KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

Drowsiness and Fatigue in Automated Driving – Empirical Data for an Integrative Framework

Veronika Weinbeer, Alexander Frey, Anna Feldhütter,
Oliver Jarosch, Claus Marberger, and Jonas Radlmayr

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

AN OVERVIEW

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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Is It the Duration of the Ride or the Non-driving Related Task? What Affects Take-Over Performance in Conditional Automated Driving?

Oliver Jarosch and Klaus Bengler

Automated Driving: The Potential of Non-driving-Related Tasks to Manage Driver Drowsiness

Veronika Weinbeer, Tobias Muhr, and Klaus Bengler

Highly automated driving: How to get the driver drowsy and how does drowsiness influence various take-over aspects?

Automated driving: subjective assessment of different strategies to manage drowsiness

IT'S OUT OF OUR HANDS NOW! EFFECTS OF NON-DRIVING RELATED TASKS DURING HIGHLY AUTOMATED DRIVING ON DRIVERS' FATIGUE

Wake Up and Take Over! The Effect of Fatigue on the Take-over Performance in Conditionally Automated Driving

AGENDA

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

- RELEVANCE IN THE CONTEXT OF AUTOMATED DRIVING
- INFLUENCE ON TAKE OVER PERFORMANCE
- STRATEGIES TO MANAGE DRIVER DROWSINESS
- CONCLUSION KEY MESSAGES

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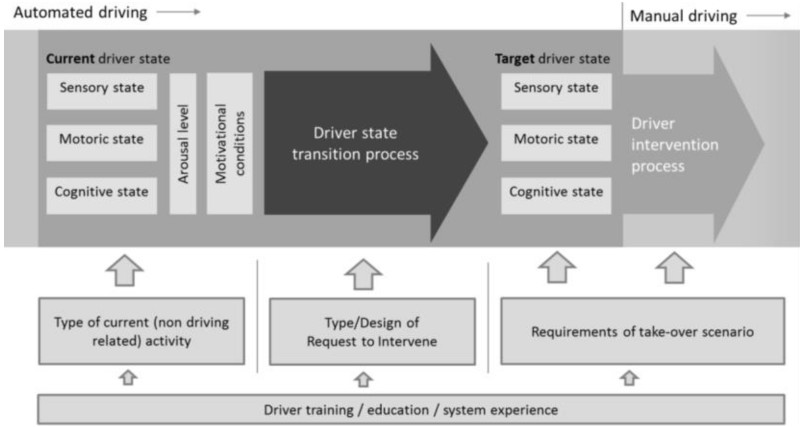
RELEVANCE IN THE CONTEXT OF AUTOMATED DRIVING

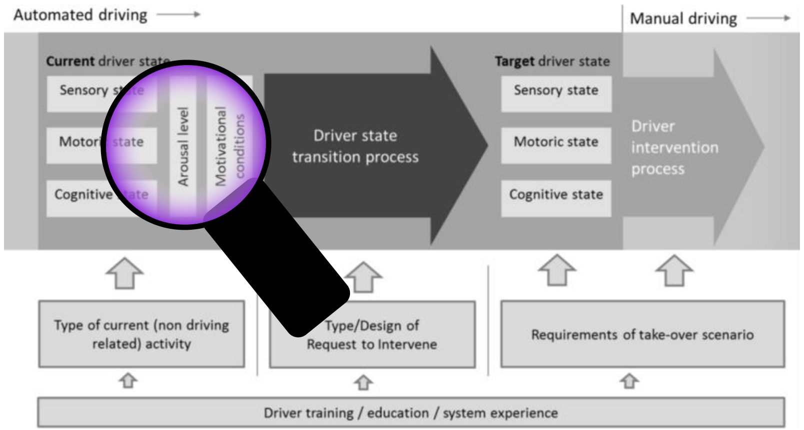
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING



(Marberger et al., 2018)

RELEVANCE IN THE CONTEXT OF AUTOMATED DRIVING

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING



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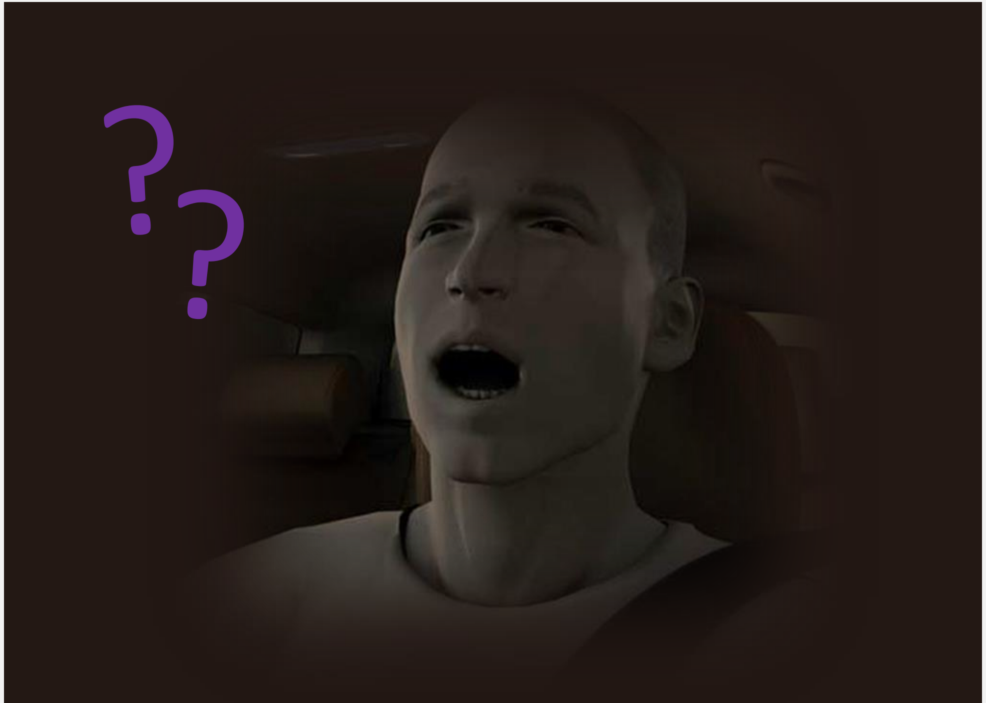

