Available online at www.sciencedirect.com
ScienceDirect
Procedia Manufacturing 3 (2015) 2403 – 2409
Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Vigilance decrement and passive fatigue caused by monotony in automated driving

Moritz Körber, Andrea Cingel, Markus Zimmermann, Klaus Bengler

Institute of Ergonomics, Technische Universität München, Boltzmannstraße 15, 85748 Garching bei München, Germany

Abstract

Besides resource depletion caused by being actively engaged in a task, there are several signs that passive monitoring, monotony and passive fatigue can also induce vigilance decrement. Partially automated driving represents such a passive situation as the driver's only task is to monitor the system. In this work, we investigate the decrement of vigilance during a partially automated highway drive in a driving simulator. Indicators used to assess the vigilance state was a reaction time task, passive fatigue was measured by eye tracking and a mind wandering questionnaire. 20 participants drove in a driving simulator for 42.5 min on a six-lane highway with partial automation activated. We found no significant effects of time-on-task on the reaction times, but significant effects on eye tracking parameters (blink frequency, blink duration, pupil diameter) and increased mind wandering. The results show that fatigue can occur without active task engagement, but future studies have to clarify the consequences in terms of reactions to critical events.

Peer-review under responsibility of AHFE Conference

*Keywords:*Automated driving; Vigilance;Fatigue; PERCLOS; Reaction times;Eye tracking

1. Introduction

Fatigue and resultant ensuing low vigilance are known to be a relevant causation for traffic accidents [1] and therefore consequences [2] and mitigation [3] of them have been focus of past research activities. However, there are different theoretical accounts on the development of fatigue. May and Baldwin [4]distinguish in their model between *active fatigue*, *passive fatigue* and *sleep-related fatigue*.

Active fatigue represents fatigue caused by being actively engaged in a task which leads to a depletion of mental resources. Relevant situations comprise driving with high traffic density, with low visibility conditions or driving for a long time. Accordingly, in the same manner, the*resource theory* of vigilance [5] states that a decrement in

Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.499

vigilance is caused by the depletion of attentional resources, because the constant discrimination between target and non-target stimuli is mentally straining.

Sleep-related fatigue represents probably the best known aspect of fatigue. This aspect comprises various performance decrements due to time of the day (circadian rhythm), sleep deprivation or sleep disorders. Driving performance for example is impaired in late evening or early morning because these hours overlap with most peoples' times of low arousal in their circadian rhythm [6]. Furthermore, Philip and colleagues [7]showed thatsleep deprivation of 6.5 h leads to significantly more inappropriate line crossings in a 10 h drive (with breaks) than compared to rested subjects.

Passive fatigue can be seen as the opposite of active fatigue: Here, task underload, monotony and automated systems are seen as the reasons for attentional loss and performance decrements. Various studies support this notion: Reduced attentional capacity [8], driving performance [9] and longer reaction times [10] are empirically shownconsequences. Consistent to that, De Waard[11] states in his thesis that monotony necessitates state-related effort to keep oneself attentive to a task and this effort could result in fatigue over time. In line with this argumentation, there is another theoretical explanation of vigilance decrement, the *mindlessness theory*[12]. Supporters of this theory state that monotony and boredom of vigilance tasks lead to task disengagement and mind wandering with task-unrelated thoughts in a way that attentional resources are drawn away and attentional lapses occur. Empirically shown effects on performance are,for example,longer reaction times [13] and a greater variability of reaction times [14].

To empirically investigate the effects of passive fatigue in a naturalistic setting, Schmidt and colleagues [15] studied the effect of a 3 h monotonous highway drive on driver's vigilance and drowsiness. Besides an increase in subjective (Karolinska Sleepiness Scale) and objective (EEG) indicators of drowsiness, they reported an increment of reaction times, i.e. a decrement in vigilance, during thecourse of the drive. The authors claim the monotonous environment of a highway drive and the long time-on-task as causes for the decrement. Other researches [16] found similar detrimental effects of monotony on lane positioning, time to lane crossing, blink frequency, heart rate variability and non-specific electro-dermal response rates in a driving simulator study.Hence, passive fatigue seems to be a relevant cause for impaired driving performance. If a vehicle automation carries out the driving task, it could lead to an even more monotonous situationsince, in the case of partial automation, the driver's only task is to monitor the system and take over vehicle control in case of a system limit[17]. Therefore, we expect that driving a partially automated vehicle will evoke passive fatigue and will result invigilance decrement. In this study, we investigate this hypothesis by means of a partially automated monotonous highway drive in a driving simulator with measurement of several fatigue and vigilance indicators.

