Drowsiness and fatigue in conditionally automated driving – Towards an integrative framework

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Abtract

The introduction of conditionally automated driving (CAD) will change the role of the driver fundamentally. Drivers can be engrossed in non-driving related tasks (NDRTs) or fulfill a new role of a passive passenger while the automation executes the dynamic driving task (DDT). In both cases, fatigue and/or drowsiness could impair drivers' availability for an upcoming take-over if the automation reaches a functional limit. In that case, CAD relies on drivers to act as a *fallback ready user* to take-over control manually. We propose an addition to the framework proposed by Marberger et al. (2017) with a more detailed look on the constructs *drowsiness and fatigue* and their interdependencies within the framework and additional aspects of driver availability. This work also provides a comprehensive overview on relevant literature regarding these constructs in general and the current state of research concerning CAD. Furthermore, it includes selected findings and recommendations from the German joint project *Cooperative Highly Automated Driving – Ko-HAF*. We conducted 14 experiments of prolonged automated driving periods, to reveal effects of drowsiness and fatigue on drivers' availability. This work integrates the lessons-learned and the development of advanced methods and procedures derived from the extensive empirical expert knowledge.

Introduction

Increasing vehicle automation (SAE International, 2016), raises new demands on drivers' abilities depending on the particular level of automation. In SAE level 2 (partial driving automation), 3 (conditional driving automation) and level 4 (high driving automation), long periods are imaginable, in which the automation executes dynamic control of the vehicle. Nonetheless, drivers will still have the need or possibility to drive manually. Especially in SAE-levels 2 and 3, humans represent the fallback level, and thus must be able to take over control in case the automation reaches a system limit. Therefore, current research projects focus on questions concerning the driver's state and availability for such a take-over (e.g. on SAE-level: Cooperative, highly automated driving – Ko-HAF, 2015 – 2018). Estimating the

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driver's availability is necessary in SAE-level 3 to decide if the human driver can act as a fallback ready user (SAE International, 2016) in a defined time span. For level 2, drivers must remain in the driving loop and monitor the automation and the surroundings. In case a system limit is met, drivers are expected to continue driving manually right away. Consequently, problems regarding the driver's attention (driver's vigilance to execute the monitoring task in SAE-level 2), driver's fatigue, or driver's drowsiness in SAE-level 3 are prominently discussed in current research (Radlmayr et al., 2014; Körber et al., 2015; Miller et al., 2015; Neubauer et al., 2012).

In addition, drowsiness and fatigue are well known and relevant causes for road accidents in manual driving. Referring to the report on drowsy driving from the National Center for Statistics and Analysis (2017), 3662 fatal crashes occurred between 2011 – 2015 due to drowsy driving or an inadequate driver's state. In another report published by the National Sleep Foundation in 2011, an alarming proportion of 52 % of the participants indicated that they had driven drowsy. 6 % of the participants reported to do so three times a week.

This highlights the challenges of designing driving automation and the necessity to focus on drowsiness and fatigue especially in SAE-level 3, conditionally automated driving (CAD): the automation level itself and the resulting paradigm shift (no need to control or monitor the system/automation/surroundings) potentially motivate higher levels of drowsiness and fatigue even though the human performance in take-overs is highly safety-critical.

Drowsiness and fatigue: literature, definitions, understanding

Starting with SAE-level 2, psychological constructs such as vigilance, fatigue, drowsiness, sleepiness and how they are interlinked with the overall driver state, play an important role for all efforts in improving road safety. In SAE-level 2, the driver needs to monitor the vehicle's guidance as well as the surrounding environment, whereby the automation requires the human to intervene immediately, if a system limit is met. However, basic psychological research indicates that these vigilance tasks are very stressful and accompanied with human failures (Parasuraman & Riley, 1997; Warm, Parasuraman, & Matthews, 2008). Laboratory experiments show that humans miss stimuli after about 15 minutes using standardized vigilance tasks (Teichner, 1974). One possible explanation could be an increasing fatigue level, caused by monotonous tasks transmitting so called passive task related fatigue (May & Baldwin, 2009).