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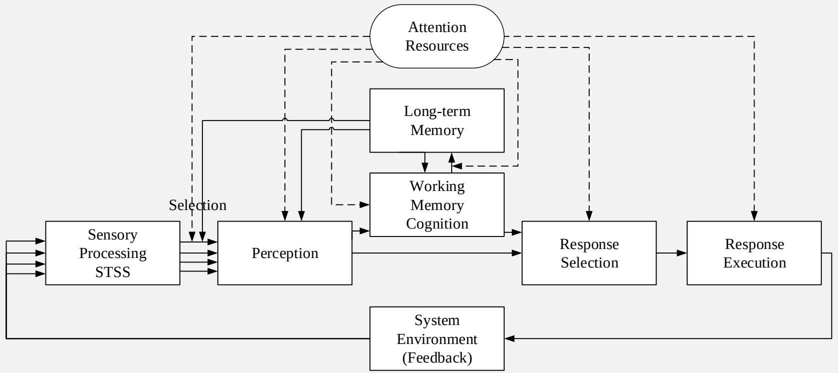
RELEVANCE IN THE CONTEXT OF AUTOMATED DRIVING

- Drowsiness *„is a transitional state between wakefulness and sleep“.* (Johns, 1998)
- Sleepiness can reduce the processing of informations (Mullins, Cortina, Drake, & Dalal, 2014).
- Sleepiness/drowsiness can be influenced by somatosensory (Johns, 1998) and by emotional and cognitive input (Saper, Barbera, & Shapiro, 2005).
- Humans suffering fatigue experience a disinclination to perform the task at hand (Brown, 1994).
- Attention and vigilance problems are likely to occur due to fatigue (Brown, 1994).



Model of human information processing (Wickens et al., 2013, p.4)

Does drowsiness/sleepiness or fatigue influence take-over performance?

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METHODICAL CHALLENGES

Does drowsiness/ sleepiness or fatigue influence take-over performance?

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES

Does drowsiness/ sleepiness or fatigue influence take-over performance?

How can these driver states be induced and assessed (in real traffic)?

INFLUENCE ON TAKE-OVER PERFORMANCE

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METHODICAL CHALLENGES

OVERVIEW

Simulators and test vehicles used in the different studies.






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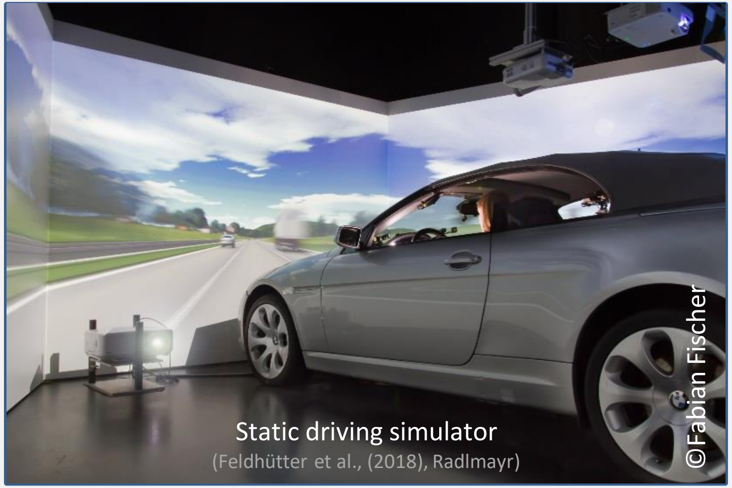
METHODICAL CHALLENGES


Static driving simulator
(Feldhütter et al., (2018), Radlmayr)
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INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES

Dynamic driving simulator
(Jarosch et al., 2017, Jarosch et al., 2019)

INFLUENCE ON TAKE-OVER PERFORMANCE

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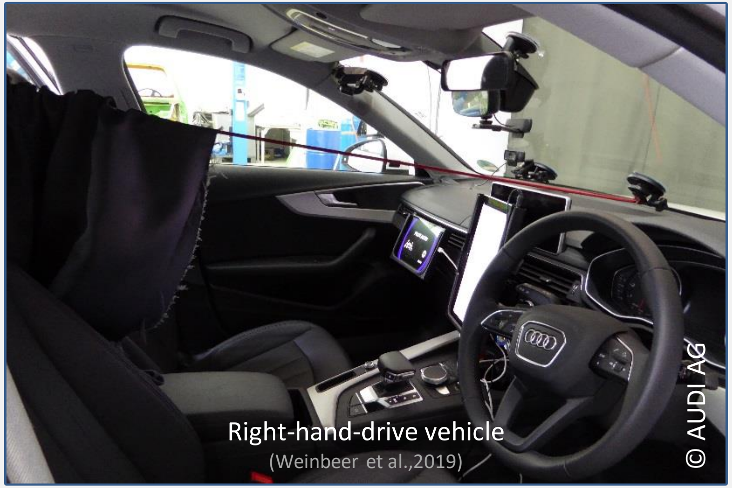
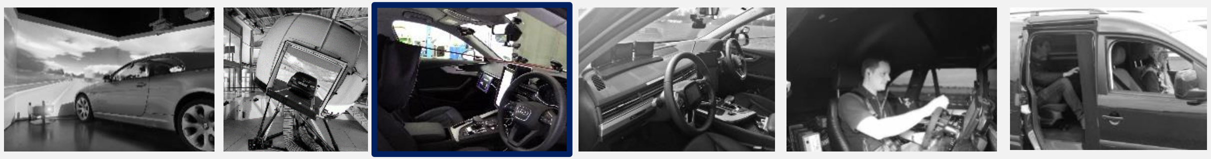
METHODICAL CHALLENGES



Right-hand-drive vehicle
(Weinbeer et al.,2019)



INFLUENCE ON TAKE-OVER PERFORMANCE

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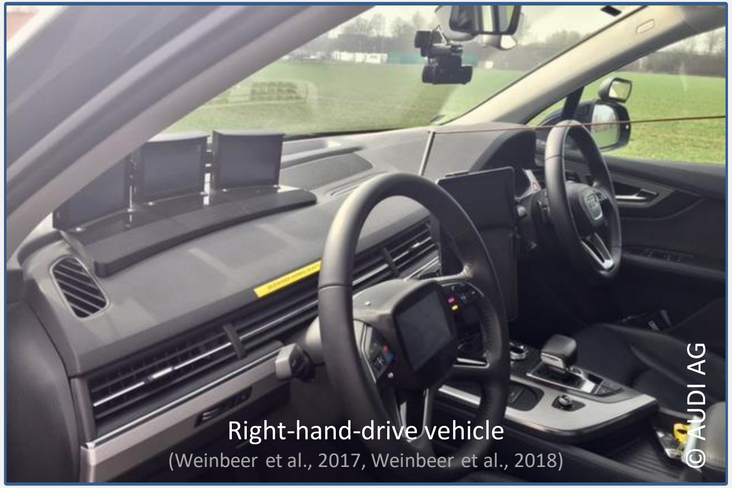

