Tenth International Conference on Managing Fatigue: Revised Abstract

Asleep behind the automated wheel – Tired and drowsy drivers in highly automated vehicles

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Problem

Drivers in vehicles with high levels of automation are sometimes required to supervise the automated vehicles and to react to take-over requests in challenging driving situations (Gasser et al., 2012). Due to the lack of active involvement in the driving situation and due to monotonous driving environments automated drivers may become fatigued and tired faster than manual drivers (Schömig et al., 2016). This may be especially true for drivers who are already tired and could potentially lead to delayed reactions, impaired driving performance and reduced situation awareness in a take-over situation (i.e. Desmond et al., 1998).

Method

To determine if driving with automation induced fatigue faster than manual driving we conducted a driving simulator study with $N = 60$ participants between 18 and 87 years of age ($M = 41.32$, $SD = 21.06$). The experimental design comprised the two between-subjects factors *(1) sleep deprivation (yes/no)* and *(2) automation (yes/no).* Half of the participants were instructed to sleep for a maximum of 5 hours the night before taking part in the study and were invited to the simulator only at night between 8 p.m. and 12 p.m. Participants in this condition had slept for an average of 4 hours and 52 minutes the night before taking part in the study. The other half of the participants was instructed to sleep normally and was invited to take part in the study either between 9 a.m. and 11 a.m. or between 3 p.m. and 5 p.m. Participants in these conditions had slept for an average of 7 hours and 52 minutes the night before taking part in the study.

Participants were then further subdivided into a manual driving condition and an automated driving condition. The automated driving condition was set up as a level 3 (conditional) automation according to SAE (2013) with the ability to overtake slower cars and react to changes in the posted speed limits. As a driving scenario we used a three lane highway with intermediate traffic density.

We analyzed the progression of fatigue during the drives using rule based facial indicators of fatigue which were recorded by three trained raters (cf. Wierwille & Ellsworth, 1994 and Dittrich et al., 2009). Facial indicators included such measures as blink duration, eye movements, yawning and other behavioral indicators of fatigue. If a participant in the sleep deprived conditions reached an intermediate level of sleepiness, a realistic complex take-over scenario was triggered to analyze take-over time and take-over quality. The same scenario was triggered in the normal sleep conditions after a total driving time of approximately one hour.

Results

Automated drivers showed a strong increase in facial indicators of fatigue after 15 to 35 minutes of driving (see Figure 1). Manual drivers only showed similarly strong indicators of fatigue in the sleep deprived condition and after a longer period of driving (see Figure 2).

As can be seen from Table 1, half of the participants in the *sleep deprived automated driving* condition had already shown indicators of intermediate levels of fatigue after 25 minutes. In the *sleep deprived manual driving* group a comparable amount of participants exhibited these indicators only after approximately 40 minutes of driving.

In the *automated driving group without sleep deprivation* a mean sleepiness level of 3.3 (indicating intermediate fatigue) was reached after approximately 35 minutes of driving. In the *manual driving group without sleep deprivation* a maximum mean sleepiness level of 1.5 (indicating light fatigue) was reached after approximately 30 minutes of driving and did not further increase with driving time. Several drivers in both automated driving conditions closed their eyes for extended periods of time or even fell asleep, as can be seen from the number of "Very strong fatigue" ratings in Figure 1.

Mean automation-off times for the automated driving conditions were marginally slower with *M* = 3.2 (*SD* = 2.1) seconds for the sleep deprived automated drive compared to *M* = 2.4 (*SD* = 0.9) seconds for the long duration automated drive. We found a significant main effect for the time to the first glance to the speedometer between the automated driving condition and the manual driving condition ($F(1,50) = 9.0$, $p < .01$)) with reaction times of *M* = 10.4 (*SD* = 6.1) seconds for the manual driving condition and *M* = 12.2 (*SD* = 5.2) seconds for the automated driving condition.

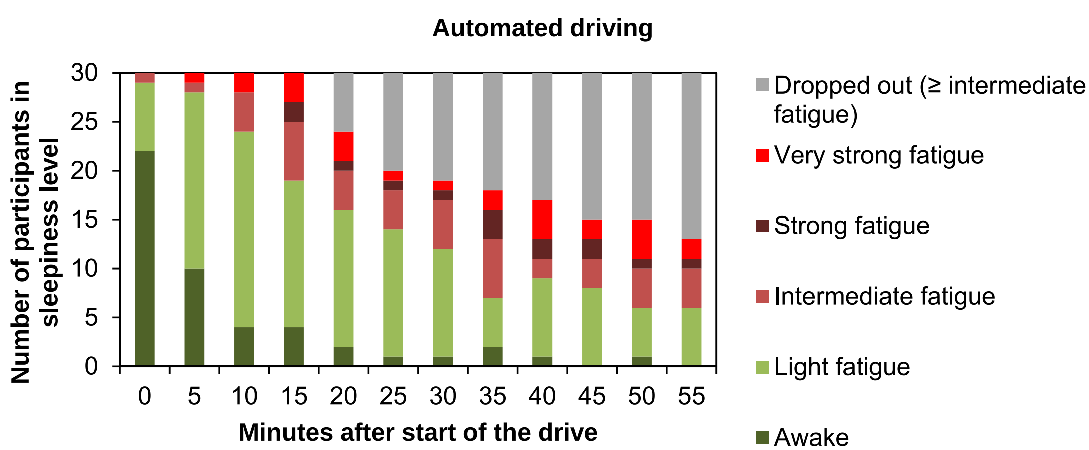

Figure 1: Development of fatigue during in the automated driving conditions. In the sleep deprived experimental conditions participants *dropped out* after reaching an intermediate level of fatigue, because a critical driving event was triggered. In the condition without sleep deprivation this event was triggered after approximately 55 minutes of driving.