As mentioned above, in SAE-level 3, drivers must still be able to take over control safely in case of a request to intervene (RtI) (Marberger et al., 2017). Hence, this paper focuses on the transitional state between wakefulness and sleep, which might impair take-over performance. Johns (1998) definded this state as "drowsiness", May and Baldwin (2009) defined this state as "fatigue", including active (increased workload/overload, intensive secondary/non-driving related task (NDRT) engagement), passive (underload conditions, monotonous/extended driving, automation effects) and sleep-related fatigue. In addition, the terms drowsiness, sleepiness, fatigue, and tiredness are often used synonymous (for example some researches investigate the influence of fatigue by using a sleepiness scale). As the sources and reasons of theses constructs often overlap considerably, we use these terms drowsiness and fatigue interchangeably in the following and focus on the influence of different causes of their development, on the possibility to detect changes in them and the general driver state respectively and on the consequences on take-over performance. Nonetheless, we provide a short overview on the most prominently used definitions, which distinguish these constructs to allow a more comprehensive understanding.

Johns (2007) defines the constructs drowsiness and fatigue according to the Shorter Oxford English Dictionary. Drowsiness is a state of being "inclined to sleep, heavy with sleepiness, half asleep, dozing", being synonymously with the adjective "sleepy" (Johns, 2007). Consequently, the state of being drowsy describes the interval between wakefulness and sleep, being the "fluctuating state that shares some of the characteristics of alert wakefulness and some of sleep" (Johns, 2007). In addition, fatigue is being understood as "weariness resulting from bodily or mental exertion", which is synonymous with "tiredness" (Johns, 2007). Consequently, the two constructs drowsiness/sleepiness and fatigue/tiredness are clearly separated from one another, allowing a clearer attribution of effects, measures and consequences. Fatigue is a "subjective state of weariness" (Johns, 2007) and can be relieved by rest, whereas drowsiness is understood to be only relieved by sleep. This is in contrast to e.g. the understanding of May and Baldwin (2009), where fatigue is understood to contain both task-related fatigue and sleep-related fatigue where the latter can be understood to represent drowsiness/sleepiness in Johns (2007) and is defined very similar in both definitions.

In addition to drowsiness and fatigue, attention in general and vigilance need to be considered in the context of automated driving. While vigilance is of higher interest for SAE-level 2, since the driver needs to monitor the automation and the surroundings, the construct of attention and attention selection of drivers needs to be considered in SAE-level 3 as well. Drivers can engage in non-driving related tasks in SAE-level 3, potentially managing their level of arousal, subsequently influencing their individual levels of drowsiness and fatigue. Markkula, Victor, and Engström (2017) provide a conceptual model of attention. The concept includes a detailed look on attentional impairments, differentiating between impairments originating from being asleep versus being drowsy but only a more general view from attentional impairments from fatigue-related causes. In addition, the model focusses on manual driving, subsequently including distraction. In the context of CAD, this distraction becomes engagement into e.g. NDRTs and rather results in automation effects on a potential take-over in contrast to a degraded performance resulting from distraction.

Concerning the relation of vigilance and drowsiness and fatigue we refer to Vogelpohl et al. (2016). Shortly summarized, vigilance is defined as a condition of general alertness, which is additionally characterized by mental arousal, affected by physical as well as mental fatigue (Vogelpohl et al., 2016). Combining both constructs (vigilance and fatigue) – and not focusing on sleep deprivation – Vogelpohl et al. (2016) explain that factors like task difficulty or the (driving) environment cause a high workload condition (immediate effect of fatigue; active mechanism) or a low workload condition (effect of vigilance, resulting in fatigue; passive mechanism).