Right-hand-drive vehicle
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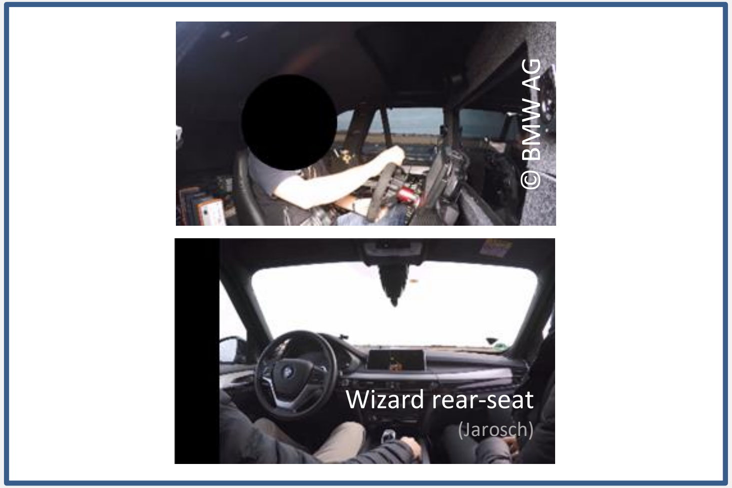

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES

METHODICAL CHALLENGES

HOW WERE THESE DRIVER STATES ASSESSED?

SUBJECTIVE ASSESSMENT

Karolinska-Sleepiness Scale (KSS)
(Akerstedt & Gillberg, 1990)

OBJECTIVE METRICS

Heartrate
Galvanic Skin Response
PERCLOS
Head position
EEG
COP of the seat

EXPERT RATINGS

mainly based on the procedure provided by Wierwille and Ellsworth (1994)

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METHODICAL CHALLENGES

DURATION OF AN AUTOMATED DRIVE

FIXED TIME

Jarosch et al., 2017; Jarosch et al., 2019; Weinbeer et al., 2019; Frey; Radlmayr;

STATE DEPENDENT

Weinbeer et al., 2017; Feldhütter et al., 2018;

KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

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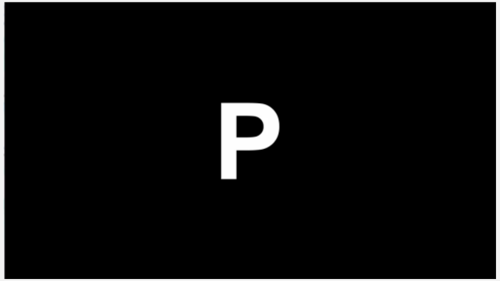
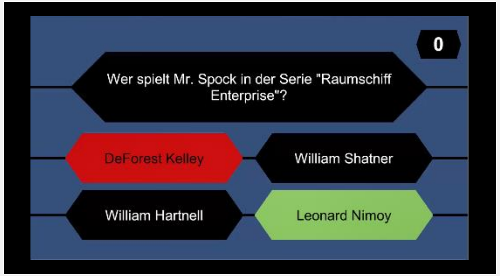
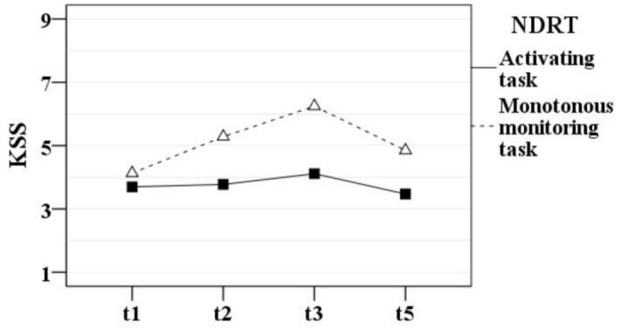
METHODICAL CHALLENGES

TASK-RELATED FATIGUE (Jarosch et al., 2017)







Self-reported sleepiness increased significantly ($p < .001$) during the monotonous monitoring task (24 min.)

During the activating task sleepiness did not change significantly.

METHODICAL CHALLENGES

TASK-RELATED FATIGUE (Jarosch et al., 2017)

- PERCLOS: PERcentage of eyelid CLOSure over the pupil over time
- Reflects slow eyelid closures („droops“) rather than blinks
- Proportion of time in a minute that the eyes are at least 80% closed
- Is considered to be among the most promising real-time measures of fatigue.

(Wierwille et al., 1994)

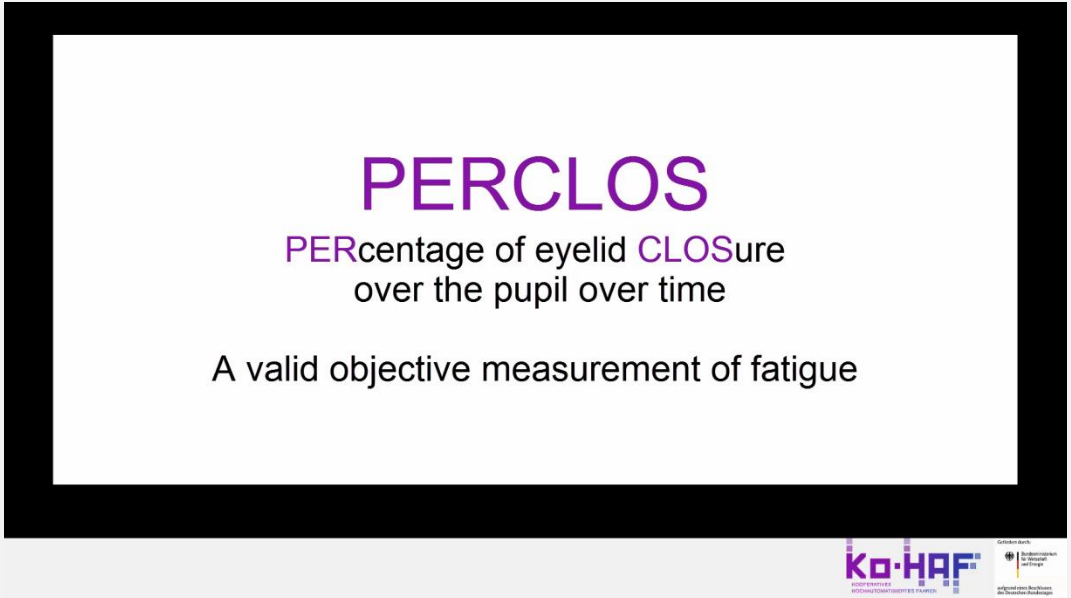
Img.: Dikablis Eyetracker

Source: https://www.ergoneers.com/wp-content/uploads/2015/11/Dikablis-Professional-product-photo.jpg

