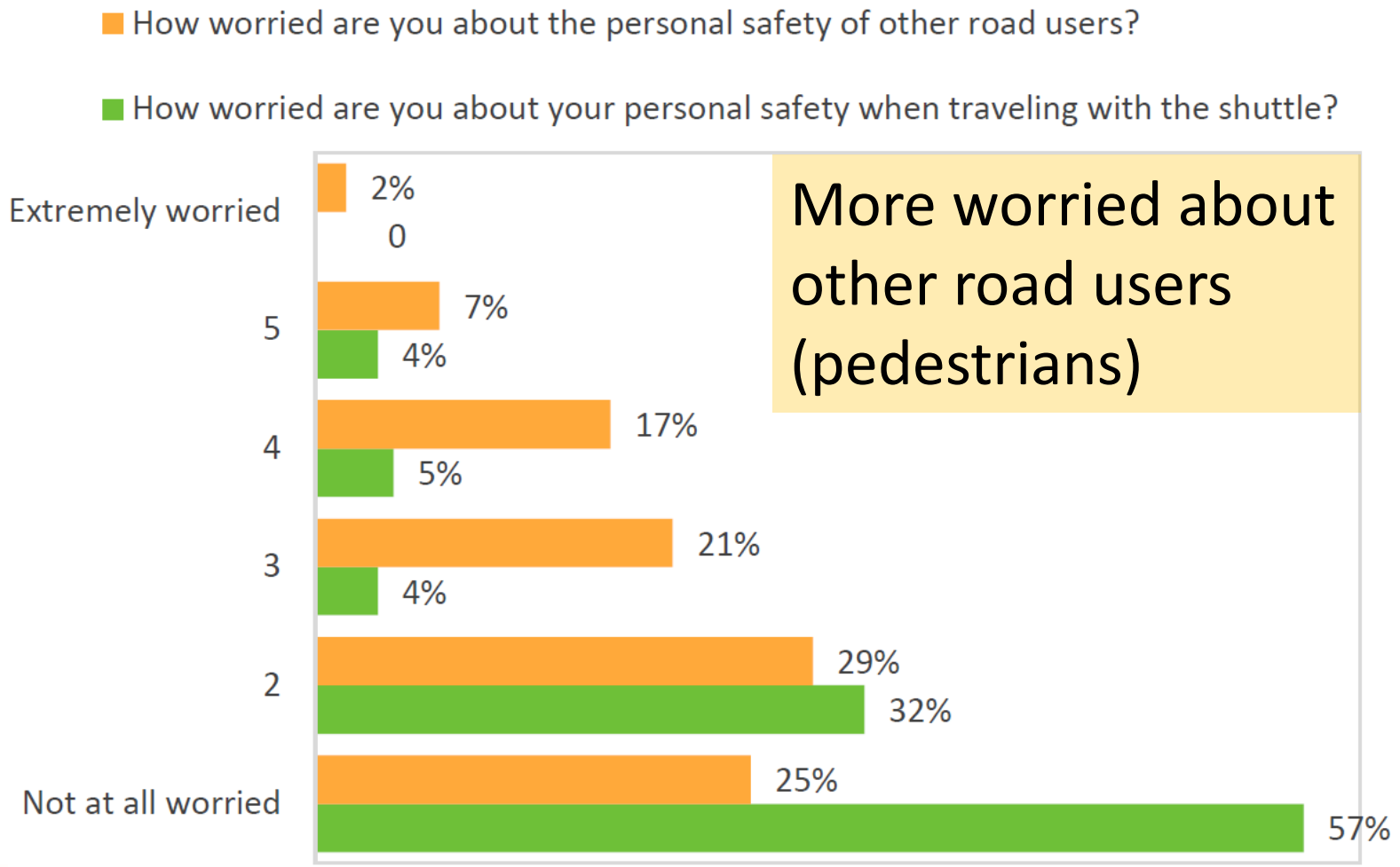
Interviews during drive
& survey post-drive, n=119,
Easymile EZ10, Berlin,
March-December 2018

Please tell us how you dissatisfied or satisfied with the following aspects of the vehicle.
Please rate your judgment on a scale from 1 to 6 (1 = very good, 6 = very bad").

Nordhoff, S., Stapel, J., Van Arem, B., & Happee, R. (under revision). Passenger opinions of interactions with an automated vehicle: An accompanied test ride study.

Ride with hidden Steward

presented as note maker



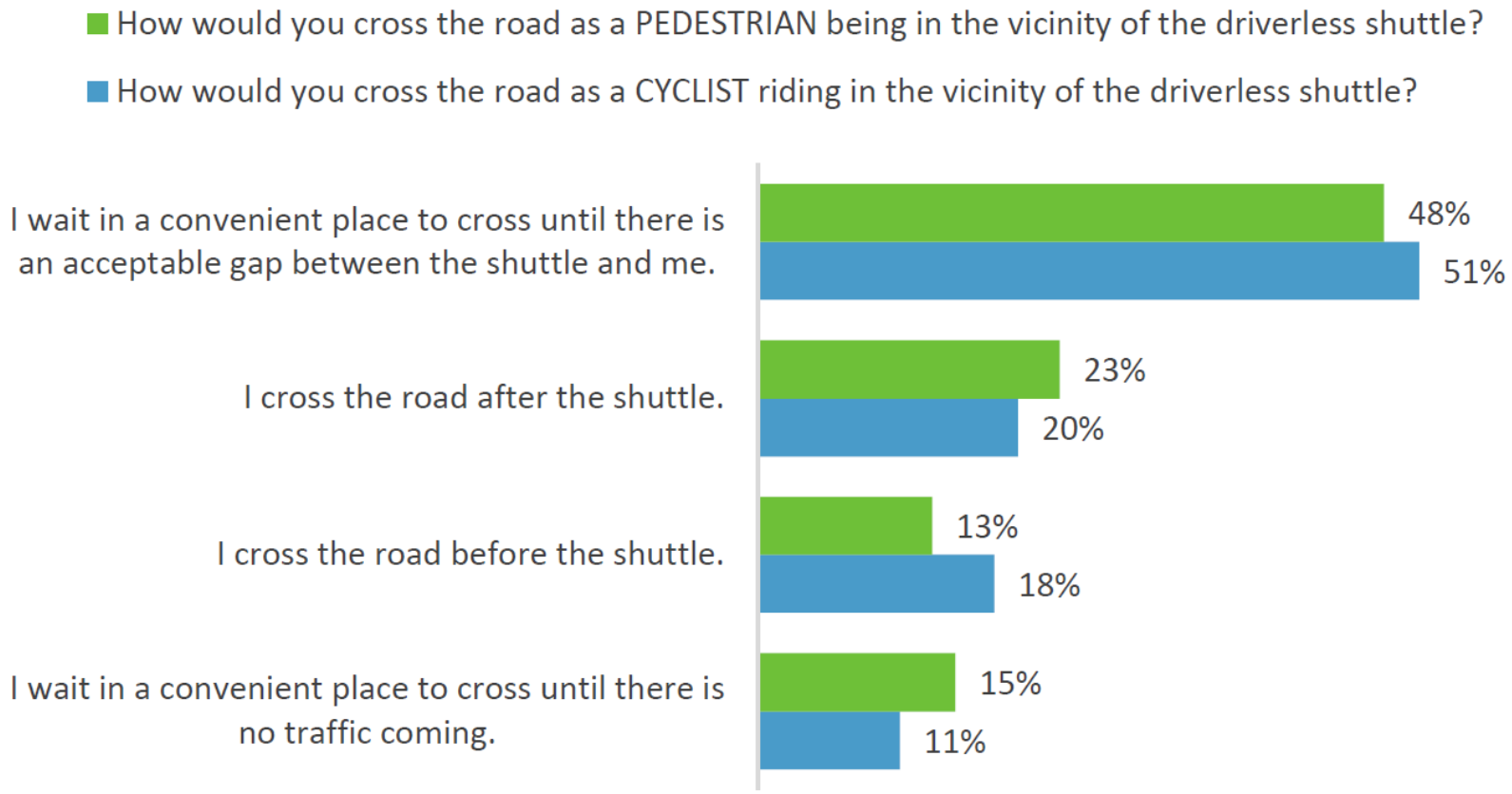
Interviews during drive
& survey post-drive, n=119,
Easymile EZ10, Berlin,
March-December 2018

