What leads drivers to illicitly nap during conditionally automated driving?

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Abstract: Automation misuse can cause traffic hazards when drivers over-rely on automation and use it in ways that are not intended by the designers of the system. Automation abuse refers to designers of automation designing systems without regard to the consequences for human performance. In a driving simulator study, half of the participants were observed sleeping at least once during six drives with a conditionally automated driving (CAD) system. Sleep is an illicit driver behaviour in CAD because drivers must be available to take over vehicle control at system boundaries. However, sleep was not only observed in the driving simulator environment, but nearly half of the participants indicated that they intend to sleep during CAD in real life. CAD usage, gaze behaviour, subjective evaluation of CAD, trust and mental model of CAD were compared for participants who indicated they intended to sleep in CAD and participants who indicated no intention to sleep. The majority of participants understood that sleep is an illicit driver behaviour in CAD. Participants with the intention to sleep used the simulated CAD more and they reported higher comfort levels during CAD usage and perceived takeover situations as safer. Semi-structures interviews after the last drive indicated that drivers would sleep during CAD once they had some experience with the system. The results suggest that drivers, after gaining experience with CAD, become complacent and sleep during CAD even though they know that it can potentially lead to dangerous situations. Sleep during CAD is both automation misuse and automation abuse. Driver monitoring systems for CAD must detect and prevent sleep in drivers.

1. Introduction

When human operators of automated systems "rely uncritically on automation without recognizing its limits", they may use it in ways not intended by the designers of the automation. On the other hand, designers of automation might design systems without considering the consequences for human behaviour (Parasuraman & Riley, 1997). In our driving simulator study on "naturalistic" usage of a conditionally automated driving (CAD) system, we observed that 14 of 30 participants napped at least once during six drives. All participants were instructed to remain "sufficiently alert" to be able to resume control of the vehicle at any time during the drives. In CAD (level 3 according to SAE, 2021), the driver must respond with a short notice to a request to intervene at system limits or system failures. In our study, participants did not receive a warning when they were classified as "unavailable" to take back control as it is requested for CAD systems (UNECE, 2021). A request to intervene was only issued when drivers reached sleep stage N2 (stable sleep according to AASM, 2017). After completing six drives with the CAD in the simulator, drivers were asked about their intention to use CAD in real life. Half of the sample said they would sleep during CAD in real life.

Over-trust, high workload and a low (perceived) risk are associated with the misuse of automation (Parasuraman & Riley, 1997). In a naturalistic driving study, misuse of automation due to overconfidence in the system's capabilities led to 57% of all safety-critical events (Kim, Song, & Doerzaph, 2020). A wrong understanding of the system or wrong 'mental model' is one factor that leads to over-trust and over-confidence in the system (Abraham, Seppelt, Mehler, & Reimer, 2017; Seppelt & Victor, 2020). Studies show that partially and conditionally automated driving contribute to the development of drowsiness (Neubauer, Matthews, & Saxby, 2014; Schömig, Hargutt, Neukum, Petermann-Stock, & Othersen, 2015; Vogelpohl, Kühn, Hummel, & Vollrath, 2019). The observed instances of sleep during our study could be partially explained by the simulator environment. However, half of the participants stated that they would sleep during CAD in real life. The aim of the presented study was to understand why drivers intend to sleep during CAD.

2. Method

The principle objective of the driving simulator study was to investigate behavioural adaptation to a CAD. Participants were invited to take part in six driving sessions in a high-fidelity driving simulator. During each drive, they could use a CAD system for motorways. Participants were instructed with the wording of §1b of the German Road Traffic Act, which specifies the responsibilities of the driver when using CAD:

"[...] the driver may divert his attention from other traffic and control of the vehicle; he must, however, remain sufficiently alert that he can comply with the obligation [to retake control in response to a request to intervene]"

During each drive, participants experienced system boundaries and requests to intervene with a takeover time budget of 15s. Two of the driving sessions, the Baseline drive and the Sleepy drive (see Table 1), were designed with the aim of investigating the effects of fatigue and sleepiness. The EEG was measured during both drives. The Sleepy drive was scheduled at 6 a.m. and participants were sleep deprived to promote sleepiness during the drive. The driving environment was designed to be monotonous in both drives, with low traffic volume and fog to limit visibility. Sleep stages were coded according to the American Academy of Sleep Medicine standard (AASM, 2017) based on EEG. Eye-tracking parameters were measured using a SmartEye® fourcamera system. Driving and system parameters were recorded using Silab®. For a more detailed description of the study design and procedure, please refer to Metz et al., 2021.