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES



INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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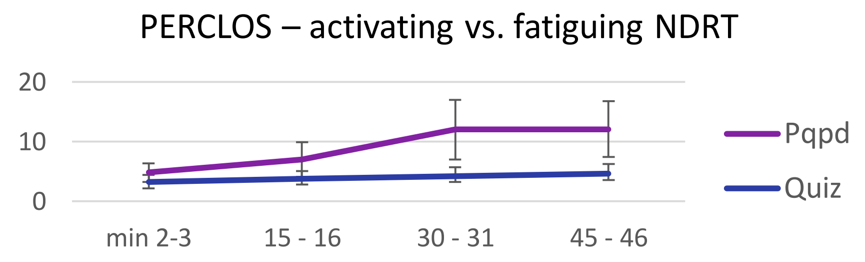
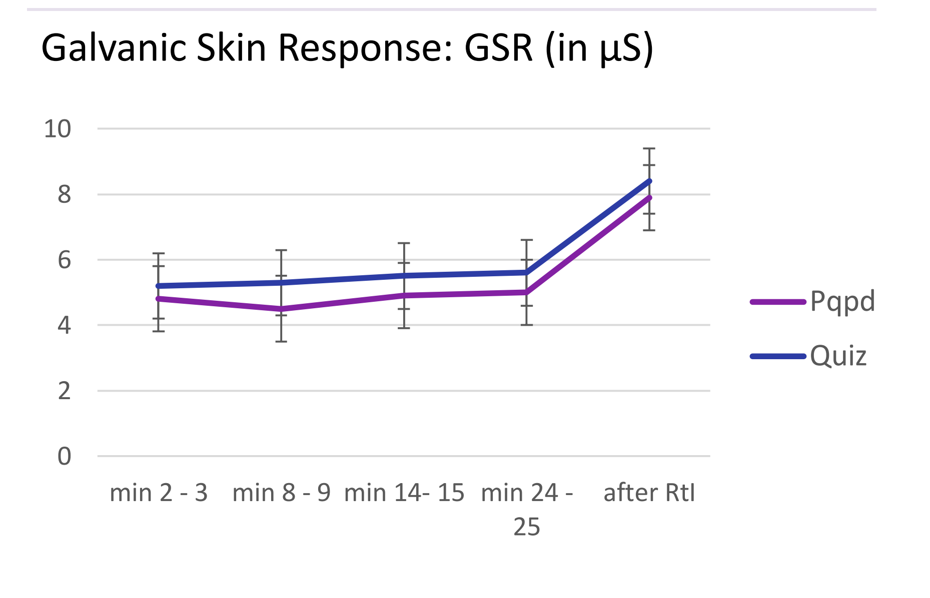


INFLUENCE ON TAKE-OVER PERFORMANCE

METHODICAL CHALLENGES



No significant differences over the course of the automated ride referring to the NDRT!
Significant differences due to the RtI.

METHODICAL CHALLENGES

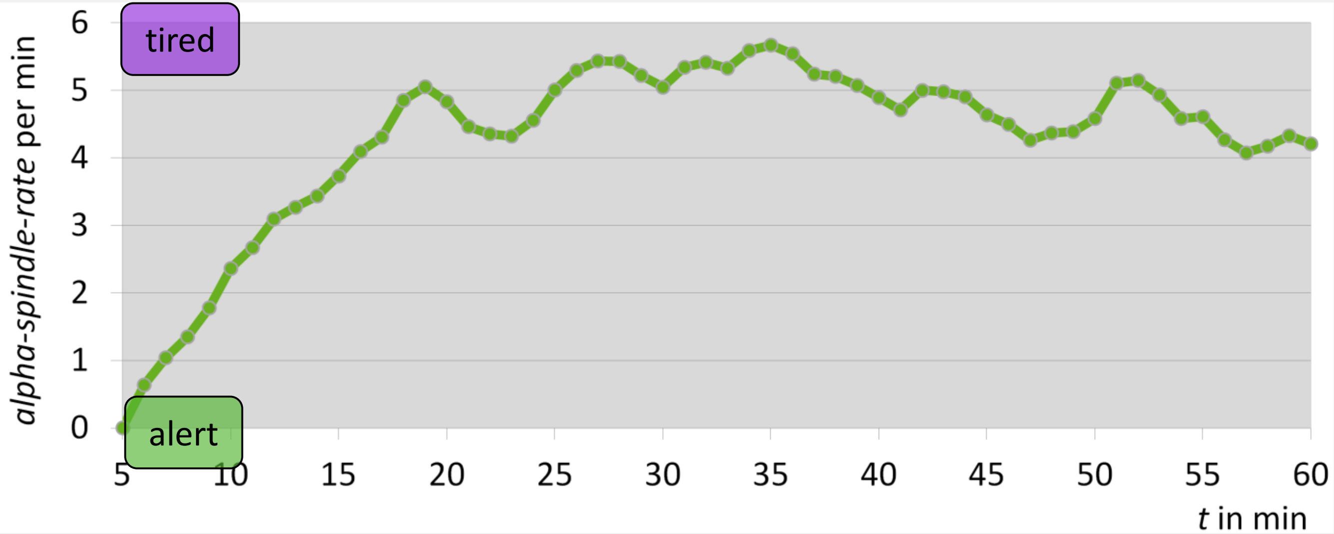
- **Wizard-of-Oz Vehicle** (WoOz) on a test track (highly monotonous oval course)
- Recording of psycho physiological data: **EEG-"alpha spindles"** (assumed as **neuronal correlates of humans' fatigue level**)
- *N* = 36: long automated periods (**approx. 60 min.**) constantly monitored by participants (regarding longitudinal and lateral control)
- **19 participants were classified as "got tired"** as follows (plot)

(Frey)

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES



Interestingly, **the fatigue level monotonously increases** up to a mean maximum of about six spindles per minute (relative to a baseline), and **remains constant after approx. 25 min.** with some oscillations.