INTERREG Deutschland Nederland

Nordhoff, S., Stapel, J., Van Arem, B., & Happee, R. (under revision).
Passenger opinions of interactions with an automated vehicle: An accompanied test ride study.

Ride with hidden Steward

presented as note maker



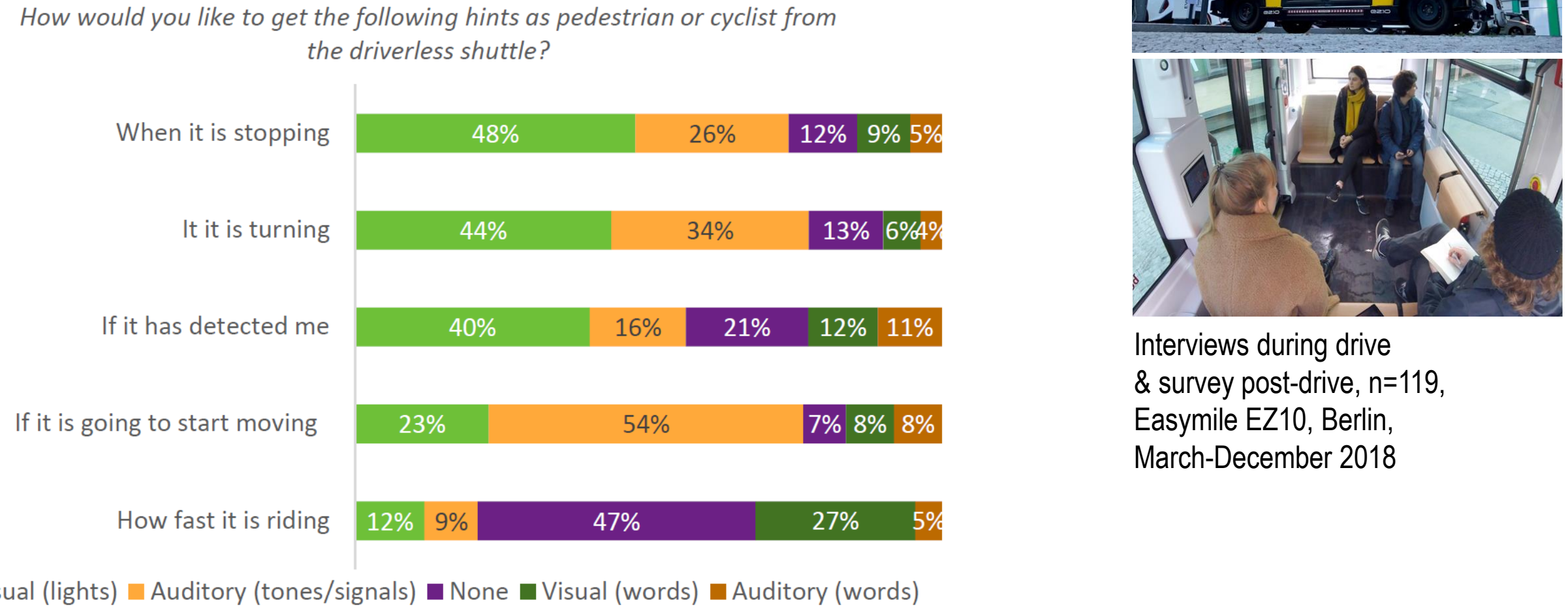
Interviews during drive
& survey post-drive, n=119,
Easymile EZ10, Berlin,
March-December 2018

INTERREG Deutschland Nederland

Nordhoff, S., Stapel, J., Van Arem, B., & Happee, R. (under revision).
Passenger opinions of interactions with an automated vehicle: An accompanied test ride study.

Ride with hidden Steward

presented as note maker



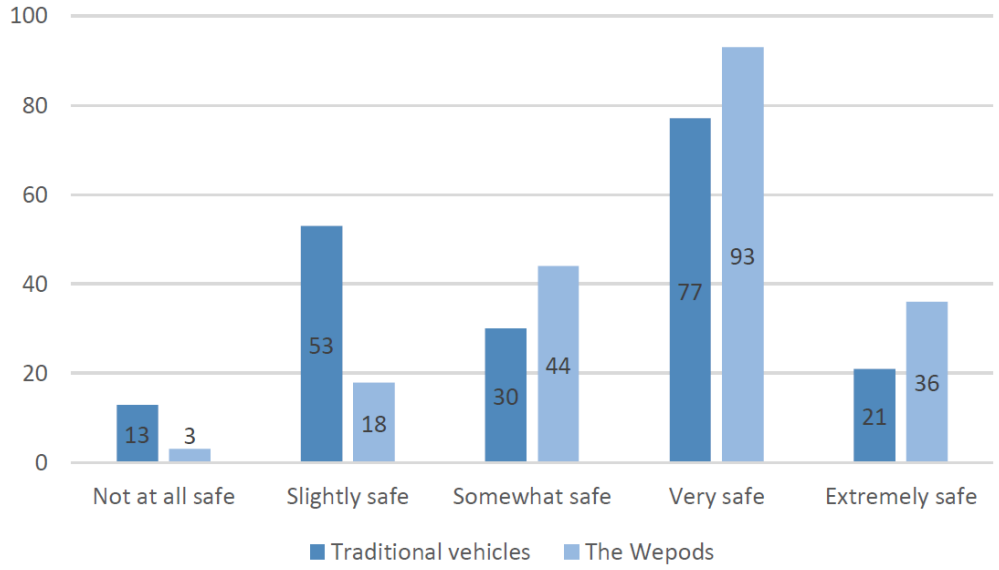
Interviews during drive
& survey post-drive, n=119,
Easymile EZ10, Berlin,
March-December 2018

INTERREG Deutschland Nederland

Nordhoff, S., Stapel, J., Van Arem, B., & Happee, R. (under revision).
Passenger opinions of interactions with an automated vehicle: An accompanied test ride study.