Focusing more on the effects of drowsiness and fatigue on human performance in the driving context, previous studies like Jewett et al. (1999) reported deteriorated reaction times in a psychomotor vigilance task in reference to hours of sleep. When the amount of sleep increased, the reaction times of the participants improved. Other aspects like diminished capacity for work, disinclination to apply effort to a task, impaired personal efficiency and subjective discomfort are also linked to fatigue (Matthews & Desmond, 2002). Impaired driving performance and deteriorated reaction times due to drowsiness and fatigue could be demonstrated in driving simulator studies as well (Philip et al., 2005). Neubauer et al. (2012) suppose that factors provoking active task-related fatigue can be minimized in conditionally automated driving as the system is performing the driving task. For example, the system will also be able to drive in high traffic-density conditions and a previous, in manual driving, distracting secondary task will turn to a non-driving related task in automated driving. In manual driving such factors provoked task-related fatigue. Contrary, different effects arise when considering passive task-related fatigue. Referring to the fatigue model of May and Baldwin (2009), factors that can lead to this form of fatigue are directly connected to automated driving. In their model they name increasing monotony and automation as examples for origins for passive task-related fatigue. Increasing automation means a reduction of tasks for the human driver which will consequently lead to a more monotonous situation when driving automated.

In conclusion, this chapter illustrates the abundance of theoretical classifications of different concepts such as attention, vigilance, drowsiness, sleepiness, fatigue, arousal, etc. While all these models add to a better understanding of the interdependencies between these constructs, only very few offer empirical backup or are specifically focussing on conditionally automated driving. Consequently, we will use drowsiness and fatigue in this work as describing various constructs relating to a more general arousal of drivers in CAD in the framework of driver availability by Marberger et al. (2017). The combination of drowsiness and fatigue is not “unified” to one new or existing term or definition in order to convey the difference between “sleep/drowsiness-related effects” and “fatigue-effects”, in line with Johns (2007) and May and Baldwin (2009). The framework by Marberger et al. (2017) offers the theoretical understanding important to this work: in conditionally automated driving, the transition from automated driving to manual driving and consequently the transition of a current driver state to a target driver state (able to take-over and continue driving manually) is of utmost interest. Thus, we will focus on effects from e.g. prolonged automated driving or monotonous or engaging non-driving related tasks on “drowsiness and fatigue” of drivers with respect to how this changes or effects can be measured and how they are affecting an upcoming take-over and drivers’ performances.

Methods and metrics to measure drowsiness and fatigue

Robust and valid measures to record humans’ drowsiness and fatigue level are required. For the assessment of drowsiness and fatigue in previous studies different methods were used. Frequently used methods can be distinguished in subjective, physiological and eye-lid based measures. A common questionnaire for the assessment of subjective drowsiness and fatigue is the Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990). With the help of a nine-point Likert scale participants have to state their level of drowsiness and fatigue. If researchers ask participants to specify their level with self-reported scales like the KSS, participants possibly are reactivated at this moment (Schmidt et al., 2011), preventing a realistic progression. In addition, humans are often not able to estimate their true drowsiness and fatigue level (Schmidt et al., 2009). A possible solution is the usage of psychophysiological data. Typical parameters are heart-rate, heart-rate variability (Manzey, 1998) and electroencephalography (EEG; Simon et al., 2011). Another method for the assessment of drowsiness and fatigue are eye-lid based metrics. Percentage of eye-lid closure over time (PERCLOS; Wierwille & Ellsworth, 1994), mean blink duration (Schleicher et al., 2008) and blink-frequency (Dinges & Grace, 1998) are described to be good indicators for drowsiness and fatigue. In general, eye-tracking methods are a useful tool to estimate humans' availability. In contrast to subjective rating tools (e.g. KSS, etc.) and intrusive physiological methods such as EEG, researchers can display the overall fatigue evolution process without disturbing the participant in case the eye-tracking is realized without a head-based eye-tracker.

The so called alpha spindles (EEG-based) are assumed as neuronal correlates of human fatigue levels (Simon et al., 2011). It is recommended to validate this method by analyzing participants' video data for example. Wierwille and Ellsworth (1994) propose an opportunity to rate the level of drowsiness and fatigue by video data using specific cues. While individual cues are not sufficient to detect drowsiness and fatigue, a higher occurrence probability is highly correlated with higher levels of drowsiness and fatigue. For example, a higher frequency of head movements such as rolling or nodding is a cue for an onset of drowsiness and fatigue (Senaratne et al., 2007). In addition, hand movements towards the face and posture adjustments have been found to be valid cues (Anund et al., 2013; Senaratne et al., 2007).