Table 1 *Overview study sessions*

Session	Group 1	Group 2
1	Short drive	Short drive
2	Short drive	Short drive
3	**Baseline drive**	**Sleepy drive**
4	Short drive	Short drive
5	**Sleepy drive**	**Baseline drive**
6	Short drive	Short drive

2.1 Post-drive questionnaire and interviews

After each drive, participants completed a short version of the L3Pilot common questionnaire (Metz et al., 2020), which included questions on trust and attitudes towards CAD, willingness to use and mobility-related questions. The scale ranged from 1 (strongly disagree) to 5 (strongly agree). The questions on the mental model of CAD were added specifically for this study.

Although the Sleepy drive was designed to induce sleepiness, we did not expect participants to sleep. After observing participants falling asleep, we designed an interview guideline on intention to sleep during AD and conducted post-drive interviews with a subsample. The interview guideline included the following questions, among others:

1. Did you sleep during the study when the automated driving system was active? Did you sleep intentionally?

2. If you could use such a system in real life, would you sleep when it was active?

3. Is it possible to respond appropriately to a request to intervene when you are asleep?

2.2 Sample

N = 31 participants (13 female, mean age = 37, SD = 12) took part in the study. The interviews were conducted with a subsample of 22 participants (7 female, mean age = 41, SD = 12). All participants held a valid driving license and had completed an extensive driving simulator training.

2.3 Data analysis

The data of one participant were excluded from the analyses due to data loss, resulting in a final sample of N = 30 participants. A Multivariate Analysis of Variance (MANOVA) was performed to compare the effects of relevant behavioural measures and questionnaire responses between participants with the intention to sleep during CAD and participants without the intention to sleep during CAD. The dependent variables were:

- **System usage (%):** proportion of time the system was activated (measured with Silab)
- **NDRA (%):** proportion of driving with CAD which was spend on non-driving related activities (coded by the experimenter throughout the drives)
- **PRC:** Percentage Road Center, proportion of time the participant's gaze was directed to the windshield (measured with SmartEye®)
- **PerCLOS:** Percentage of eyelid closure, an eye-**tracking** based measure of driver drowsiness (Dinges & Grace, 1998), measured with SmarteEye®)
- **Willingness to use:** "I would use this system if it was in my car."
- **Perceived safety:** "I felt safe when driving with the system active."
- **Workload:** "Driving with this system was demanding."
- **Trust:** "I trust the system to drive."
- **Comfort:** "Driving with the system active was comfortable."
- **Increased drowsiness:** "Driving with the function on long journeys would make me tired."
- **Safety during takeover:** "During the takeover I always felt safe."

3. Results

14/30 participants experienced EEG-verified sleep at least once (Observed Behaviour). In the questionnaire after the sixth driving session, 15/30 participants stated that they would sleep at least very infrequently if they had CAD in their car (Behavioural intention). In the same questionnaire, participants were asked about their mental model of CAD. They had to indicate if a statement was correct (Yes) or incorrect (No) or if they were not sure (I don't know). 2/30 participants stated that sleeping is allowed in CAD and three participants were not sure if it is allowed (Mental model, see Table 2).

Table 2 *Overview of observed behaviour during the study, behavioural intention in real usage and mental model of CAD*

Observed behaviour	Behavioural intention	Mental model (Sleep allowed)		
		Yes	No	I don't know
Sleep	Yes	2	6	3
	No	0	3	0
No sleep	Yes	0	4	0
	No	0	12	0

3.1 Behavioural data and questionnaire data

The MANOVA revealed significant effects of system usage, NDRA engagement, willingness to use, comfort and perceived safety during takeover on the behavioural intention to sleep (for an overview of statistical figures, see Table 3).