A widespread indicator of vigilance decrement is an increase in reaction times to target stimuli [5]. We therefore implemented an auditory secondary task (oddball paradigm) that contains infrequent higher pitched target stimuli and frequent lower pitched non-target stimuli. This paradigm has already been successfully used to assess vigilance by Schmidt and his team[15]. Other means of measurement focus on eye tracking: McIntire and colleagues [18] reported an increase in blink frequency and blink duration associated with vigilance performance decrement. Abe and colleagues [19] associate the percentage of eye closure (PERCLOS) for a given time accompanied by a decrease in pupil diameter with an increase in drowsiness and a decrease in vigilance. Other researchers support this notion and report an increase in eye closure when driving with automation activated [20]. Schleicher and his colleagues [21] investigated multiple indicators and show further validation for eye tracking as a measurement for fatigue. We therefore investigate several eye tracking parameters during the drive in expectation of similar results. Monotony has also been shown to lead to a decoupling of attention from the task and to the onset of mind wandering or daydreaming[5]. The task then is solved automatically while the attentional focus switches to private thoughts. Matthews and colleagues [22] introduced a comprehensive stress state questionnaire that is used to assess subjective state in tasks. One sub-factor of this questionnaire is called worry and contains scales both for the amount of task-irrelevant thought (TIT) and task-relevant thought (TRT) that can be used to assess mind wandering and distraction by own thoughts[23, 24]. Because monitoring a partial automated vehicleon a highway is a monotonous and undemanding task, we expect that the unused attentional resources will be used for mind wandering and therefore we expect an increase in both the TIT and TRT scores.

2. Method

2.1. Sample

Four participants were excluded due to data logging problems. The remaining sample of 20 participants consists of 2 females (10 %) and 18 males (90 %). Mean age was *M* = 23.3 years (*SD* = 2.64, min = 19, max = 29). Mean driving experience was *M* = 5.78 years (*SD* = 2.35) and mean driven kilometers in the past year were*M* = 10566 km (*SD* = 10531). Participation was rewarded with 20 euros.

2.2. Measures

2.2.1. Vigilance task

Participants' vigilance performance was assessed by means of an auditory oddball paradigm. In this paradigm, one has to react to infrequent (20 % of trials) high-pitched (500 Hz) target stimuli and ignore frequent (80 % of trials) lower pitched(400 Hz) non-target stimuli. Inter-stimulus interval was set at a random value between 4–6 s to avoid unconscious automated responses. Response was given via a button at the steering wheel. Besides the mean reaction times, the mean of the 80% slowest responses has been analyzedsince it is seen to be especially sensitive to vigilance changes [15]. Also, the mean standard deviation of reaction times was analyzed to detect attentional lapses [14]. Reaction times longer than 4000 ms have been excluded from the analysis.

2.2.2. Eye tracking

Eye tracking measurements were conducted by using the remote eye tracking system FaceLab. This system works with two cameras, an infrared sensor and a data record frequency of 60 Hz, thus creating 60 data points per second. Measured parameters were pupil diameter, blink frequency, blink duration and PERCLOS (percentage of time the eye is closed more than 75 % in 10000 frames).

2.2.3. Mind wandering

Mind wandering was assessed by the two subscales *Task Irrelevant Thought* and *Task Relevant Thought* of the Dundee Stress State Questionnaire (DSSQ) [22], which both contain 8 items and a Likert-like response scale from 1 (never) to 5 (very often). The questionnaire was presented two times: The first presentation questioned the participants thought content on the first 5 min of the drive, whereas the second presentation questioned thought content of the last 5 min of the drive. To avoid interruption of the drive, both parts were handed out after the experimental drive consequentially, which means, the participants had to remember their thought content of the first 5 min to answer the first questionnaire.

2.2.4. Simulator and driving track

The study was conducted in a static driving simulator with a front field view of about 180° and three additional screens for rear mirrors. The participants drove for 42.5 min on a six-lane highway with partial automation activated, i.e. longitudinal as well as lateral control was carried out by the vehicle automation, but the automation had to be monitored throughout the entire period. The automation changed to the middle lane at the beginning of the experiment and stayed there keeping a constant speed of 125 km/h. The most right of the three lanes from the participants' direction was crowded with slower vehicles (around 72 km/h), the lane to the left was occupied by infrequently passing faster vehicles (around 180 km/h).

