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EEG alpha spindles and prolonged brake reaction times during auditory distraction in an on-road driving study

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ABSTRACT

Driver distraction is responsible for a substantial number of traffic accidents. This paper describes the impact of an auditory secondary task on drivers' mental states during a primary driving task. $N=20$ participants performed the test procedure in a car following task with repeated forced braking on a non-public test track. Performance measures (provoked reaction time to brake lights) and brain activity (EEG alpha spindles) were analyzed to describe distracted drivers. Further, a classification approach was used to investigate whether alpha spindles can predict drivers' mental states.

Results show that reaction times and alpha spindle rate increased with time-on-task. Moreover, brake reaction times and alpha spindle rate were significantly higher while driving with auditory secondary task opposed to driving only. In single-trial classification, a combination of spindle parameters yielded a median classification error of about 8% in discriminating the distracted from the alert driving. Reduced driving performance (i.e., prolonged brake reaction times) during increased cognitive load is assumed to be indicated by EEG alpha spindles, enabling the quantification of driver distraction in experiments on public roads without verbally assessing the drivers' mental states.

1. Introduction

Driver distraction and inattention lead to a substantial number of traffic accidents. In 2009, 5474 people died in road accidents in the United States due to driver distraction, amounting to 16% of all fatal crashes. Additionally, 448,000 injuries where at least one form of driver distraction was noticed were registered in police crash reports (NHTSA, 2010). Natural driving studies, where drivers are monitored during everyday driving, revealed an even higher influence of driver distraction on crashes, though with a broader definition of inattention, including fatigue among other things (Klauer et al., 2006). These authors reported distraction was responsible for 78% of crashes and 65% of near-crashes for automobiles. Olson et al. (2009) found distraction a contributing factor in 71% of crashes and 46% of near-crashes for heavy trucks. These naturalistic driving studies are based mainly on video analysis, a radar system, lane tracking and vehicle data in predefined safety-critical events related to randomly chosen baselines. While this approach has a high ecological validity and apparently identifies observable distraction, it is not possible to identify internally directed attention which is also known as daydreaming or highway-hypnosis (Wertheim, 1991). A stimulus presented in the eye-field of a person heading to that stimulus is not necessarily attended and consciously perceived. This so-called "looked-but-failed-to-see" phenomenon is a major cause of accidents (Herslund and Jorgensen, 2003). Given that cognitive resources are often divided among various tasks besides that of driving, performance in processing of relevant information is not always constant. In regions over the pre-frontal and parietal cortex, decision is made about the importance of a stimulus and whether attention should be paid to it (Birbaumer and Schmidt, 2010). If the incoming distraction is rated more important than the primary driving task, then

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parts of the attention resources are shifted to the current secondary task.

Neuronal processes underlying attention shifts during driving can be described with different methods. Bowyer et al. (2009) investigated the influence of a conversation while watching a driving scene using magneto-encephalography (MEG). Without conversation, higher brain activity in the visual cortex (85 ms after stimulus onset) and in the right superior parietal lobe (200–300 ms after stimulus onset) resulted in shortened reaction times to small red lights embedded in a driving scene (conversation: M = 1043 ms, SE = 65.0 ms; no conversation: M = 944 ms, SE = 48.0 ms). Reduced amplitude in brain activity and an increased mean reaction time could be seen during additional hands-free conversation, while there was no statistically significant difference in miss rates. In a companion paper, Hsieh et al. (2009) conducted a study with identical design using fMRI. They investigated a frontal-parietal network that indicates effects of conversation on visual event detection. Compared to driving only, reaction times to visual events were prolonged during covert conversation. The authors assume a top-down influence of frontal regions on the synchronization of neural processes within the two key regions of superior parietal lobe and extrastriate visual cortex.

Foxe et al. (1998) found effects of the stimulus modality in parieto-occipital activity (~10 Hz). In an intermodal selective attention paradigm, visually presented words indicated the to-be-attended modality. Participants showed a higher parieto-occipital alpha activity in preparation for anticipated auditory input compared to anticipated visual input, indicating a disengaged visual attentional system. Cooper et al. (2003) have found similar correlations between alpha activity and direction of attention. They reported significantly higher alpha amplitudes for internally than for externally directed attention.