Table 3 *Means, Standard Deviations and One-Way ANOVA of observed behaviour and questionnaire answers based on the Behavioural intention to sleep*

Measure	Behavioural intention				F(1, 27)	p
	Yes		No			
	M	*SD*	*M*	*SD*		
System usage (%)	**0.93**	**0.03**	**0.87**	**0.11**	**4.267**	**.049**
NDRA (%)	**0.79**	**0.14**	**0.56**	**0.35**	**6.210**	**.019**
PRC	0.23	0.10	0.37	0.24	4.095	.053
PerCLOS	0.14	0.12	0.18	0.24	0.543	.467
Willingness to use	**4.53**	**0.52**	**3.71**	**1.20**	**5.806**	**.023**
Perceived safety	4.07	0.70	3.50	1.10	2.799	.106
Workload	1.60	0.51	1.93	1.00	1.277	.268
Trust	3.40	1.55	3.71	0.82	0.455	.506
Comfort	**4.53**	**0.64**	**3.71**	**1.10**	**6.370**	**.018**
Increased drowsiness	3.40	1.24	3.50	2.03	0.026	.873
Safety during takeover	**4.60**	**0.51**	**3.64**	**1.15**	**8.605**	**.007**

3.2 Interview data

When interviewed after the drive, 7/22 drivers stated that they would sleep when using a CAD system. They stated that time would pass more quickly and they would catch up on sleep. Some participants indicated that they would only sleep under certain conditions, for example only in low traffic scenarios or only on familiar routes. Some participants indicated that they would observe the system first and if it worked as intended, they would feel safe enough to sleep. In general, participants who intended to sleep indicated that it would make their journey easier. Only one participant believed that it is possible to respond appropriately to a request to intervene after sleep.

4. Discussion

Sleep is an illicit behaviour during CAD and it can lead to dangerous situations if drivers are not able to take over vehicle control at system boundaries. Despite repeated experience with system boundaries, half of the participants of our driving simulator study stated their intention to sleep during CAD. The majority of the sample was aware that sleeping is not allowed in CAD. Thus, a wrong system understanding was not the reason for participants' intention to sleep. Contrary to Parasuraman and Riley's (1997) definition of automation misuse as being associated to over-trust, we found no relationship between trust and intention to sleep. Participants who were generally more willing to use CAD and used it more frequently during the study indicated their intention to sleep in CAD. This was also reflected in interview statements that participants found it useful and comfortable to sleep while travelling. Increased sleepiness due to automation or the objective drowsiness during CAD use, as measured with PerCLOS, did not influence the intention to sleep in CAD. The perceived safety of driving with CAD did not have an effect, but the perceived safety during takeovers had an effect on the intention to sleep. One explanation for this could be that drivers who experience takeover situations as safe might believe that they can handle these situations safely after waking up from sleep. It seems that after drivers gain experience with the system, they become complacent (Parasuraman & Manzey, 2010). Although they are aware of system boundaries, they develop the false feeling that "everything is fine" when in fact, sleep can lead to hazards in takeover situations (Wörle, Metz, Othersen & Baumann, 2020). However, it has to be taken into account that in our study, although we used EEG to monitor driver state and detect sleep in drivers, we did not warn participants before they fell asleep. That way, the CAD system enabled drivers to sleep and did not prevent them from falling asleep. Drivers sleeping during CAD in our study and drivers' intention to sleep is an abuse of automation. CAD enables drivers to retrieve from the driving task and therefore increases the risk for sleep.

5. Conclusions

Despite knowing that it is not allowed, drivers might become complacent and sleep when using a CAD system. Sophisticated driver monitoring systems should be implemented not only to detect drowsiness, but also to prevent drivers from falling asleep. If a driver falls asleep, a minimal risk maneuver should be initiated to ensure safety.

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