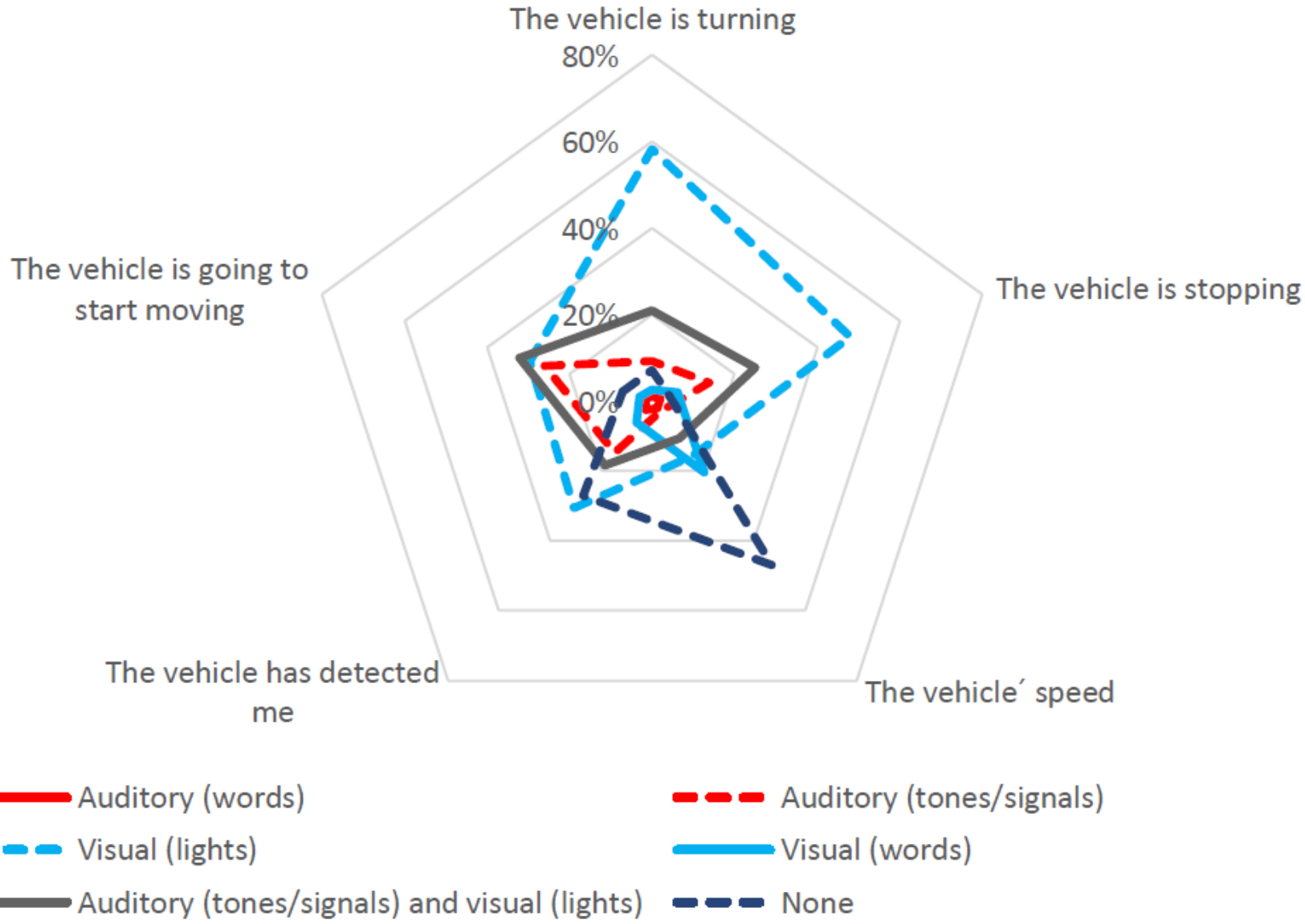
Acceptance WEpods by VRU

- Pedestrians & cyclists at Wageningen campus (2017)
  - face-to-face interviews (N=22), focus group (N=8)
  - online survey (N=198)
- VRUs feel significantly safer sharing the road with WEpods (max 15 km/h) as with traditional motor vehicles (max 30 km/h)
- VRUs which already encountered WEpods feel safer
- Driving direction was not sufficiently clear
  45.5% - it was not clear
  36.4% - only clear if moving
  18.1% - it was clear
- Many were not aware that the WEpods had a steward
  40.9% - it has a steward
  27.3% - it doesn't have
  31.8% - I do not know



Rodriquez (2017) Safety of pedestrians and cyclists when interacting with self-driving vehicles. A case study of the WEpods. MsC TUDelft.