(Frey)

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES

DURATION OF AN AUTOMATED DRIVE

FIXED TIME

Jarosch et al., 2017; Jarosch et al., 2019; Weinbeer et al., 2019; Frey; Radlmayr;

STATE DEPENDENT

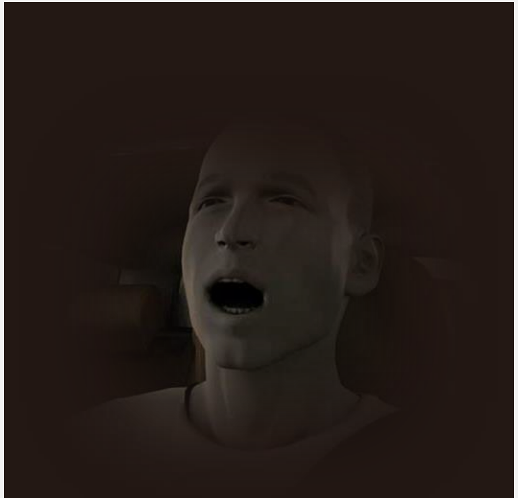
Weinbeer et al., 2017; Feldhütter et al., 2018;

INFLUENCE ON TAKE-OVER PERFORMANCE

METHODICAL CHALLENGES

DROWSINESS
(Weinbeer et al., 2017)

time (minutes)	DL4 (cumulative percentage)	DL6 (cumulative percentage)
0	0.00 %	0.00 %
5	3.33 %	0.00 %
10	10.00 %	0.00 %
15	20.00 %	0.00 %
20	23.33 %	3.33 %
25	30.00 %	10.00 %
30	46.67 %	16.67 %
45	60.00 %	40.00 %
60	73.33 %	56.67 %
75	76.67 %	60.00 %
>75	**76.67 %**	**63.33 %**
	never reached DL4: 23.33%	never reached DL6: 36.67%



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INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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METHODICAL CHALLENGES

Does drowsiness/ sleepiness or fatigue influence take-over performance?

How can these driver states be induced and assessed (in real traffic)?

INFLUENCE ON TAKE-OVER PERFORMANCE

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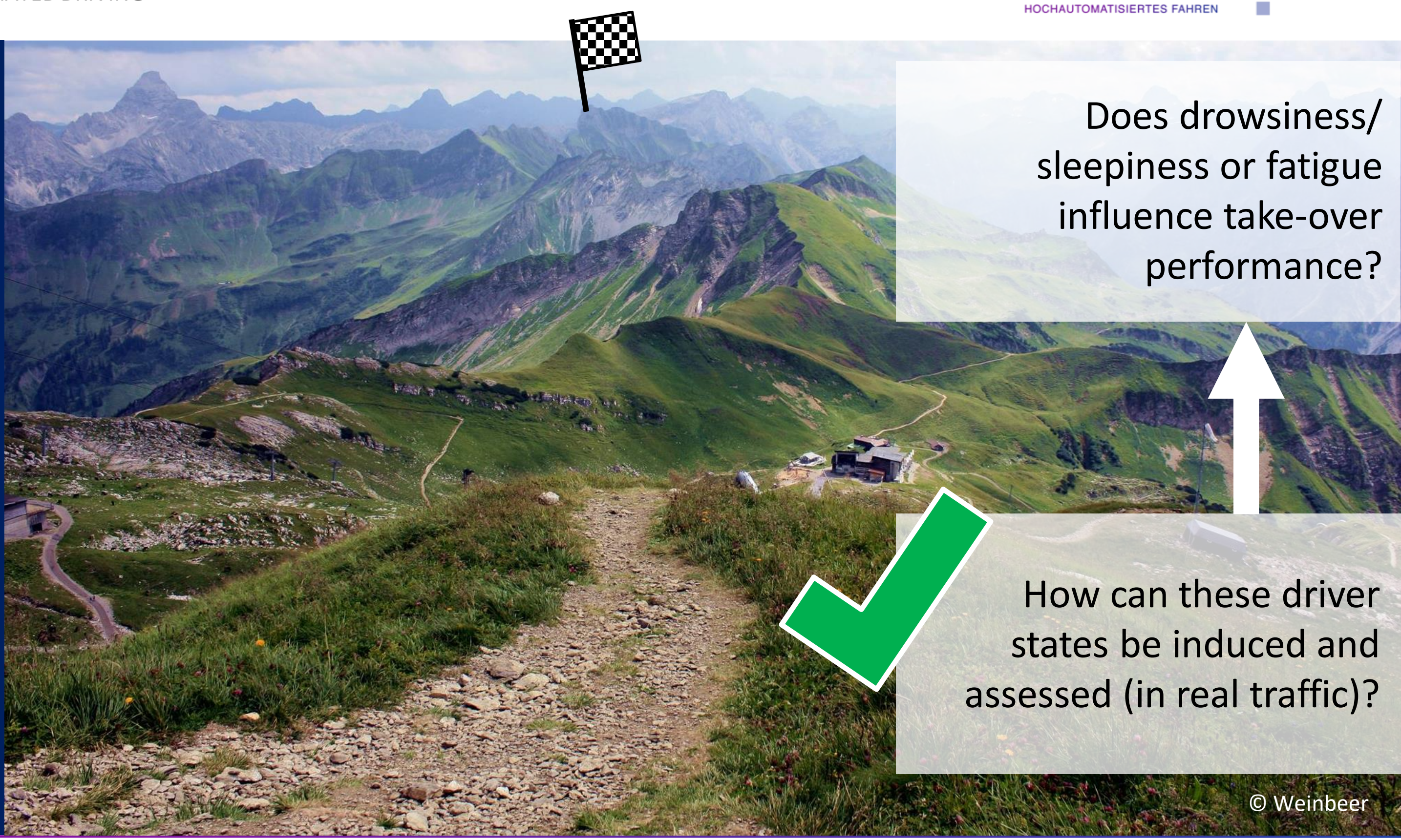
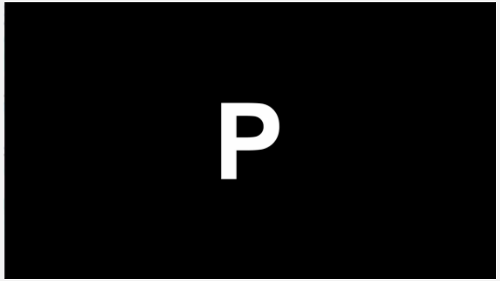


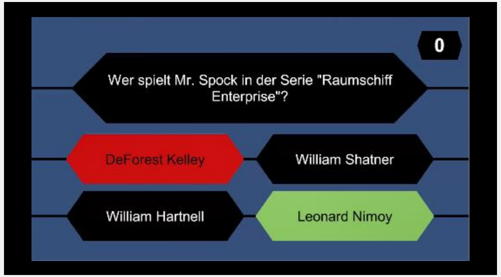
INFLUENCE ON TAKE-OVER PERFORMANCE

Take-over time and driving-related parameters

(25 Min.)

- No differences were found for the different NDRTs.
- Two accidents occurred after the TOR.
- One after the activating and one after the monotonous monitoring task.

