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Elisabeth Schmidt

Effects of Thermal Stimulation during Passive Driver Fatigue

With a foreword by
Prof. Dr. Angelika C. Bullinger-Hoffmann

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Geleitwort

Die zunehmende Automatisierung des Fahrens hat zum Ziel, den Fahrer merklich von der Fahraufgabe zu entlasten, führt jedoch auch zu Ermüdungseffekten. Elisabeth Schmidt widmet ihre Dissertation in diesem Kontext der Beeinflussung des Fahrerzustands durch gezielte Kühlung verschiedener Körperregionen und der Messung des Fahrerzustands.

Mit ihrer Arbeit zu den Effekten von Kühlung auf die passive Müdigkeit von Fahrern führt sie mit drei Fahrsimulatorstudien eine sehr differenzierte Betrachtung des Potenzials der Kühlung des Fahrers durch Luftströmung durch. Ihre Ergebnisse geben klare Hinweise darauf, dass eine zustandsorientierte Klimatisierung als vierminütige Kühlung des Oberkörpers gestaltet werden sollte. Sie zeigen aber auch, dass deren Potenzial bei wiederholter Anwendung nicht überbewertet werden darf. Bezüglich der Akzeptanz einer automatisierten Kühlung findet Frau Schmidt heraus, dass diese hoch ist, so die Fahrer über den Zweck der Kühlung informiert sind.

Die Studien von Frau Schmidt sind im Fahrsimulator durchgeführt, bieten aber dennoch aufgrund ihres differenzierten Vorgehens eine gute Grundlage für die Entwicklung, Gestaltung und Evaluation einer automatisierten Kühlung in der Praxis.

Während die Dissertation auf passive Müdigkeit zugeschnitten ist, bieten die erarbeiteten Ergebnisse und die transparent diskutierten offenen Fragestellungen Potenzial für die Erforschung anderer Müdigkeitsformen.

Ich wünsche Elisabeth Schmidt daher zahlreiche interessierte Leserinnen und Leser aus Wirtschaft und Wissenschaft – und zahlreiche Fahrerinnen und Fahrer zunehmend automatisierter Fahrzeuge, die aufgrund automatisierter Kühlung wach und sicher ihr Ziel erreichen!

Angelika C. Bullinger-Hoffmann

Chemnitz, im Mai 2019

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Elisabeth Schmidt

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List of Abbreviations

Abbreviation	Explanation
A	answer
AC	air conditioner
ADACL	Activation Deactivation Adjective Check-list
ANS	autonomic nervous system
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BF	breathing frequency
bpm	beats per minute
C	Celsius
CID	central information display
cm	centimeter
CO_2	carbon dioxide
COMB	combination of light, sound, scent and climate
CONT	control condition without cooling
COOL	condition with cooling
DWA	driving without awareness
ECG	electrocardiogram
EEG	electroencephalogram
e.g.	exempli gratia

EOG	electrooculogram
HF	high frequency component of HRV
HMI	human-machine interaction
HR	heart rate
HRV	heart rate variability
Hz	Hertz
i.e.	id est
km/h	kilometers per hour
KSS	Karolinska Sleepiness Scale
LDA	linear discriminant analysis
LF	low frequency component of HRV
m	meter
M	mean
Mdn	median
min	minute
mm	millimeter
ms	millisecond
n	sample size
PERCLOS	percentage of eye closure
PNS	parasympathetic nervous system
ppm	part per million
rel	relative
RMSSD	root mean square of successive differences
ROC	receiver operating characteristic

RQ	research question
s	second
S	Siemens
SAE	Society of Automotive Engineers
SCL	skin conductance level
SD	standard deviation
SDNN	standard deviation of normal-to-normal intervals
SE	standard error
Se-6	microsiemens
SNS	sympathetic nervous system
SR	sleep-related
SSS	Stanford Sleepiness Scale
SVM	support vector machine
t	time
TR	task-related
UEQ	User Experience Questionnaire
U.S.	United States
UX	user experience
vs.	versus
y	years

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Abstract

Driver fatigue accounts for a large portion of vehicular crashes. Aside from an increased safety risk, fatigue also raises discomfort while driving. There has been initial research on countermeasures against driver fatigue and several fatigue models highlight the importance of the causal factors of fatigue when conceptualizing countermeasures against fatigue.

Thermal stimulation has been suggested as a countermeasure against passive fatigue caused by task underload. There exist few driving studies, however, that investigate the use of thermal stimuli as fatigue countermeasures. These studies used different stimulus settings, such as stimulus temperature, duration and because cooled body parts. In addition the degree of sleep deprivation in their samples varied. Thus, these studies yield inconclusive results. From the existing insights, it remains unclear under which thermal conditions fatigue can be mitigated. Furthermore, most of the studies did not address the issue of reduced thermal comfort when applying thermal stimulation. Therefore, the main research focus of this thesis is directed to the effect of thermal simulation in mitigating passive fatigue of non-sleep-deprived drivers while maintaining the drivers' comfort.

This dissertation investigated the effect of thermal stimulation in a series of driving simulator experiments. To induce passive fatigue in the drivers, a monotonous highway drive with very little traffic was chosen. This traffic scenario was tested in a simulator study (n=46) to demonstrate that it could induce sufficiently high subjective fatigue. An increase in heart rate variability and a decrease in breathing frequency were measured during the monotonous traffic scenario which confirms onset of fatigue.

Once passive fatigue was successfully induced, the effects of a 6-minute thermal stimulus of 17 °C, directed to the upper body of the drivers were analyzed (n=34). Responses to the stimulus from the subjects included

significantly decreased subjective fatigue ratings, an increase in pupil diameter and an increase in skin conductance which are indicators of a short-term activation of the sympathetic nervous system.

In follow-up studies, the effects of different stimulus durations (2 and 4 minutes, n=33) and lower leg cooling (n=42) on passive driver fatigue were investigated. The results show that 4-minute cooling yielded more pronounced effects in heart rate and pupil diameter variation than the 2-minute cooling. The 4-minute lower leg cooling did not affect any of the recorded physiological parameters, however, the drivers felt subjectively more awake.

These studies showed that sufficiently intensive cooling of the upper body of the drivers reduced passive fatigue in the short-term.

The scope of the research included the development of a fatigue-based triggering of climatic changes in the vehicle cabin. In order to develop a regression model for the detection of fatigue, a secondary data analysis of three driving simulator studies with monotonous highway drives was conducted. With a logistic regression of the input parameters heart rate variability, skin conductance level and pupil diameter, fatigue could be detected with an accuracy of 77 %.

The last simulator study employed the regression model to trigger the thermal stimuli based on the drivers' fatigue level (n=94). The study revealed that a 4-minute thermal stimulus of 15 °C directed towards the drivers' upper body, only affected physiological fatigue during the first and second applications. The third application of the stimulus did not yield a significant activation.

A further result of this thesis was the importance of a transparent interaction strategy for the fatigue countermeasure, which includes rationale for the suggested cooling. The strategy should also leave the autonomy of the drivers to accept or reject the suggested countermeasure.

Concluding, the thesis contributes the following insights to the research field of driver fatigue. The studies of the thesis showed that thermal stimulation of the upper body caused physiological and subjective effects which

can be associated with a short-term sympathetic activation. In contrast to upper body cooling, leg cooling did not yield physiological activation. Furthermore, the study on repeated stimuli showed that thermal stimulation is subject to habituation.

Keywords: fatigue, fatigue countermeasures, thermal stimulation, vitalization