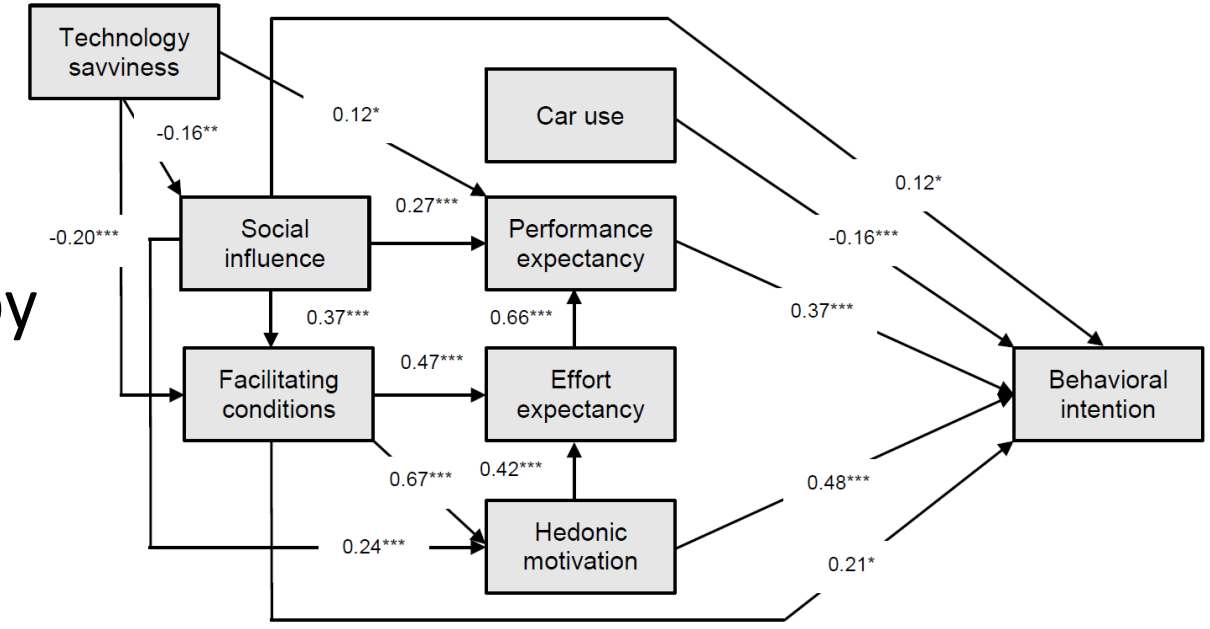
VRU want to be informed



Rodriquez (2017) Safety of pedestrians and cyclists when interacting with self-driving vehicles. A case study of the WEpods. MsC TUDelft.

Can we predict acceptance?

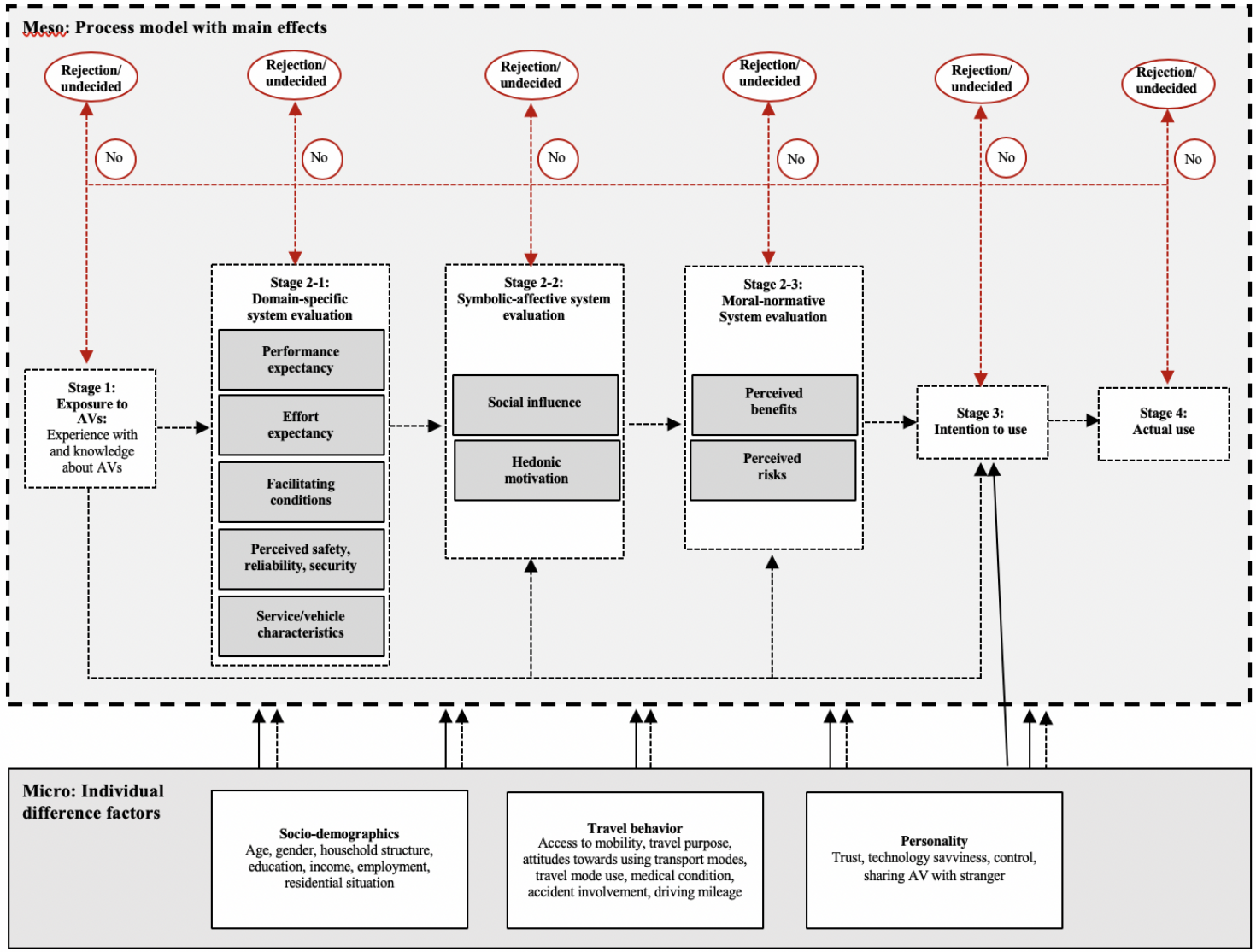
- Studies show substantial variance in response between participants
- behavioural intentions to use automated vehicles are most strongly driven by
  1) hedonic motivation, followed by
  2) performance expectancy, and
  3) social influence



Nordhoff, S., Madigan, R., Van Arem, B., Merat, N., & Happee, R. (under review). Structural equation modeling discloses interrelations between predictors of automated vehicle acceptance.

Can we predict acceptance?

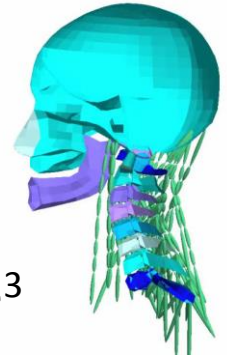
- Surveys support significance of most relations
- This shows effects at **personal level**
- Now we need to relate acceptance to **actual PT system design**
  - Service level
  - Motion comfort
  - Social security
  - Perceived safety
- Based on systematic variations in operational PT

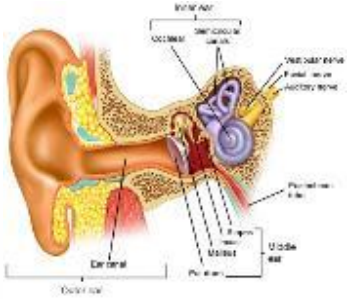


Nordhoff S, Kyriakidis M, van Arem B, Happee R. (2019). A Multi-Level Model on Automated Vehicle Acceptance (MAVA): A Review-Based Study. TIES.