Sonnleitner et al. (2012) also found higher alpha activity while driving with as opposed to driving without auditory secondary task (in this case in terms of alpha spindles defined as sinusoidal patterns within a widened alpha band [6–13 Hz]). A detailed description of alpha spindles including a detection scheme can be found in Simon et al. (2011). The lowest alpha spindle rate (occurrence per minute) while driving was registered during the visuomotor secondary task with the highest visual information input. It is assumed that alpha spindles indicate the intensity of visual information processing. More specifically, they are assumed to refer to the thalamo-cortical gating for incoming sensory information (Pfurtscheller, 2003) and are therefore significantly involved in facilitating selective attention (Cohen, 1993).

To determine the influence of decreased visual information processing on brake reaction times, the exact process from the flashing of the brake lights until the braking of the car has to be investigated. Burkhardt (1985) reported that it takes an average of 640 ms from when an object is fixated until the brake pedal is contacted. Muscle contraction is initiated in an interval from 220 ms (2nd percentile) through 450 ms (50th percentile) to 580 ms (98th percentile). This part of the brake reaction time should be impacted by fatigued or distracted driving. In a simulator study, Strayer et al. (2006) investigated the brake reaction times (among other things) of drunk drivers (i.e., blood alcohol concentration at 0.8% w/v) and cell phone drivers (hands-held and hands-free cell phone) in a car-following study. The mean brake reaction times in response to the braking lead car varied between 777 ms (Baseline), 779 ms (Alcohol) and 849 ms (Cell Phone). The mean separation to the lead car ranged from 26.0 m (Alcohol) via 27.4 m (Baseline) to 28.4 m (Cell Phone) with time to collision varying between 8.5 s (Baseline), 8.1 s (Cell Phone) and 8.0 s (Alcohol). While cell phone drivers had slower reactions and greater separations, intoxicated drivers showed a more aggressive driving style (i.e., they hit the brakes harder, had shorter following distances). Even if the underlying mechanisms clearly differed, the authors concluded that impairments associated with using a cell phone can be as profound as those associated with drunk driving, including a comparable risk of traffic accidents.

The aim of the present study is to identify neurophysiological correlates of driver distraction as well as the influence of distraction on reaction times to forced braking. These factors were previously investigated in a laboratory study, wherein participants performed an analogous task in a driving simulator (Sonnleitner et al., 2012). In order to maximize ecological validity, the setting was transferred to real cars on a non-public test track. A major goal of the study was to replicate these findings in this realistic driving environment.

Additionally, machine learning methods were used to investigate whether the identified neural correlates can be used to predict driver distraction on a single-trial level.

Hypotheses. Performing an auditory secondary task will result in a higher mental workload and a reduced degree of visual information processing by the driver.

(a) Therefore, *driving with an auditory secondary task* is expected to increase brake reaction times and alpha spindle rate as compared to *driving only*.
(b) With ongoing *time-on-task*, brake reaction times as well as alpha spindle rate are expected to increase due to task-related fatigue.
(c) Alpha spindle rate is expected to predict driver distraction on a single-trial level (i.e., three-minute-block).

2. Methods

2.1. Participants

In total, 25 individuals participated in this study. Five of the resulting datasets had to be excluded from further analysis due to technical problems or noisy data. Therefore, the sample consisted of 20 participants (22–53 years, mean: 29.0 years, five females). Subjects were recruited from an in-house database in which volunteers for experiments are listed. Every subject had normal or corrected-to-normal vision, reported normal hearing and had no history of psychiatric or neurological diseases. Participation was voluntary and occurred during working hours. All experimental procedures were conducted in accordance with the ethic guidelines of the Declaration of Helsinki. All assessments were performed by the same research personnel, who were well trained and had relevant experience in rehabilitation research. Data were collected anonymously. Informed consent was obtained after the task had been explained. Participants were informed they had the option to end participation in the experiment at any time without any type of penalty. Participants received a gift worth approximately € 20 for their participation.

2.2. Driving task (primary task)

The study was conducted on a non-public test track in an unused military training area in Münsingen, Germany. Participants were instructed to always prioritize the primary task and to drive in accordance with official traffic regulations. They had to drive three rounds on the test track, one round being 37 km long with varying horizontal and vertical curves. The setup consisted of two Mercedes-Benz S-Class cars: the lead car was navigated by an investigator and the following car was driven by the participant. Participants were instructed to follow the lead car at a constant distance of approximately 20 m away at a maximum speed of 60 km/h. In order to obtain a reference for the required distance, the participant's car was parked 20 m behind the lead car before the start of the experiment. The investigator in the lead vehicle initiated braking from 60 km/h to 40 km/h with an interstimulus interval of