Concluding, the various methods and metrics of detecting drowsiness and fatigue all present individual strengths and weaknesses but our experience in Ko-HAF has shown, that eye-tracking methods present the most promising tool. While head-based solutions typically offer a higher quality of tracking, these solutions are not qualified for future use in commercial vehicles due to obvious reasons. Concerning specific metrics, we found eye-lid-based metrics to be most valid for detecting drowsiness and fatigue.

Recommendations for the empirical setup

Driving simulators are a prominent tool to display any situation with high experimental control and any automated driving function. The simulation can induce a situation which prompts participants to become tired without representing a hazard. However, driving simulators typically work with projectors in dark environments. This effect of lighting could affect valid measurements of driver's fatigue (Åkerstedt et al., 1979). Contrary, studies in real-driving environments deal with low internal validity, because reproducibility is very weak even though the surroundings are real. For more details on the validation of selected driving simulator scenarions in comparison to a real driving scenario, please refer to Frey (2016). A solution balances advantages and disadvantages concerning internal and external validity problems. Test track conditions can perform very satisfactorily, if experimenters take the monotony, daytime and participant's instruction into account.

To realize a realistic impression of vehicle automation on a test track, a so-called Wizard of Oz test vehicle can be used (Dahlbäck, Jönsson & Ahrenberg, 1993). There are some differences in vehicle concepts, but they all look to create an illusion of a pre-defined automated driving setting. In complex and highly immersive implementations, participants sit on the driver's seat and are able to drive manually. Additionally, the wizard is able to take over longitudinal and lateral control of the vehicle by using a second set of pedals and a steering wheel in a darkened compartment behind the participant (invisible for him/her). This adds the possibility of automated driving for participants. All levels of vehicle automation can be reproduced by fitting the compartment with the necessary hardware, cameras and displays for the wizard. This allows for a very broad and powerful empirical setup, since different levels of automation can be realized by instructed and trained "wizard-drivers" without the need to use a dedicated technical system. In less immersive Wizard of Oz vehicles, an additional steering function and pedals from the passenger's seat is sufficient for the research question and setup. In this case, participants are informed about the wizard but can still experience effects of automated driving, e.g. engaging into non-drivig related tasks (Marberger et al., 2007). The usage of Wizard of Oz vehicles on test tracks is very advantageous: Real vehicle dynamics with arbitrary reliability and functional scope of an automated driving system are combined with moderate experimental control and realistic environmental influences (e.g. weather conditions, lighting, noises, etc.). This led to several experiments using Wizard-of-Oz-vehicles of different maturity concerning the displayed automation. The experiments focused mainly on the development of drowsiness and fatigue in real driving environments to allow a proof of concept of corresponding experiments in simulators. In many experiments on drowsiness and fatigue in simulators, the simulator environment is portrayed as limiting the validity of the methodical approach: participants might be more prone to allowing drowsiness and fatigue due to the different risk setting. Even though the experiments in real traffic were unable to compare safety critical take-overs, results indicate that the development of drowsiness and fatigue does not show differences between simulator and real traffic surroundings in the Wizard-of-Oz approach. This adds to the validity of results from simulator experiments on the influence of drowsy and fatigued drivers in take-overs. Different driving scenarios can lead to a development of different fatigue patterns. In the German, nationally funded project *Cooperative, highly automated driving – Ko-HAF*, several partners conducted experiments to induce drowsiness and fatigue by using monotonous setups, e.g. a prolonged duration of automation without NDRTs or highly monotonous NDRTs like the Pqpd-task (Jarosch & Bengler, 2019). Regarding a similar, monotonous setup in a wizard-of-Oz vehicle, results from simulator studies in comparison with EEG data from a Wizard-of-Oz setup indicate that the onset and development of drowsiness and fatigue can be compared regardless of the authenticity of the surrounding environment (Wizard-of-Oz vs. simulator).

Empirical work on drowsiness and fatigue in Ko-HAF

In Ko-HAF L3 automation features were of high interest. The human factors work package focused on driver state in general and drowsiness and fatigue specifically.