Motion Comfort & Sickness

- Motion sickness
  - Drivers virtually insensitive
  - Passive passengers suffer most,
  - Especially without window views [1,2]
- Remedies
  - Smooth driving style
  - Visual context & computer integration
  - Seating
- Research approach
  - Investigate motion sickness, comfort & Non Driving Task uptake on road
  - Model comfort, motion perception & posture maintenance[3]

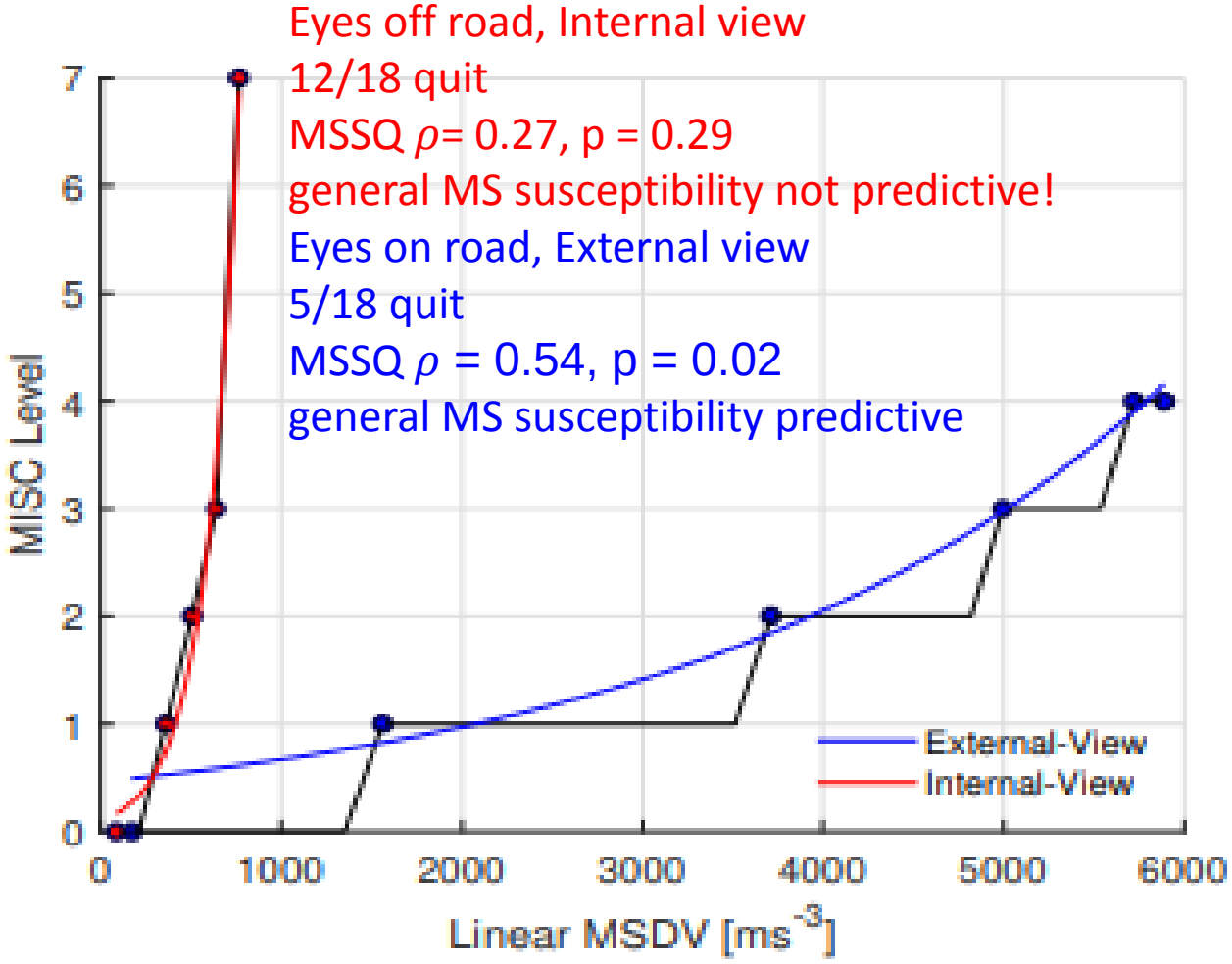




1) Diels, Bos (2015) Self-driving carsickness. Applied Ergonomics
2) Griffin, Newman (2004) Visual field effects on motion sickness in cars.
3) vd Horst (2002), Forbes (2014), de Bruijn (2015), Happee (2017).

Sickening Drive

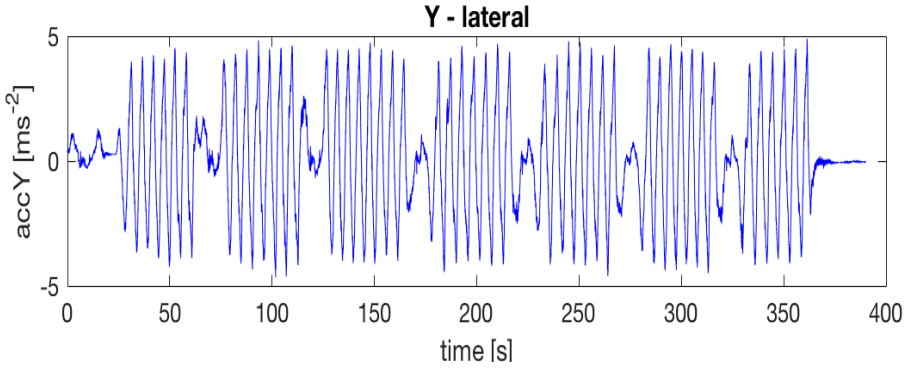
- Condition
  - 0.2 Hz slalom, 7 m, 25 km/h
  - 30 minutes
  - passenger mid rear seat
  - eyes on/off road (identical posture)
- Measures
  - MISC (#18) each minute
  - XSENS 6D body motion (#11)
  - ECG & ESR

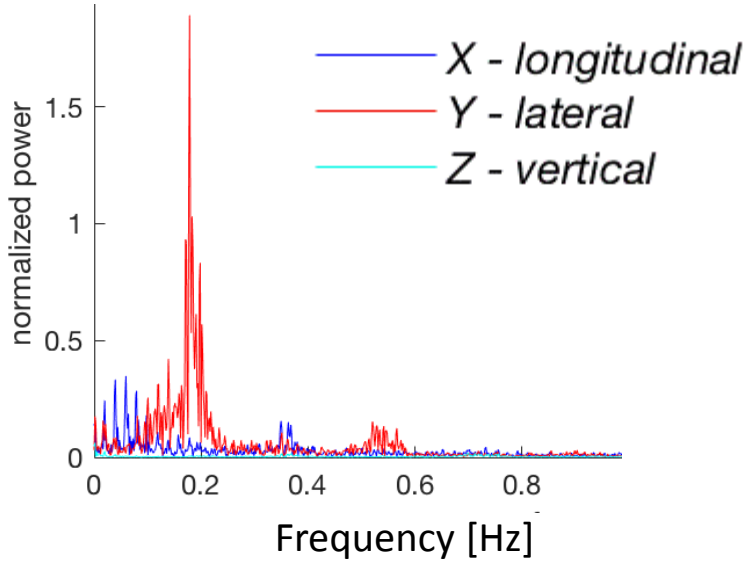


Dosage (6000 reached after about 30 min)

