Oral presentation

Multi-Sensor Vigilance Detection in Train Drivers – a Simulator Study

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SUMMARY

Our study investigated the reliability of multi-sensor systems for detecting low vigilance in train drivers operating under Grade of Automation Level 2 (GOA2) conditions. A high-fidelity train simulator study with 14 professional train drivers examined physiological indicators of mental fatigue using electrocardiography (ECG), electroencephalography (EEG), breathing rate, eye tracking, skin conductance, and self-reported sleepiness. While all physiological changes aligned with expected mental fatigue effects, heart rate variability showed the only statistically significant difference. However, blink duration, missed dead man's handle reminders, and self-reported sleepiness showed large effect sizes, suggesting their potential for real-time driver monitoring. These findings will be compared with a real-world study using the same sensor system, informing the development of wearable monitoring solutions to enhance safety in automated rail systems.

KEYWORDS

Train driver vigilance, physiological monitoring, automated rail systems, mental fatigue

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Introduction

The advancement of automation in rail transport, including Grade of Automation Level 2 (GOA2), presents new challenges for train driver vigilance. While partial automation offers several operational benefits, human operators must remain highly attentive to ensure safety. Extended monitoring tasks can result in mental fatigue and decreased vigilance, increasing the likelihood of errors. A promising approach to mitigating this risk involves multi-sensor systems that track the driver's physiological state and identify signs of reduced vigilance in real time (Schackmann & Bosch, 2024). Our study explored this issue by evaluating the reliability and feasibility of various sensor technologies for detecting low vigilance in train drivers.

Method

To investigate this, a study was conducted using a high-fidelity train simulator with 14 professional train drivers (13 identifying as male, 1 as female; mean age of 36.5 +- 15.4 and 14 +- 15.1 years of professional experience). Each participant completed three fully automated driving sessions, with no operational tasks required other than activating the dead man's handle and reacting to objects on track by using the signal horn, as validated in a previous study (Wasle et al., 2023). During the second drive, a mental fatigue induction task was introduced, consisting of a 55-minute n-back task with four levels of difficulty designed to impose cognitive workload and simulate the mental fatigue experienced during extended real-world train operations.

Throughout the study, various body-worn sensors were used to monitor physiological signals linked to mental fatigue. Compared to the first drive, mental fatigue in the third drive was expected to manifest as longer reaction times, more missed dead man's handle reminders, higher heart rate variability (Csathó et al., 2024), reduced breathing rate (Grassmann et al., 2016), longer and less frequent blinks or changes in saccade mean and peak velocity (Bafna & Hansen, 2021), decreased skin conductance peaks (Kreibig, 2010), increased EEG frontal theta power as measured by the Fp1, Fp2, Fz, F3, F4, F7, and F8 electrodes of a wet electroencephalogram (Hamann & Carstengerdes, 2023), and higher self-reported mental fatigue. As none of the measures met the assumption of normality, signed-rank Wilcoxon tests were performed on the mean values per measure per participant, with Bonferroni correction applied to the alpha significance level to account for multiple comparisons.

Results

The respective results are displayed in Table 1. All differences between drive 1 and 3 went into the expected direction. Only the heart rate variability was significantly lower in drive three than one. However, the amount of missed dead man's handle reminders, blink duration and self-reported sleepiness show a large effect size.

Table 1: Respective results of the signed-rank Wilcoxon tests for the different measures.

Measure	V	p-value	Rank-Biserial Correlation (r_b)	Effect Size Interpretation
Heart rate variability	3.0	< 0.001	0.967	Very large
Skin conductance peaks	26.5	0.959	0.518	Moderate
Reaction times to objects	54.0	0.588	0.407	Moderate
Missed dead man's handle reminders	33.0	0.25	0.637	Large
Breathing rate	40.0	0.232	0.273	Small to moderate
Blink duration	17.0	0.57	0.622	Large
Frontal theta	51.0	0.952	0.514	Moderate to large
Self-reported sleepiness	17.5	0.168	0.833	Large

Conclusions

Of the measures that could automatically be measured in a train driver's cab, heart rate variability and blink duration seem the most promising measures that should be further evaluated. In addition, this experiment was repeated with 6 train drivers in a real-world study. Our talk will give insights into the comparison between these simulator results and the real-world study. Overall, our findings aim to enhance safety in automated rail systems by identifying the most promising measures for driver vigilance monitoring.

References

Bafna, T., & Hansen, J. P. (2021). Mental fatigue measurement using eye metrics: A systematic literature review. *Psychophysiology*, *58*(6), e13828. https://doi.org/10.1111/psyp.13828

Csathó, Á., van der Linden, D., & Matuz, A. (2024). Change in heart rate variability with increasing time-on-task as a marker for mental fatigue: A systematic review. *Biological Psychology*, *185*, 108727. https://doi.org/10.1016/j.biopsycho.2023.108727

Grassmann, M., Vlemincx, E., Leupoldt, A. von, Mittelstädt, J. M., & van den Bergh, O. (2016). Respiratory Changes in Response to Cognitive Load: A Systematic Review. *Neural Plasticity*, *2016*, 8146809. https://doi.org/10.1155/2016/8146809

Hamann, A., & Carstengerdes, N. (2023). Assessing the development of mental fatigue during simulated flights with concurrent EEG-fNIRS measurement. *Scientific Reports*, *13*(1), 4738. https://doi.org/10.1038/s41598-023-31264-w

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, *84*(3), 394–421. https://doi.org/10.1016/j.biopsycho.2010.03.010

Schackmann, D., & Bosch, E. (2024). Automated Detection of Train Drivers' Head Movements: A Proof-of-Concept Study. *Automation*, *5*(1), 35–48. https://doi.org/10.3390/automation5010003

Wasle, H., Goralzik, A., Thomas-Friedrich, B., Schackmann, D., & Bosch, E. J. (2023). When Something Is in the Way: Parameters of Perception and Reaction Speed in Train Drivers. In *5th International Conference on Human Systems Engineering and Design: Future Trends and Applications (IHSED 2023),* Dubrovnik, Croatia. https://elib.dlr.de/196902/