During the project duration from June 2015 to November 2018, a total of 33 empirical studies, with 1723 participants, in over 1750 hours, resulting in 30 publications were conducted, focusing on the topics automation effects (including effects of NDRTs and drowsiness and fatigue) and optimizing the transition from automated to manual driving. This work provides a comprehensive overview of the studies on drowsiness and fatigue that were already published. Papers in press or in planning are in line with the presented findings and conclusions here.

Weinbeer et al. (2017) used a right-hand-drive vehicle (participants were never able to intervene in the real driving process) acting as a Wizard-of-Oz automated vehicle to investigate the suitability of different measures to induce drowsiness and the influence of drowsiness on take-over time aspects. The experiment was conducted in real traffic on a stretch of German Autobahn. Two experts evaluated participants' drowsiness level (DL) during the test drive. Depending on the individual level of drowsiness, a request to intervene (RtI) was triggered. There was no statistically significant influence of drowsiness on take-over time aspects. Results suggest that drowsy drivers are still able to perceive and react to a request to intervene. However, the take-over scenario as a known and prominent factor influencing take-over performance was of overall very little complexity and criticality. In addition, any quality metrics such as accelerations could not be measured using this specific Wizard-of-Oz approach. The experiment showed that the methodological approach can induce and enhance drowsiness during simulated automated driving.

Further, Weinbeer et al. (2018) looked at different options to counteract drowsiness. Participants assessed various options of a driver-state related strategy and of a system-based strategy before and after a tiring simulated automated drive. Results showed that reducing the maximum speed was the best rated system-based option and that a specific use of NDRTs was the driver-state related option that was most widely supported. The work provides initial insights into the acceptance of various strategies for managing drowsiness during automated driving from a user perspective.

Jarosch et al. (2017) investigated the difference between activating and monotonous tasks during CAD in a driving simulator study. In addition, the development of drowsiness and fatigue was measured using the metric percentage of eye-lid closure (PERCLOS) and the self-report Karolinska Sleepiness Scale (KSS). Results suggest that fatigue can be caused through a monitoring task in CAD. PERCLOS could be confirmed as a valid parameter for detecting fatigue in CAD. Furthermore, passive task related fatigue caused by a 25 min monotonous monitoring task does not affect the drivers' take over capability negatively in this setting. The data from this experiment was compared with a follow-up experiment.

In this driving simulator study Jarosch and Bengler (2019) compared the effects from prolonged automated driving with the engagement into NDRTs. In case participants were driving 25 minutes and were engaging in an activating NDRT, results suggest that participants executed a lane change necessary to pass the system limit in the take-over situation. In case the NDRT was monotonous, less participants would execute the lane change but rather come to a full stop in their ego lane. Contrary, after a 50 min automated drive and engaging in the same two NDRTs, more participants reacted by stopping on their ego lane. Again, more participants excuted a lane change maneuver when engaging in the activating task compared to the monotonous task. In the 50 min condition six participants lost control of their vehicle during the take-over compared to one participant in the 25 min condition. These differences in the take-over performance are significant, suggesting that drivers can show major decrements the take-over performance if they are driving conditionally automated for longer periods of time and cannot engage in any activating activity.

Weinbeer, Muhr, and Bengler (2019) investigated the effects of different NDRTs and their effects on drowsiness and fatigue. After a relaxation phase, the sample was divided into three groups that were given different non-driving-related tasks (a dictation, a sport activity and a relaxation task). No participant of the dictation- or sport-activity-group exceeded a high level of self-reported drowsiness after the reactivation phase. These results show that the use of NDRTs has the potential to represent a suitable option for managing driver drowsiness. Concluding, activating NDRTs have the potential to counteract high levels of drowsiness.