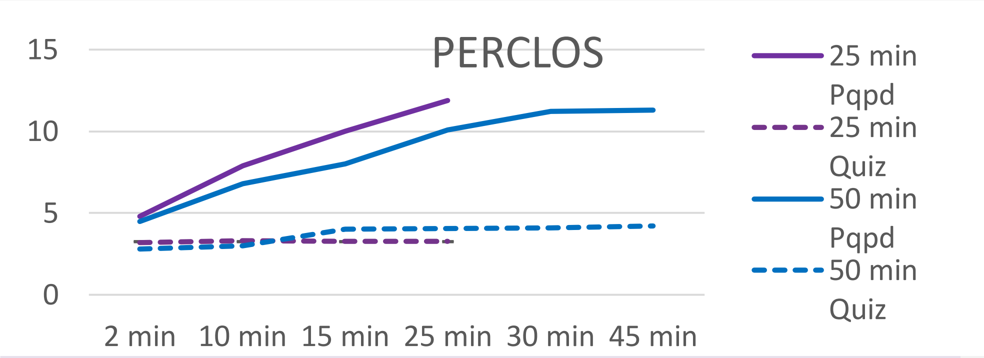


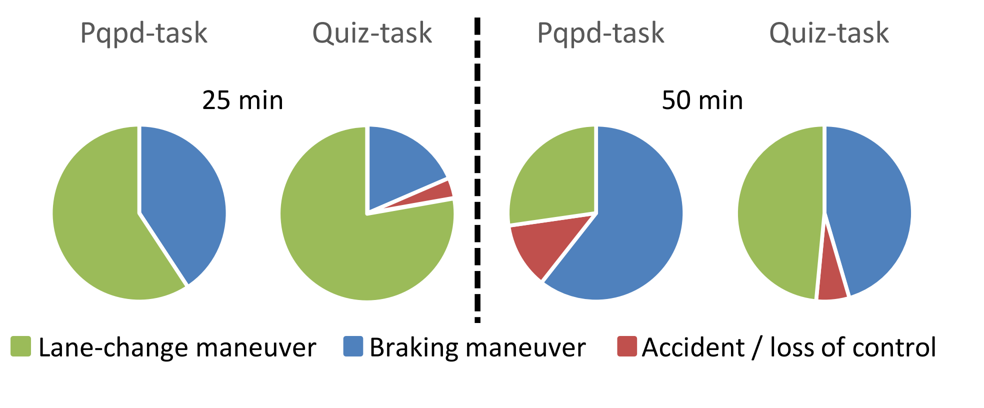


(Jarosch et al., 2017)

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING





- In a follow-up study the duration of the automated ride was increased to 50 min. The NDRTs and the scenario were identical to the first study.
- Take-over performance was impaired, especially for the monotonous NDRT.
(Jarosch et al., 2019)

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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Method: Driving simulator study (N=57, age=33 years, SD=13y)

Between subject factor
Group (level of automation and traffic destiny)

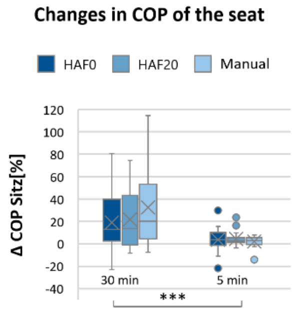
Within subject factor
Duration (2x5 min vs. 30 min)

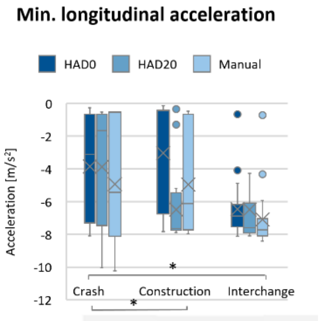
	Automation level	Traffic density	Duration of automated driving
HAD0	HAD	0 veh./km	30 min
HAD20		20 veh./km	5 min
Manual	Manual		5 min

Within subject factor
Take-over situation

Construction site	Crash Site	Autobahn interchange

Results





Conclusion

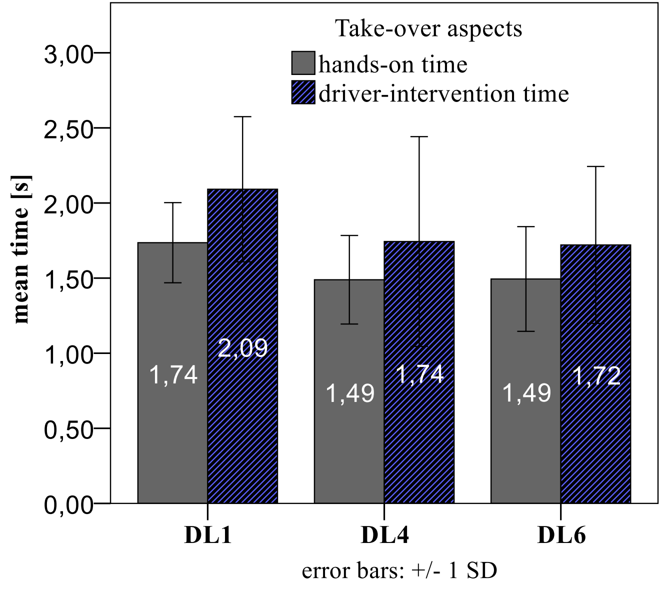
- Prolonged automated driving has significant influence on Eyes on Road Rate (EOR), pupil diameter and COP (activity of driver)
- Significant differences between the situations concerning
  - Min. longitudinal and max. lateral acceleration
  - Take-over time

(Radlmayr)

INFLUENCE ON TAKE-OVER PERFORMANCE

Take-over time aspects

- The drowsiness level did not significantly influence take-over time aspects.
- Some participants showed suprise in case of a RtI (gave a startled sound).