Sickening Drive

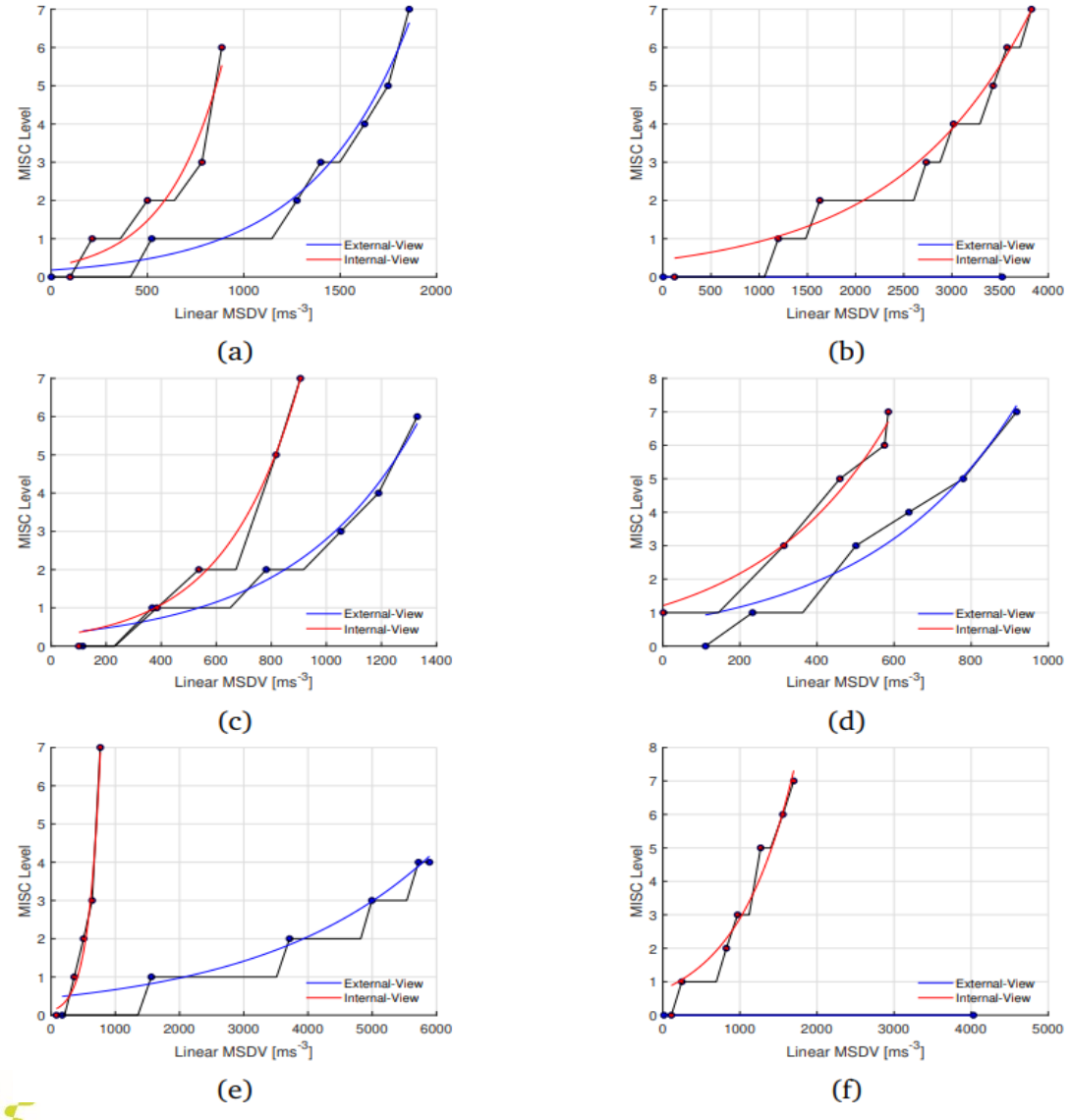
- Condition
  - 0.2 Hz slalom, 7 m, 25 km/h
  - 30 minutes
  - passenger mid rear seat
  - eyes on/off road
    identical posture
- Measures
  - MISC (#18) each minute
  - XSENS 6D body motion (#11)
  - ECG & ESR