Feldhütter, Kroll, and Bengler (2018) also looked at the development of drowsiness and fatigue and their potential impact on driving performance in take-overs during the transition from conditionally automated driving to manual driving. The effect of fatigue on the take-over performance was examined in a driving simulator study with 47 participants assigned to two conditions: fatigued or alert. In the alert condition, the desired driver state was promoted by specific measures (e.g. daytime, caffeinated beverages, physical exercise). In the fatigued condition, the take-over situation was triggered once participants reached a certain level of drowsiness and fatigue. Two trained, independent observers assessed the drivers' state with the support of a technical fatigue assessment system based on objective eyelid-closure metrics. In the alert condition, participants drove conditionally automated for a fixed 5-minute period. Since the request to intervene was issued only when a specific level of drowsiness and fatigue was reached by both the raters and the objective technical systems, actual periods of CAD differed in their duration. Results showed no significant difference between participants' take-over times in the two conditions. However, drivers in the fatigued condition showed more signs of stress and burden during the take-over situation. Additionally, their take-over behaviour was assessed to be less confident behavior when coping with the situation. This behavior may negatively affect the transition from conditionally automated driving to manual driving in more complex situations.

Concluding, the experiments demonstrated that it was feasible to induce drowsiness and fatigue during CAD and measure the change in driver state by using the appropriate methods and metrics. The development of drowsiness and fatigue showed high individual differences with little to no effects on the take-over performance. Nonetheless, extreme levels of drowsiness and fatigue might be seldom during the CAD but should still be avoided to avoid critical take-over behaviour in more complex situations or even the possibility of unsuccessful take-overs. Activating NDRTs showed a high potential to counter drowsiness and fatigue and potentially offer a way of prolonging the periods of conditionally automated driving.

Towards an integrative framework

While the theoretical and empirical work on drowsiness and fatigue in manual driving provides a very well-researched basis for CAD as well, the overview in this work underlines the necessity for a more integrative view. While various definitions and theoretical considerations allow a conceptual understanding of drowsiness and fatigue and connected constructs, in CAD the focus is shifting to the effects of drowsiness and fatigue on the driver state and the take-over performance. In case NDRTs or prolonged automated driving leads to a change in driver state in general and the effects can be attributed to an onset of drowsiness and fatigue, more important than a clear assignment to an individual construct is the effect on the current driver state. Regarding a target driver state necessary for a successful transition and succeeding manual driving performance in and after a take-over, the connection between these effects and what happens during the automated drive is of utmost importance. In addition, empirical results from Ko-HAF underline the complexity of quantifying this connection, since results indicate great inter- and intraindividual differences between participants. Nonetheless, results show that it was possible to induce drowsiness and fatigue in test situations without sleep deprivation but in the context of CAD. Driver state changes could be detected by using several metrics and methods under these experimental conditions and allow valuable recommendations for future research. In addition, results indicate while driving with conditional automation, extreme levels of drowsiness and fatigue (drivers close to falling asleep) must be avoided. Concerning higher levels of drowsiness and fatigue, clear and consistent effects on take-over behavior and performance could not be found. More importantly, 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. Concluding, most work on drowsiness and fatigue in the context of conditionally automated driving focusses on the safety-critical take-over process and potential problems for a successful take-over during automated driving. Concerning the general acceptance of automated vehicles in addition with the user experience necessary for the technology to be used by future customers, we recommend additional research being conducted focussing not only on safety-critical topics but comfort-related questions as well.

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References

Åkerstedt, T., & Gillberg, M. (1990). Subjective and Objective Sleepiness in the Active Individual. *International Journal of Neuroscience, 52,* 29-37.

Åkerstedt, T., Fröberg, J.E., Friberg, Y., Wetterberg, L. (1979). Melatonin excretion, body temperature and subjective arousal during 64 hours of sleep deprivation. *Psychoneuroendocrinology, 4*, 219-25.

Anund, A., Fors, C., Hallvig, D., Akerstedt, T., & Kecklund, G. (2013). Observer rated sleepiness and real road driving: an explorative study. *PloS one,* 8.

Dahlbäck, N., Jönsson, A., & Ahrenberg, L. (1993). Wizard of Oz studies: why and how. *In Proceedings of the 1st International Conference on Intelligent User Interfaces* (pp. 193-200). Orlando, USA: ACM New York

Dinges, D.F., & Grace, R. (1998). *PERCLOS: A valid psychophysiological measure of alertness as assessed by psychomotor vigilance* (Report FHWA-MCRT-98-006). US Department of Transportation, Federal Highway Administration.