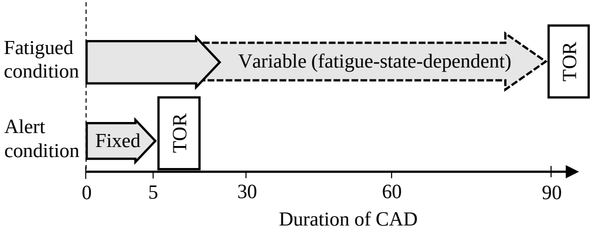
(Weinbeer et al., 2017)

KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

Method: Driving simulator study (N=47, age=24 years, SD=4y)

Between subject factor

Fatigue level (alert vs. fatigued)



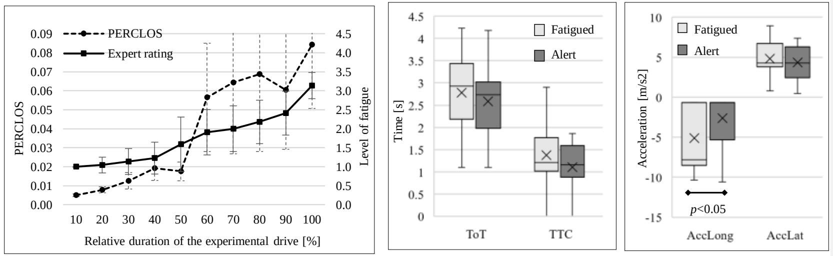
Fatigue Assessment in Fatigued Condition

- Two trained observers rated independently the participants' fatigue in real-time according to the scale of Karrer-Gauß (2011)
- Supported by fatigue detection tool developed by Feldhütter, Feierle, Kalb, and Bengler (2018)

Take-over Situation: Crash Site

- Medium complexity
- Right lane
- Time budget to take over: 6 sec

Results



Conclusion

- 77% of tested participants reached higher levels of fatigue within 90 minutes (mean time of driving = 42minutes, min=19min; max=80min)
- Fatigued driver conducted significant more frequently a full-braking maneuver and produced higher longitudinal accelerations due to full braking
- Fatigued drivers seemed to overreact in such a way that they conducted rather an unsecured minimal risk maneuver in order to reduce the risk of a collision than a consciously planned maneuver

(Feldhütter et al., 2018)

INFLUENCE ON TAKE-OVER PERFORMANCE

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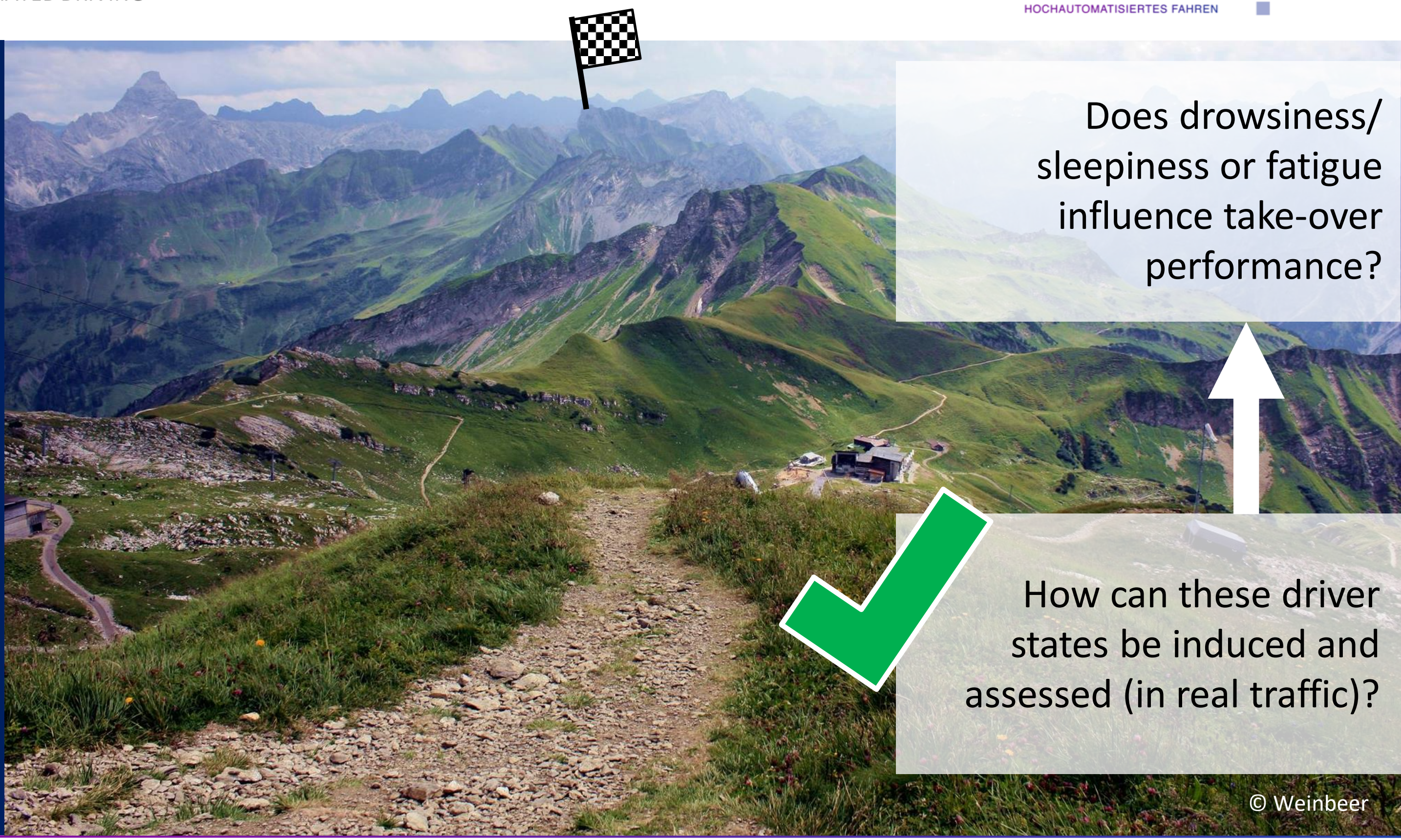
METHODICAL CHALLENGES



Does drowsiness/ sleepiness or fatigue influence take-over performance?

How can these driver states be induced and assessed (in real traffic)?

INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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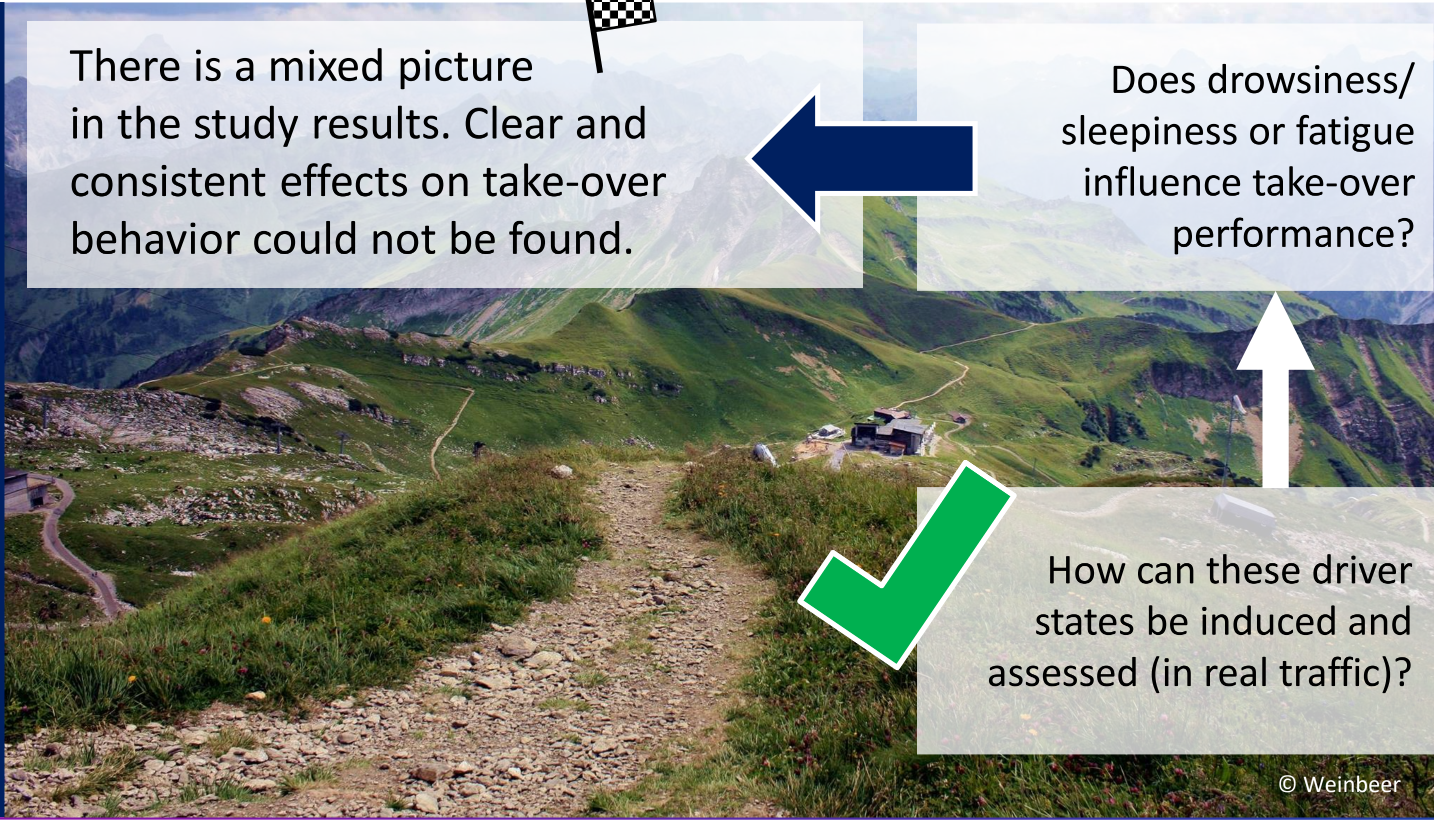
METHODICAL CHALLENGES



There is a mixed picture in the study results. Clear and consistent effects on take-over behavior could not be found.

Does drowsiness/ sleepiness or fatigue influence take-over performance?

How can these driver states be induced and assessed (in real traffic)?

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DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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STRATEGIES TO MANAGE DRIVER DROWSINESS

DRIVER-STATE-RELATED STRATEGY

(Weinbeer et al., 2018)

The reactivation potential of non-driving-related tasks was proved.

The reactivation remained effective even after the reactivation phase.

STRATEGIES TO MANAGE DRIVER DROWSINESS

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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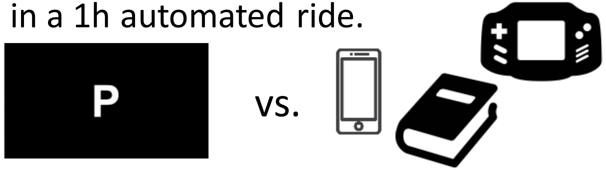
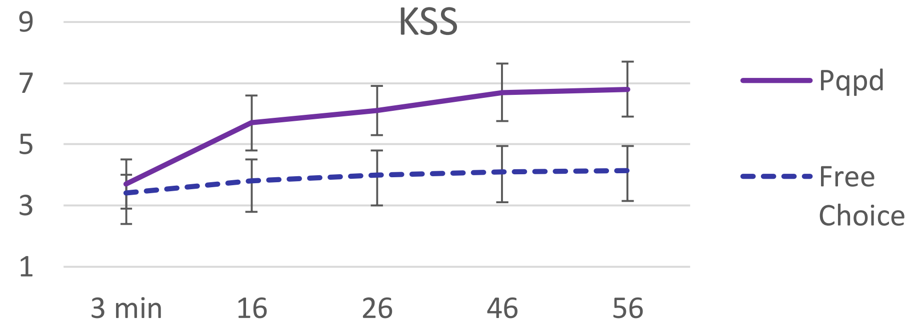
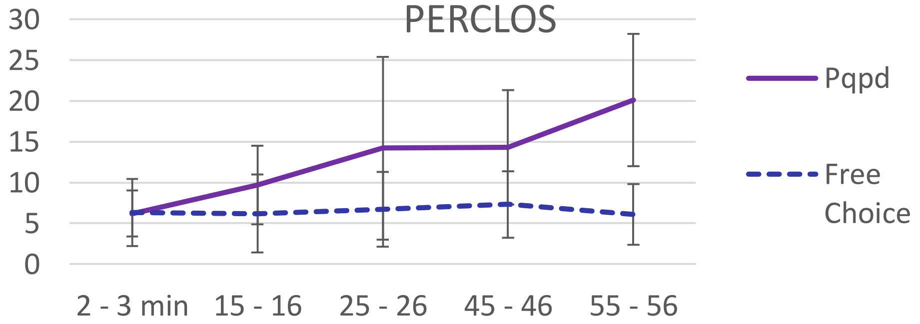
- In a Wizard-of-Oz on-road study effects of a monotonous monitoring task (Pqpd) were compared to a free-choice activity in a 1h automated ride.



- Fatigue did only emerge in the monotonous monitoring task group. In the free choice group it stayed on a significant lower level.





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CONCLUSION

METHODICAL CHALLENGES

It was possible to induce drowsiness and fatigue in test situations (without sleep deprivation).
Driver state changes could be detected by using several metrics and methods (under experimental conditions).

INFLUENCE ON TAKE-OVER BEHAVIOR

While driving with conditional automation, extreme levels of drowsiness and fatigue (drivers close to falling asleep) must be avoided. Clear and consistent effects on take-over behavior could not be found.

MANAGEMENT OF DRIVER DROWSINESS

Based on the detection of high levels of drowsiness and fatigue, countermeasures (e.g. a specific offer of NDRTs) can be initiated to avoid or to postpone such extreme driver states.

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