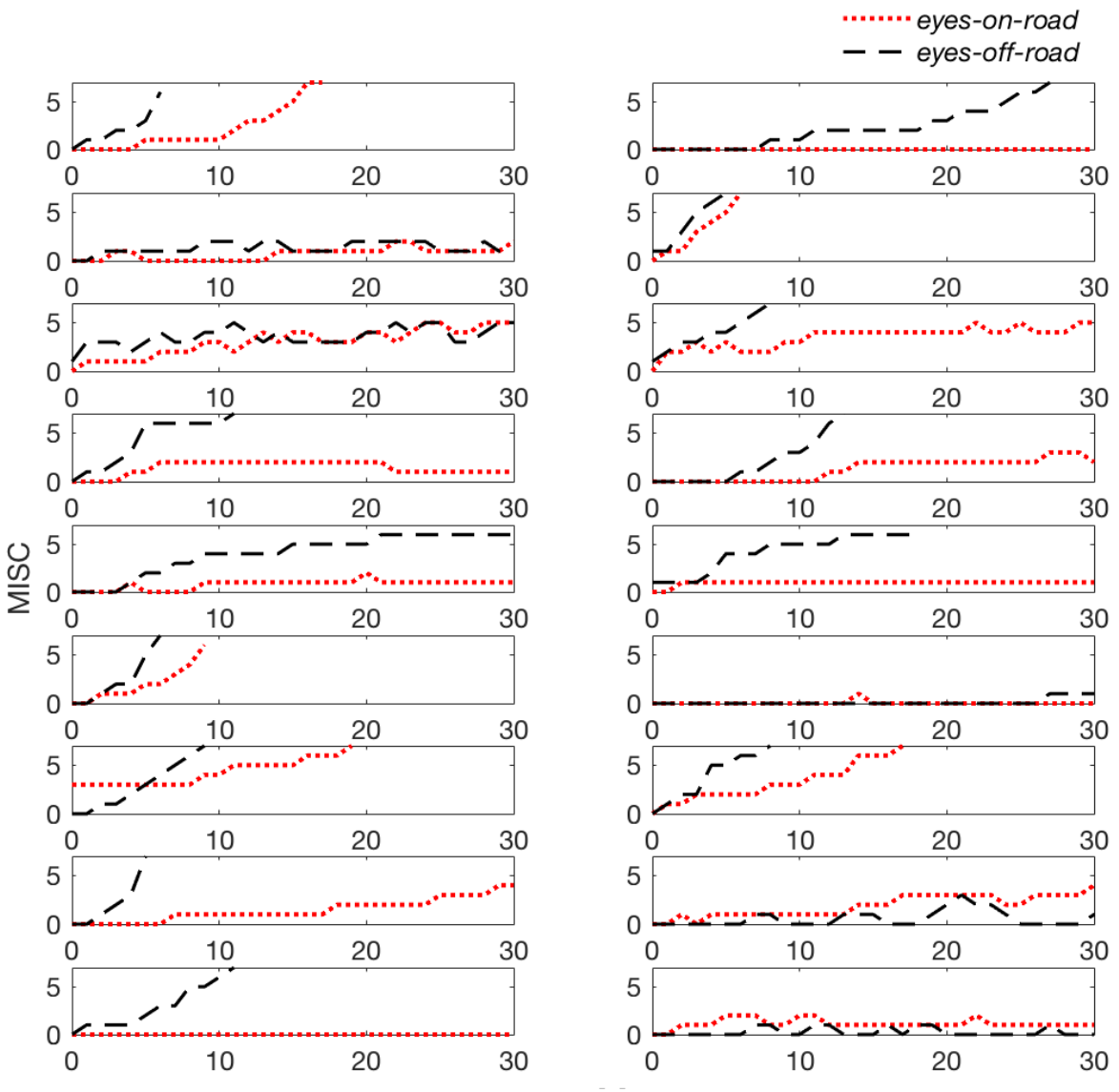




INTERREG Deutschland Nederland

Sickening Drive – effect of vision - individual

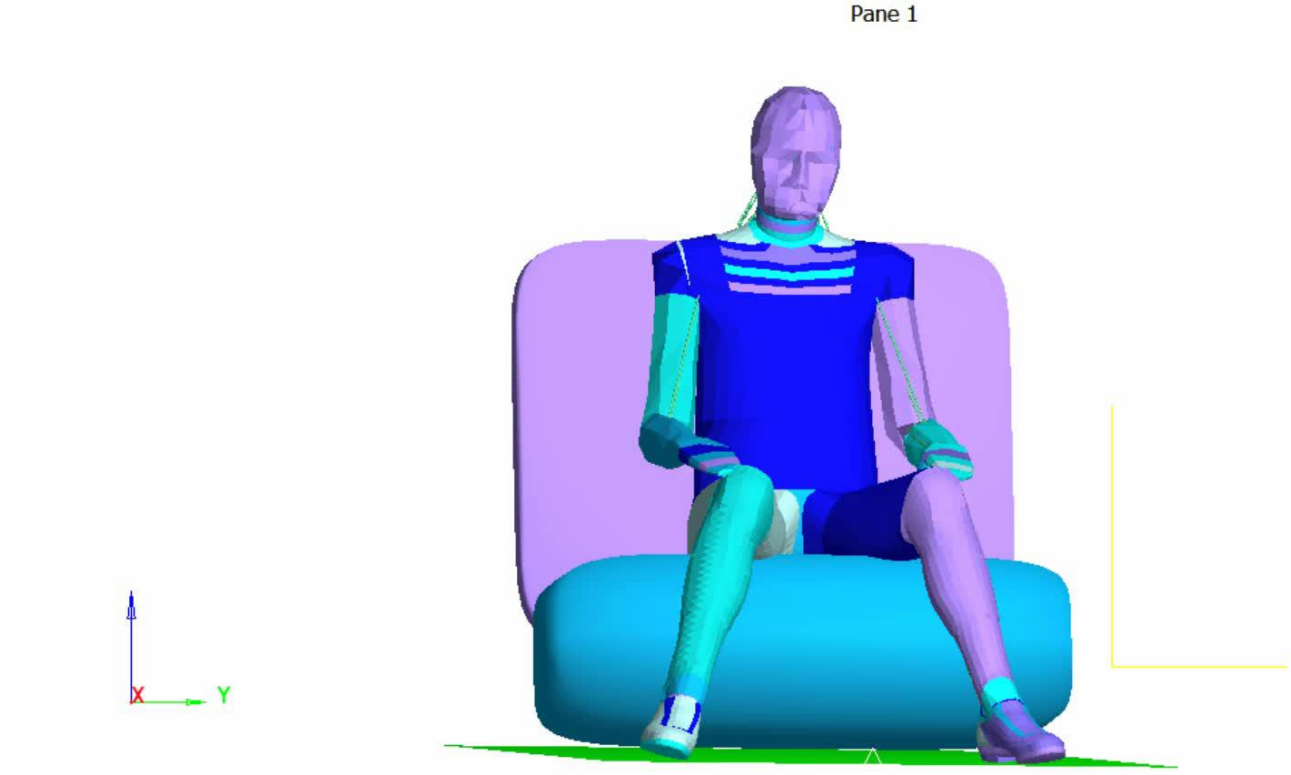




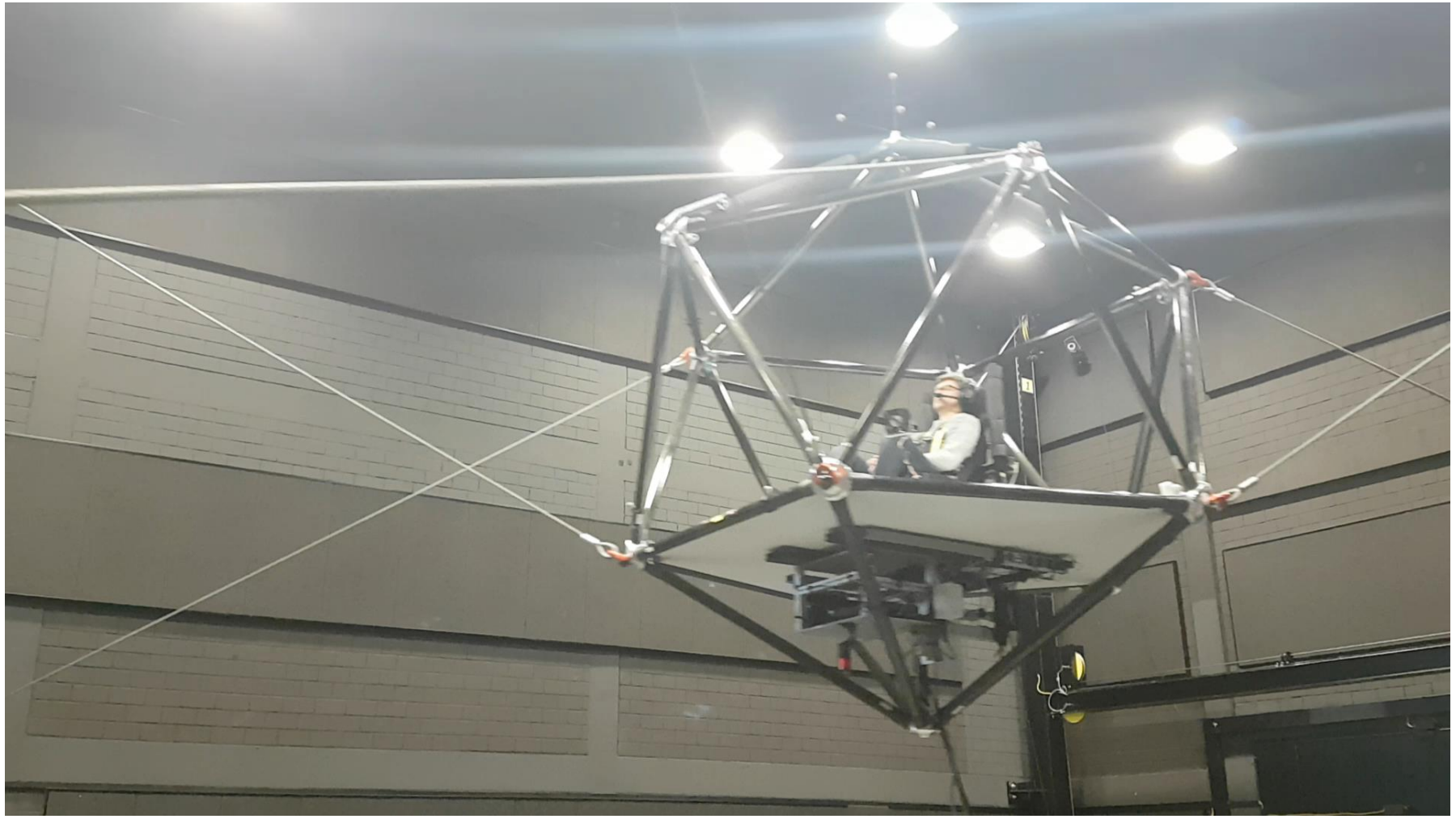
Sickening drive simulation

3D simulation – motion applied at seat

- First Biomechanical model predicting
  - seated motion for comfort
    lateral & forward
- Existing models focus on
  - vertical comfort loading
  - crash conditions

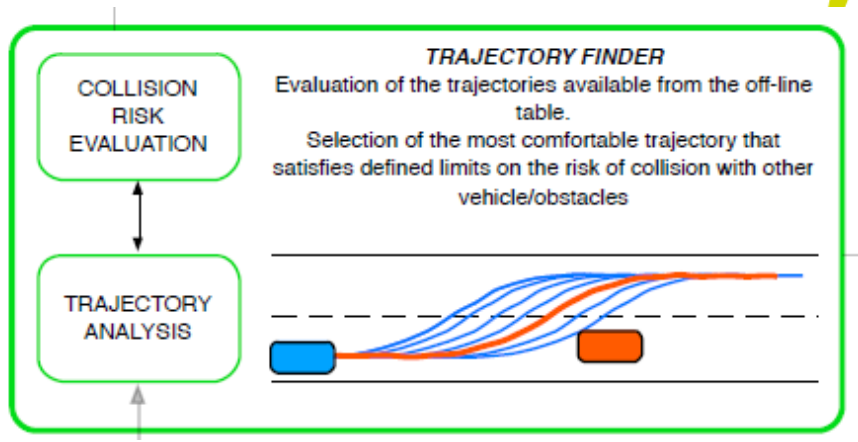


Motion sickness experiment at Max Planck

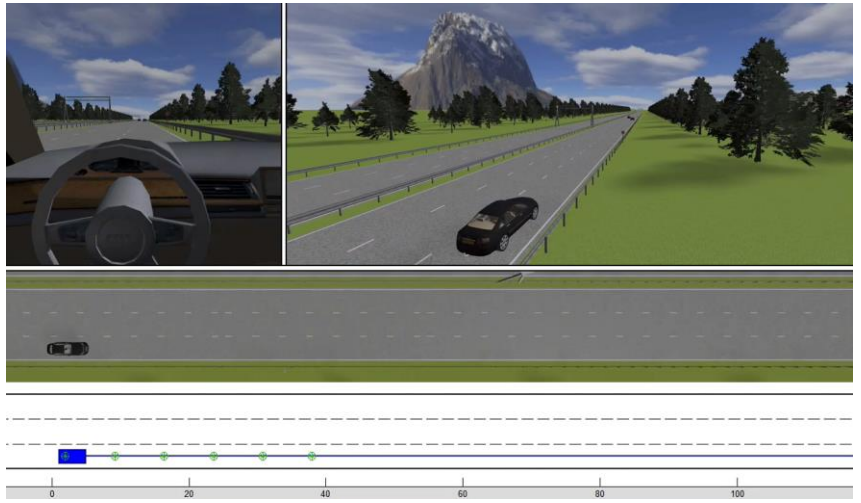


Optimal Motion

- AV controllers optimise [1,2]
  - safety (in critical scenarios)
  - road capacity
  - energy efficiency
  - comfort
- To design AV we need mathematical criteria translating vehicle motion to comfort, for
  - automation (longitudinal & lateral)
    - path, curve speed, interaction other road users
  - suspension (vertical, roll, pitch)
    - predictive skyhook control
    - active roll [2]



[2]



1. Wang M, Hoogendoorn S, Daamen W, van Arem B, Happee R. (2015). Game theoretic approach for predictive lane-changing and car-following control. TRPC
2. Arrigoni S, Cheli F, Manazza SS, Gottardis P, Happee R, Arat MA, Kotiadis D. (2015). Autonomous vehicle controlled by safety path planner with collision risk estimation coupled with a non-linear MPC. 24th International Symposium on Dynamics of Vehicles on Roads and Tracks, Aug 18, 2015.
3. Bif M. (2014). Vorausschauende Fahrwerk Regelung zur Reduktion der auf die Insassen wirkende Querbeschleunigung. PhD thesis IKA, RWTH Aachen University.

Acceptance of driverless public transport

- Consumers are generally positive
- Low speeds are a bottleneck in utility
- Human supervision by a control room is desired
- Occupants more concerned about safety of other road users
- Motion comfort and motion sickness will become more critical in longer trips