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
AN OVERVIEW
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

September 19th & 20th, 2018
Ko-HAF – Drowsiness and Fatigue in Automated Driving
AGENDA
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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

(Marberger et al., 2018)

(https://www.volkswagen-newsroom.com/de/muedigkeitserkennung-3932)
RELEVANCE IN THE CONTEXT OF AUTOMATED DRIVING

DROWSINESS AND FATIGUE IN 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).

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

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Model of human information processing (Wickens et al., 2013, p.4)
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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Does drowsiness/sleepiness or fatigue influence take-over performance?
INFLUENCE ON TAKE-OVER PERFORMANCE
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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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OVERVIEW
Simulators and test vehicles used in the different studies.
INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODOLOGICAL CHALLENGES

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

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

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

INFLUENCE ON TAKE-OVER PERFORMANCE
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

Right-hand-drive vehicle
(Weinbeer et al., 2017, Weinbeer et al., 2018)
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METHODOICAL CHALLENGES

Wizard rear-seat (Jarosch)

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METHODICAL CHALLENGES

BASt Wizard-of-Oz Vehicle (WoOz) (Frey)

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## Methodical Challenges

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

### Objective Metrics
- Heart rate
- Galvanic Skin Response
- PERCLOS
- Head position
- EEG
- COP of the seat

### Expert Ratings
- mainly based on the procedure provided by Wierwille and Ellsworth (1994)

## How Were These Driver States Assessed?
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
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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;
Self-reported sleepiness increased significantly ($p < .001$) during the monotonous monitoring task (24 min.)
During the activating task sleepiness did not change significantly.
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
PERCLOS

PERcentage of eyelid CLOSure
over the pupil over time

A valid objective measurement of fatigue
INFLUENCE ON TAKE-OVER PERFORMANCE

DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

METHODICAL CHALLENGES

PERCLOS – activating vs. fatiguing NDRT

Pqpd
Quiz
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)
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)
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DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

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;
## DROWSINESS

(Weinbeer et al., 2017)

<table>
<thead>
<tr>
<th>time (minutes)</th>
<th>DL4 (cumulative percentage)</th>
<th>DL6 (cumulative percentage)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00 %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>5</td>
<td>3.33 %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>10</td>
<td>10.00 %</td>
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<tr>
<td>15</td>
<td>20.00 %</td>
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<td>20</td>
<td>23.33 %</td>
<td>3.33 %</td>
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<td>25</td>
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<td>10.00 %</td>
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<td>16.67 %</td>
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<td>60.00 %</td>
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<td>60</td>
<td>73.33 %</td>
<td>56.67 %</td>
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<tr>
<td>75</td>
<td>76.67 %</td>
<td>60.00 %</td>
</tr>
<tr>
<td>&gt;75</td>
<td>76.67 %</td>
<td>63.33 %</td>
</tr>
</tbody>
</table>

never reached DL4: 23.33%
never reached DL6: 36.67%

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INFLUENCE ON TAKE-OVER PERFORMANCE

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

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

Method: Driving simulator study (N=57, age=33 years, SD=13y)
Between subject factor
Group (level of automation and traffic destiny)

<table>
<thead>
<tr>
<th>Automation level</th>
<th>Traffic density</th>
<th>Duration of automated driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAD0</td>
<td>HAD</td>
<td>0 veh./km</td>
</tr>
<tr>
<td>HAD20</td>
<td>Manual</td>
<td>20 veh./km</td>
</tr>
<tr>
<td>Manual</td>
<td>Manual</td>
<td>20 veh./km</td>
</tr>
</tbody>
</table>

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

- 30 min
- 5 min

Results

Changes in COP of the seat

Min. longitudinal acceleration

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)
Take-over time aspects

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

(Weinbeer et al., 2017)
### INFLUENCE ON TAKE-OVER PERFORMANCE

**DROWSINESS AND FATIGUE IN AUTOMATED DRIVING**

#### 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 = 42 minutes, min=19 min; max=80 min)
- Fatigued driver conducted significantly 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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Does drowsiness/sleepiness or fatigue influence take-over performance?

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

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

- 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
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING

**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.
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.
REFERENCES
DROWSINESS AND FATIGUE IN AUTOMATED DRIVING


Pictures:
- VW: https://www.volkswagen-newsroom.com/de/muedigkeitserkennung-3932
- AUDI AG: https://www.audi-mediacenter.com/de/suche?query=uhr&type=image&utf8=%E2%9C%93

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