2.2.5. Procedure

After being welcomed by the experimenter, the participants completed a demographic questionnaire. Then a training session for the secondary task began until the participants indicated that they felt comfortable with performing the task. After that, the experimental drive started. After the drive, the participants completed both parts of the DSSQ and received their monetary reward.

3. Results

A significance level of α = .05 was set for all hypothesis tests. If Mauchly test for sphericity returned significant results, Greenhouse-Geisser correction was used. Error bars depict standard error. Sample size for reaction times was *n* = 20. For data analysis, we divided the experimental drive intonine5-min parts labelled as t1–t9.

Table 1.Results of the vigilance task.

Mean RT [ms]	Mean *SD*	Mean misses (%)	Mean false alarms (%)
633.38	153.10	0.65	0.80

Table 1 lists descriptive values of the oddball task. The mean reaction time over the whole experimental drive was 633.38 ms (*SD* = 153.10). Figure 1 shows the mean reaction times for the oddball task in course of the experimental drive. Repeated measurements ANOVA revealed no significant effects for the factor time-on-task (F(4.31, 81.95) = 1.26, p = .27, η_p^2 = .06). Figure 2 shows the results for the 80 % slowest reaction times.Also, no significant effect for the factor time-on-task was found (F(2.94, 55.85) = 1.43, p = .19, η_p^2 = .07).Figure 3 shows the results for the mean standard deviation of reaction times. No significant effect for the factor time-on-task was found (F(3.30, 62.78) = 1.37, p = .21, η_p^2 = .07).As a result of data logging problems, the sample size for the eye tracking measures is n = 16.

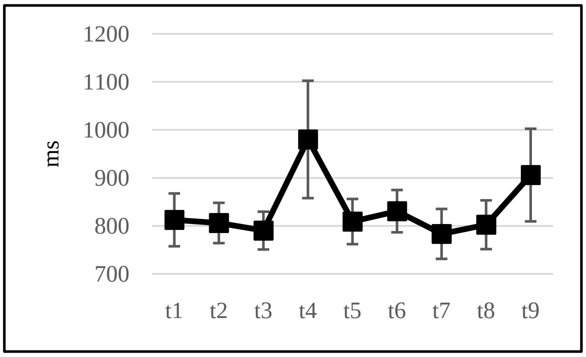

Fig.1: Means of the reaction times.

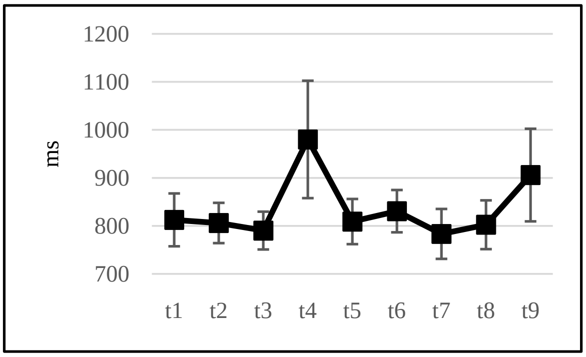

Fig. 2: Means of the 80% slowest reaction times.

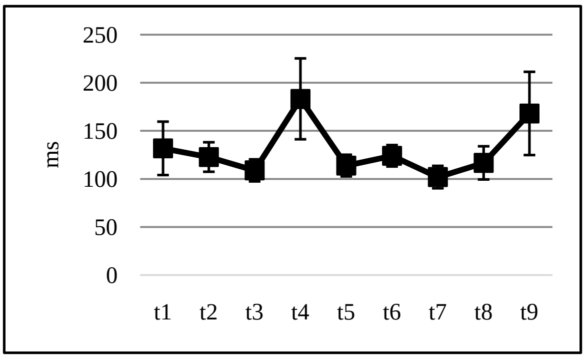

Fig. 3. Standard deviation of reaction times within subjects.