Feldhütter, A., Kroll, D., & Bengler, K. (2018). Wake Up and Take Over! The Effect of Fatigue on the Take-over Performance in Conditionally Automated Driving. In *Proceedings of the 2018 IEEE 21st International Conference on Intelligent Transportation Systems (ITSC)*. In Press.

Frey, A.T. (2016). *Statischer und dynamischer Fahrsimulator im Vergleich-Wahrnehmung von Abstand und Geschwindigkeit* (Berichte der Bundesanstalt fuer Strassenwesen, Unterreihe Fahrzeugtechnik Volume 115). Bergisch-Gladbach: Bundesanstalt für Strassenwesen.

Jarosch, O., & Bengler, K. (2019). Is It the Duration of the Ride or the Non-driving Related Task? What Affects Take-Over Performance in Conditional Automated Driving? In: S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, Y. Fujita (Eds.), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Advances in Intelligent Systems and Computing, Volume 823*. Cham: Springer.

Jarosch, O., Kuhnt, M., Paradies, S., & Bengler, K. (2017). It is out of our Hands now! Effects of Non-driving related Tasks during Highly Automated Driving In Kathy Holeton (Ed.), *Proceedings of the 9th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. Manchester Village, USA.

Jewett, M.E., Dijk, D.J., Kronauer, R.E., & Dinges, D.F. (1999). Dose-response Relationship Between Sleep Duration and Human Psychomotor Vigilance and Subjective Alertness. *Sleep, 22*, 171-179.

Johns, M. (2007). Drowsy Driving and the Law. *Tasmania Law Reform Institute, 12*.

Johns, M. (1998). Rethinking the assessment of sleepiness. *Sleep Medicine Reviews, 2*, 3-15.

Körber, M., Cingel, A., Zimmermann, M., & Bengler, K. (2015). Vigilance Decrement and Passive Fatigue Caused by Monotony in Automated Driving. In T. Ahram, W. Karwowski, D. Schmorrow (Eds.), *Procedia Manufacturing*, *Volume 3* (pp. 2403-2409). Amsterdam: Elsevier B.V.

Manzey, D. (1998). Psychophysiologie mentaler beanspruchung. *Ergebnisse und Anwendungen der psychophysiologie. Enzyklopädie der Psychologie, 100*, 799-864.

Marberger, C., Mielenz, H., Naujoks, F., Radlmayr, J., Bengler, K., & Wandtner, B. (2017). Understanding and Applying the Concept of "Driver Availability" in Automated Driving. In N.A. Stanton (Ed.), *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2017 International Conference on Human Factors in Transportation* (pp. 595-605). Cham: Springer International Publishing.

Marberger, C., Korthauer, A., Manstetten, D., Naujoks, F., Wiedemann, K., & Purucker, C. (2007). Hochautomatisiertes Fahren im öffentlichen Verkehr – Erste Ergebnisse einer Realfahrzeugstudie zur Bewertung der User Experience sowie der Fahrleistung in Übernahmesituationen. In M. Lienkamp (Ed.) *Proceedings of the Tagung Fahrerassistenz, Volume 3*. München.

Markkula, G., Victor, T., & Engström, J. (2017). Attention Selection and Multitasking in Everyday Driving: A Conceptual Model. *Driver Distraction and Inattention*, 51-78.

Matthews, G., & Desmond, P.A. (2002). Task-induced fatigue states and simulated driving performance. *The Quarterly Journal of Experimental Psychology Section A, 55*, 659-686.

May, J.F., & Baldwin, C.L. (2009). Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*, 218-224.

Miller, D., Sun, A., Johns, M., Ive, H., Sirkin, D., Aich, S., & Ju, W. (2015). Distraction Becomes Engagement in Automated Driving. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Volume 59, Issue 1* (pp. 1676-1680). Thousand Oaks, USA: Sage.

National Center for Statistics and Analysis. (2017). *Drowsy Driving 2015* (Crash•Stats Brief Statistical Summary. Report No. DOT HS 812 446). Washington, DC: National Highway Traffic Safety Administration.

