A neuroscientific approach for investigating mental fatigue biomarkers in simulated driving trials

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Extended Abstract

Introduction

A non-adequate psychophysical condition represents a major cause of road accidents [1]. In particular, almost the 20% of crashes are caused by mental fatigue, with dramatic consequences. Investigation of fatigue early signs becomes crucial to develop tools able to recognise in advance the onset of fatigue episodes. This is extremely relevant for professional drivers who drive for prolonged periods.
Nowadays, automotive industry provides some on-board systems aimed to recognize an altered driving behaviour. However, these systems are affected by a poor accuracy, resulting in several misclassifications causing drivers' mistrust of technology.
The current systems to detect mental fatigue can be divided into three main categories:
1) Driving behaviour-based systems, based on information coming from the vehicle to detect any anomalous driving pattern.
2) Drivers' behaviour-based systems, based on overt drivers' behaviour, such as eyes movements, facial expressions and head position.
3) Drivers' psychophysiological signals-based systems, based on physiological parameters as a direct measure of the driver's state.
A lot of research has been already done on this topic, providing evidence about the possibility of recognizing a state of severe fatigue, while the aim of our research was to investigate whether it is possible to detect the onset of fatigue, since anticipation will be crucial for developing safer vehicles.

Materials and Methods

Twelve volunteer professional drivers (truck drivers) have been recruited to take part in an experimental protocol, performed in a truck simulator. The experiment took place in the afternoon to increase the chance of inducing mental fatigue and it consisted in driving for 45 minutes in a monotonous city-like environment [2]. Before performing the monotonous driving task, participants were asked to drive for

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15 minutes in a high-difficulty racetrack to "stress" the driver, increasing the probability of fatigue onset the following monotonous driving task[3].

Figure 1. Picture of the experimental setup, with the driver seat in the simulator and wearing measurements devices.

Traditional assessment tools, such as subjective measures (driver's perception), telemetry of driving parameters (driver's performance), and environmental data (temperature, light, CO2 saturation) have been integrated by advanced neuroscientific tools (brain, ocular and heart parameters) to assess the driver's psychophysical state, in order to get a complete and multimodal "picture" of the problem.

In particular, the Karolinska Sleepiness Scale [4] was used to collect the individual self- assessment of fatigue before and after the driving task. In terms of physiological measures, the Mindtooth Touch EEG headset[2] (BrainProducts GmbH, Germany) was used to measure brain activity, while Empatica E4 wristband (Empatica Inc., USA) was used to measure heart activity and skin sweating. Eyes movements were recorded by means of Tobii Pro Glasses 2 (Tobii Tech., Sweden). Telemetry of vehicular data was provided directly by the simulator, while environmental data were gathered by means of ad-hoc developed sensor.

The EEG-based Mental Drowsiness index [5] was used to identify and label, per each participant, the driving periods at lowest and highest fatigue. Therefore, the analysis was performed by comparing these two conditions of "Low" and "High" fatigue for each participant.

Results

The subjective assessment confirmed that the drivers experienced mental fatigue increasing, since the average score rose from almost 2 before the beginning of the monotonous driving task, to 4 until its conclusion. While KSS score equal to 2 is considered 'Very alert', KSS score equal to 4 is considered 'Fairly alert', supporting the hypothesis of alertness decreasing as a prodrome of fatigue onset.

At this point, by comparing the timeframes of "Low" and "High" fatigue for each participant, the following evidence have been obtained for the "High" fatigue state (because of the small sample size, a p-value threshold equal to 0.1 has been considered to identify the relevant results):

- Increasing of Eye Blink Rate ($p = 0.07$);
- Decreasing of Eye Blink Duration ($p = 0.1$);
- Less ocular fixations on the cockpit instrumentation ($p = 0.03$);
- More duration of fixations over the external environment ($p = 0.1$);
- Reduced variability (standard deviation) in rolling along the longitudinal axis ($p = 0.03$);
- Reduced variability of acceleration pedal position ($p = 0.08$);
- Higher concentration of CO2 in the air ($p = 0.12$, tendency).

Conclusions

The overall analysis of all the collected measures provided interesting insights on the psychophysiological experience of drivers. The subjective assessment confirmed that the drivers experienced mental fatigue, but the joint analysis of the different measures seems to suggest that it was an early-stage fatigue. The causes of this fatigue have been the monotonicity of the driving task and an increasing concentration of CO2 in the air. Ocular activity parameters, specifically eye blink rate and duration, demonstrated to be sensitive to mental fatigue, apart from the EEG-based neurometric that has been used as the gold standard. This onset of fatigue produced significant variations on the drivers' behaviour, in particular in terms of visual scanning patterns (eye movements) and usage of accelerator. The holistic approach based on the joint analysis of multimodal measures provided interesting insights on the psychophysiological experience of drivers and can pave the way for new monitoring systems able to allow higher discrimination performance and ideally to anticipate the more severe states of fatigue.

Keywords: Human Factor, Mental Fatigue, Driving Behaviour, Neurophysiology, Eye Tracking, Truck drivers.

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