Figure 4 shows the trend of the blink duration in course of the experiment. A significant effect for the factor time-on-task was found ($F(4.30, 64.49) = 4.05$, $p < .001$, $\eta_p^2 = .21$), as well as a significant trend ($F(1, 15) = 13.65$, $p = .002$, $\eta_p^2 = 48$).Figure 5 shows the trend of the blink frequency in course of the experiment. A significant effect for the factor time-on-task was found ($F(2.01, 30.16) = 4.23$, $p = .024$, $\eta_p^2 = .22$), as well as a significant trend ($F(1, 15) = 6.62$, $p < .021$, $\eta_p^2 = .31$).Figure 6 shows the trend of the pupil diameter in course of the experiment. A significant effect for the factor time-on-task was found ($F(2.75, 41.22) =7.69$, $p < .001$, $\eta_p^2 = .34$), as well as a significant trend ($F(1, 15) = 12.66$, $p = .003$, $\eta_p^2 = .46$).Figure 7 shows the trend of the PERCLOS in course of the experiment. No significant effect for the factor time-on-task was found ($F(1.52, 21.22) = 1.25$, $p = .277$, $\eta_p^2 = .08$); The linear trend was almost significant ($F(1,14) = 4.21$, $p = .059$, $\eta_p^2 = .23$).Figure 8 shows the results for the DSSQ questionnaire, consisting of the subscales Task Irrelevant Thoughts (TIT) and Task Relevant Thoughts (TRT). Both subscales differ between the first 5 min (TIT_1: $M = 1.51$, $SD = 0.61$; TRT_1: $M = 2.32$, $SD = 0.60$) and the last 5 min of the experiment (TIT_2: $M = 1.75$, $SD = 0.51$; TRT_2: $M = 2.63$, $SD = .58$). We conducted a t-test and found a significant difference (TIT: $t(18) = 1.94$, $p = .03$; TRT: $t(18) = 2.50$, $p = .01$).

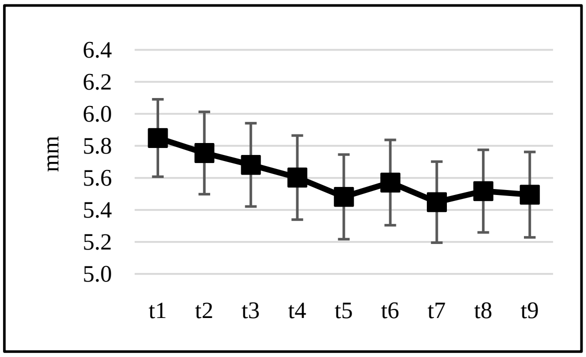

Fig. 4. Trend in pupil diameter over time.

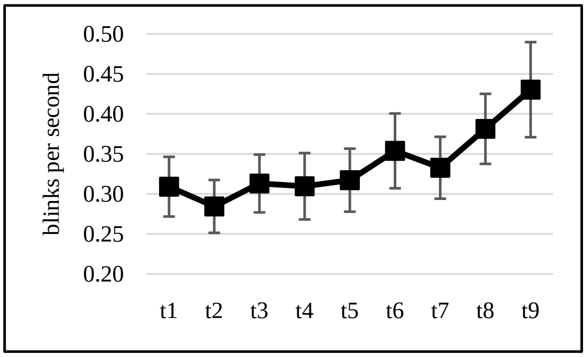

Fig. 5. Trend in blink frequency over time.

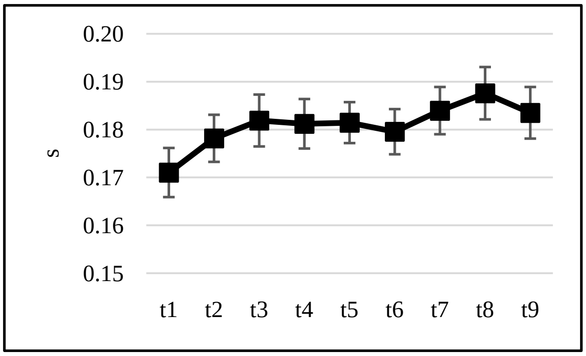

Fig. 6. Trend in blink duration over time.

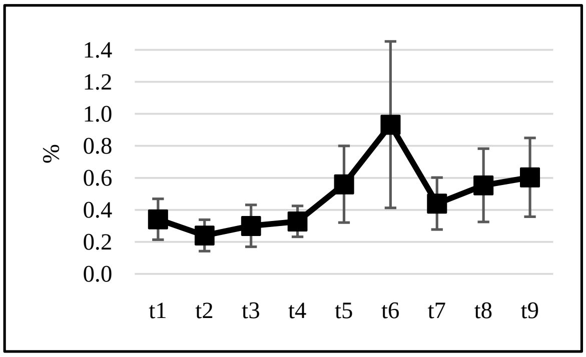

Fig. 7. Trend in PERCLOS over time.