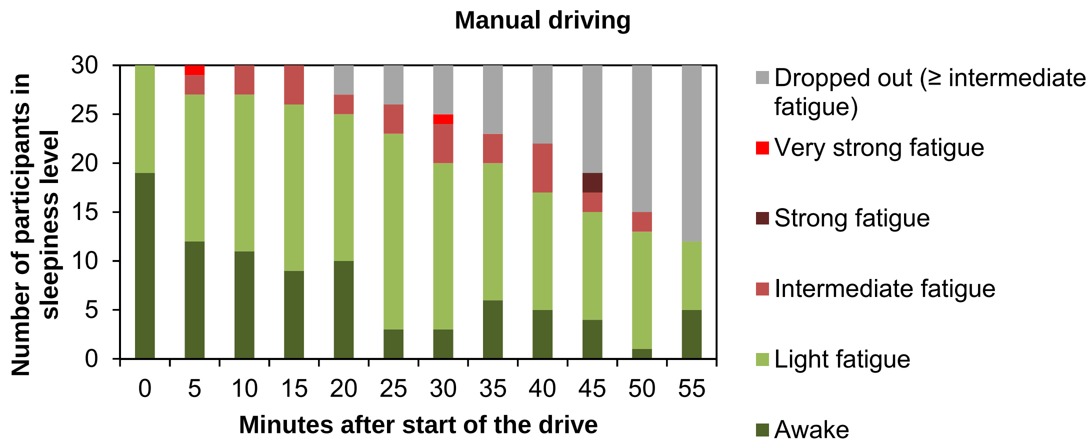

Figure 2: Development of fatigue during in the manual driving conditions. In the sleep deprived experimental conditions participants *dropped out* after reaching an intermediate level of fatigue, because a critical driving event was triggered. In the condition without sleep deprivation this event was triggered after approximately 55 minutes of driving.

Table 1: Mean sleepiness ratings by trained raters for the four experimental conditions over time. Dashes indicate that 50% of the participants had dropped out of the ratings due to the take-over request. Mean values for <50% of the participants would not appropriately reflect sleepiness levels and are therefore not reported.

	Mean sleepiness ratings by trained raters after … minutes of the drive											
Experimental Condition	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
Automated Driving + Sleep Deprivation	0.4	1.5	2.1	3.1	3.7	-	-	-	-	-	-	-
Automated Driving + Long Drive	0.2	0.7	1.2	1.6	2.3	2.2	2.3	3.3	3.7	3.2	3.8	3.2
Manual Driving + Sleep Deprivation	0.4	1.4	1.0	1.2	1.1	1.2	1.6	1.3	-	-	-	-
Manual Driving + Long Drive	0.1	0.5	0.5	0.7	0.7	0.9	1.5	0.9	1.0	1.3	1.1	0.5

Discussion

Drivers with high levels of automation are not able to stay alert to their surroundings during extended periods of automated driving without secondary tasks. Some drivers may even fall asleep and become unaware of system errors or changes in the driving conditions. This effect seems to be especially pronounced with sleep deprived drivers, but is also present in drivers without sleep deprivation after longer periods of automated driving. Reaction times may not be directly transferable from a driving simulator to real world driving. However, already approximately 30 minutes of automated driving (or 15 minutes of sleep deprived automated driving) without manual interventions by the driver and no secondary tasks may leave up to half of the drivers in automated vehicles drowsy or falling asleep. Longer reaction times for the first glance to the mirror in the automated driving condition may indicate a delay in the build-up of situation awareness after a take-over situation.

Fatigued drivers could pose a serious hazard in complex take-over situation where driver intervention is required and situation awareness of a fatigued driver may be diminished.

Driver fatigue monitoring could be necessary in highly automated cars to ensure a certain level of alertness during the drive. Distraction through in-car infotainment or nomadic devices could also help to reduce sleepiness during automated driving and provide information to the car about the drivers' level of preparedness for a take-over situation.

Summary

Drivers in highly automated vehicles become tired faster than manual drivers. This effect is especially pronounced for sleep deprived drivers. Fatigued drivers in automated vehicles may not be able to adequately react to take-over scenarios and would likely be unable to detect system errors. Driver fatigue monitoring, regular transitions back to manual driving or the use of in-car infotainment systems during the automated drive may be able to reduce the adverse effects of sustained periods of automated driving and keep the driver alert for rare critical situations, but were not researched in this study. The effectiveness of such countermeasures for fatigue in automated drivers should be the focus of future investigations.

References

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