Neubauer, C., Matthews, G., Langheim, L., & Saxby, D. (2012). Fatigue and Voluntary Utilization of Automation in Simulated Driving. *Human Factors, 54*, 734-746.

Philip, P., Sagaspe, P., Taillard, J., Valtat, C., Moore, N., Åkerstedt, T., … Bioulac, B. (2005). Fatigue, Sleepiness, and Performance in Simulated Versus Real Driving Conditions. *Sleep, 28*, 1511-1516.

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors, 39*, 230-253.

Radlmayr, J., Gold, C., Lorenz, L., Farid, M., & Bengler, K. (2014). How Traffic Situations and Non-Driving Related Tasks Affect the Take-Over Quality in Highly Automated Driving. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Volume 58, Issue 1* (pp. 2063-2067). Thousand Oaks, USA: Sage.

SAE International (2016). *Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems* (Surface Vehicle Recommended Practice J3016). Warrendale, USA. SAE International.

Schleicher, R., Galley, N., Briest, S., & Galley, L. (2008). Blinks and saccades as indicators of fatigue in sleepiness warnings: looking tired? *Ergonomics, 51*, 982-1010.

Schmidt, E.A., Schrauf, M., Simon, M., Buchner, A., & Kincses, W.E. (2011). The short-term effect of verbally assessing drivers' state on vigilance indices during monotonous daytime driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 14*, 251-260.

Schmidt, E.A., Schrauf, M., Simon, M., Fritzsche, M., Buchner, A., & Kincses, W.E. (2009). Drivers' misjudgement of vigilance state during prolonged monotonous daytime driving. *Accident Analysis & Prevention, 41*, 1087-1093.

Senaratne, R., Hardy, D., Vanderaa, B., & Halgamuge, S. (2007). Driver Fatigue Detection by Fusing Multiple Cues. In D. Liu, S. Fei, Z. Hou, C. Sun, & H. Zhang (Eds.), *Advances in Neural Networks, Volume 4492* (pp. 801-809). Berlin, Heidelberg: Springer-Verlag.

Simon, M., Schmidt, E.A., Kincses, W.E., Fritzsche, M., Bruns, A., Aufmuth, C., … Schrauf, M. (2011). EEG alpha spindle measures as indicators of driver fatigue under real traffic conditions. *Clinical Neurophysiology, 122,* 1168-1178.

Teichner, W.H. (1974). The Detection of a Simple Visual Signal as a Function of Time of Watch. *Human Factors, 16,* 339-352.

Vogelpohl, T., Vollrath, M., Kühn, M., Hummel, T., & Gehlert, T. (2016). *Übergabe von hochautomatisiertem Fahren zu manueller Steuerung* (GDV Berichte 47, Teil 2). Berlin: GDV.

Warm, J.S., Parasuraman, R., & Matthews, G. (2008). Vigilance Requires Hard Mental Work and Is Stressful. *Human Factors, 50*, 433-441.

Weinbeer, V., Muhr, T., & Bengler, K. (2019). Automated Driving: The Potential of Non-driving-Related Tasks to Manage Driver Drowsiness. In: S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, Y. Fujita (Eds.), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Advances in Intelligent Systems and Computing, Volume 823*. Cham: Springer.

Weinbeer, V., Bill, J.S., Baur, C., & Bengler, K. (2018). Automated driving: subjective assessment of different strategies to manage drowsiness. In D. de Waard et al. (Eds.) *Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2017 Annual Conference* (pp. 5-17). Downloaded from http://hfes-europe.org.

Weinbeer, V., Baur, C., Radlmayr, J., Bill, J.S., Muhr, T., & Bengler, K. (2017). Highly automated driving: How to get the driver drowsy and how does drowsiness influence various take-over-aspects? In M. Lienkamp (Ed.) *Proceedings of the Tagung Fahrerassistenz, Volume 8*. München.

Wierwille, W.W., & Ellsworth, L.A. (1994). Evaluation of driver drowsiness by trained raters. *Accident Analysis & Prevention, 26*, 571–581.