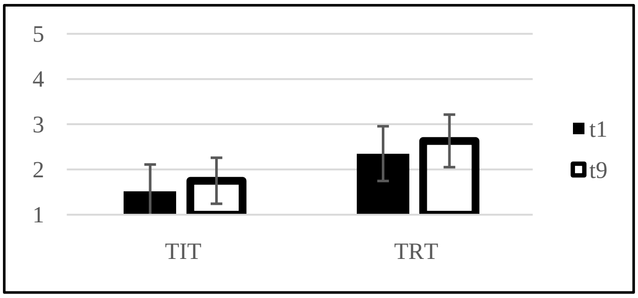

Fig. 8: Comparison of thought content between the first and last 5 min of the experimental drive.

4. Discussion

In this study, we examined the effects of partial automated driving on participants' vigilance and passive fatigue in a driving simulator.

Mean reaction times in the vigilance task increased by 43 ms (93 ms for the 80 % longest reaction times) over the course of the 42.5 min drive, although this effect was not significant.The task was possibly too easy for a performance decrement to occur since almost no misses or false alarms arose. It is also imaginable that participants were kept at a constant medium arousal level by doing the easy vigilance task which could have been beneficial for the vigilance performance.Besides that, in Schmidt and his colleagues'[15] study, the vigilance task was the secondary task in addition to manual driving. In this study, a vehicle automation was used by the participants and thus the vigilance task became the primary active task (besides passive monitoring). Hence, less attentional resources were depleted in course of the experiment and the participants could focus more on the vigilance task, which might therefore had been too easy. A closer look at Schmidt and his team's[15] resultsalso revealed that they did not observe an increase in reaction times prior to one hour of driving, which is an indication that same results could ensue with our setting but with a longer driving time.

The remaining eye tracking indicators for fatigue (pupil diameter, blink frequency, blink duration) except PERCLOS showed a significant increase in fatigue in course of the experimental drive.Rauch and colleagues [25] state in their model that eye tracking indicators precede performance indicators.Thus, in a longer experimental drive, a decrement in vigilance performance (i.e. increase in reaction times) couldpossiblyfollow the eye tracking indicators.

In addition to the eye tracking measures, participants reported more engagement with their thoughts in the last five minutes of the experimental drive compared to the first five minutes.This is in line with our expectation that, because of the low task demand, participantsdivert their attention away from performing the task to engagement with their own thoughts.

Future work has to find out how the vigilance performance and the eye tracking measures of fatigue are related to a reaction to critical traffic events when driving with partial automation. The length of the experimental drive could be prolonged in future studies because similar studies indicate a growing effect with time-on-task (e.g. [15]) Furthermore, the road in this experiment was crowded with other road users. Monotony could be increased with lower traffic density that could in turn accentuate the observed trends.

In conclusion, the eye tracking results show that fatigue can occur even when there is no activeengagement in a driving task, supporting the relevance of passive fatigue caused by automation. Participants reported more engagement with their own thoughts at the end of the drive in comparison to the beginning, which can be seen as an indication for a lack of engagement in monitoring the automation. Nevertheless, no significant increase in reaction times occurred in the vigilance task.

References

[1]National Highway Traffic Safety Administration, "Traffic safety facts 2004: A compilation of motor vehicle crash data from the fatality analysis reporting system and the general estimates system (DOT HS 809 919)," *US Department of Transportation, Washington, DC*, 2006.

[2]P. Thiffault and J. Bergeron, "Monotony of road environment and driver fatigue: a simulator study," (eng), *Accid Anal Prev*, vol. 35, no. 3, pp. 381–391, 2003.

[3]E. A. Schmidt, M. Schrauf, M. Simon, A. Buchner, and W. E. Kincses, "The short-term effect of verbally assessing drivers' state on vigilance indices during monotonous daytime driving," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 14, no. 3, pp. 251–260, 2011.

[4]J. F. May and C. L. Baldwin, "Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 12, no. 3, pp. 218–224, 2009.

[5]W. S. Helton and P. N. Russell, "Brief mental breaks and content-free cues may not keep you focused," *Exp Brain Res*, vol. 219, no. 1, pp. 37–46, 2012.

[6]M. G. Lenné, T. J. Triggs, and J. R. Redman, "Time of day variations in driving performance," *Accident Analysis & Prevention*, vol. 29, no. 4, pp. 431–437, 1997.

[7]P. Philip, P. Sagaspe, J. Taillard, C. Valtat, N. Moore, T. Åkerstedt, A. Charles, and B. Bioulac, "Fatigue, sleepiness, and performance in simulated versus real driving conditions," (eng), *Sleep*, vol. 28, no. 12, pp. 1511–1516, 2005.

[8]M. S. Young and N. A. Stanton, "Malleable Attentional Resources Theory: A New Explanation for the Effects of Mental Underload on Performance," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 44, no. 3, pp. 365–375, 2002.

[9]G. Matthews and P. A. Desmond, “Task-induced fatigue states and simulated driving performance,” *Q J Exp Psychol A*, vol. 55, no. 2, pp. 659–686, 2002.
[10]D. J. Saxby, G. Matthews, J. S. Warm, E. M. Hitchcock, and C. Neubauer, “Active and passive fatigue in simulated driving: Discriminating styles of workload regulation and their safety impacts,” *Journal of Experimental Psychology: Applied*, vol. 19, no. 4, pp. 287–300, 2013.
[11]D. De Waard, “The Measurement of Drivers’ Mental Workload,” Doctoral, Traffic Research Centre, University of Groningen, Haren, Netherlands, 1996.
[12]I. H. Robertson, T. Manly, J. Andrade, B. T. Baddeley, and J. Yiend, “'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects,” *Neuropsychologia*, vol. 35, no. 6, pp. 747–758, 1997.
[13]M. R. Yanko and T. M. Spalek, “Driving With the Wandering Mind: The Effect That Mind-Wandering Has on Driving Performance,” *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 56, no. 2, pp. 260–269, 2013.
[14]P. Seli, J. A. Cheyne, and D. Smilek, “Wandering minds and wavering rhythms: Linking mind wandering and behavioral variability,” *Journal of Experimental Psychology: Human Perception and Performance*, vol. 39, no. 1, pp. 1–5, 2013.
[15]E. A. Schmidt, M. Schrauf, M. Simon, M. Fritzsche, A. Buchner, and W. E. Kincses, “Drivers’ misjudgement of vigilance state during prolonged monotonous daytime driving,” *Accident Analysis & Prevention*, vol. 41, no. 5, pp. 1087–1093, 2009.
[16]G. S. Larue, A. Rakotonirainy, and A. N. Pettitt, “Driving performance impairments due to hypovigilance on monotonous roads,” *Accid Anal Prev*, vol. 43, no. 6, pp. 2037–2046, 2011.
[17]T. M. Gasser, “Rechtsfolgen zunehmender Fahrzeugautomatisierung: Gemeinsamer Schlussbericht der Projektgruppe,” F 83, 2012.
[18]L. K. McIntire, R. A. McKinley, C. Goodyear, and J. P. McIntire, “Detection of vigilance performance using eye blinks,” *Applied Ergonomics*, vol. 45, no. 2, pp. 354–362, 2014.
[19]T. Abe, T. Nonomura, Y. Komada, S. Asaoka, T. Sasai, A. Ueno, and Y. Inoue, “Detecting deteriorated vigilance using percentage of eyelid closure time during behavioral maintenance of wakefulness tests,” *International Journal of Psychophysiology*, vol. 82, no. 3, pp. 269–274, 2011.
[20]S. Buld, H.-P. Krüger, S. Hoffmann, A. Kaussner, H. Tietze, and I. Totzke, “Wirkungen von Assistenz und Automation auf Fahrerzustand und Fahrsicherheit,” *Abschlussbericht BMBF*, vol. 19, p. 9812, 2002.
[21]R. Schleicher, N. Galley, S. Briest, and L. Galley, “Blinks and saccades as indicators of fatigue in sleepiness warnings: looking tired?,” (eng), *Ergonomics*, vol. 51, no. 7, pp. 982–1010, 2008.
[22]G. Matthews, L. A. Joyner, K. Gilliland, J. Huggins, and S. Falconer, “Validation of a comprehensive stress state questionnaire: Towards a state big three?,” in *Personality Psychology in Europe*, I. Mervielde, Deary, I, De Fruyt, F, and I. Ostendorf, Eds, Tilburg: Tilburg University Press, 1999, pp. 335–350.
[23]E. Barron, L. M. Riby, J. Greer, and J. Smallwood, “Absorbed in Thought: The Effect of Mind Wandering on the Processing of Relevant and Irrelevant Events,” *Psychological Science*, vol. 22, no. 5, pp. 596–601, 2011.
[24]M. Körber and K. Bengler, “Potential Individual Differences Regarding Automation Effects in Automated Driving,” in *Interacción '14: Proceedings of the XV International Conference on Human Computer Interaction*, New York, NY, USA: ACM, 2014, pp. 1–7.
[25]N. Rauch, A. Kaussner, H.-P. Krüger, S. Boverie, and F. O. Flemisch, “The importance of driver state assessment within highly automated vehicles,” in *16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services*, 2009.