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Alpha spindles as neurophysiological correlates indicating attentional shift in a simulated driving task

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ABSTRACT

The intention of this paper is to describe neurophysiological correlates of driver distraction with highly robust parameters in the EEG (i.e. alpha spindles). In a simulated driving task with two different secondary tasks (i.e. visuomotor, auditory), $N=28$ participants had to perform full stop brakes reacting to appearing stop signs and red traffic lights. Alpha spindle rate was significantly higher during an auditory secondary task and significantly lower during a visuomotor secondary task as compared to driving only. Alpha spindle duration was significantly shortened during a visuomotor secondary task. The results are consistent with the assumption that alpha spindles indicate active inhibition of visual information processing.

Effects on the alpha spindles while performing secondary tasks on top of the driving task indicate attentional shift according to the task modality. As compared to alpha band power, both the measures of alpha spindle rate and alpha spindle duration were less vulnerable to artifacts and the effect sizes were larger, allowing for a more accurate description of the current driver state.

1. Introduction

1.1. Alpha band activity

Traditionally the alpha activity in the EEG was thought to reflect general cortical idling (Berger, 1929). As for the functional significance of the alpha component, Mann et al. (1996) observed a decrease in occipital alpha band power during visual stimulation and scanning tasks and Pfurtscheller et al. (1996) reported a task-related decrease of alpha band power over sensorimotor areas during visual processing or foot movement (μ-rhythm).

However, several findings are incompatible with the assumption of alpha reflecting cortical idling leading some to conclude that alpha band oscillations represent active inhibition irrespective of the direction of attention (Ray and Cole, 1985) or the active inhibition of sensory information in task-irrelevant cortical areas (Jokisch and Jensen, 2007; Klimesch et al., 2007).

Ray and Cole (1985) also reported that alpha and low beta activity is more sensitive to attentional demands especially in the parietal areas and is only weakly represented in the frontal areas. Cooper et al. (2003) found a clear relationship between alpha and both direction of attention (external and internal) and increased task demands. Alpha band power was higher during internally directed attention and during increased workload at various scalp sites. Klimesch (1999) suggested that event-related desynchronisation (ERD) in the lower alpha band (6–10 Hz) can be obtained in response to a variety of non-task-specific factors. It is topographically widespread over the scalp and reflects more general task demands and attentional processes. Foxe et al. (1998) suggested that ~10 Hz oscillations in parieto-occipital areas are affected by the direction and maintenance of visual or auditory attention. Participants had to do an intermodal selective attention task where word cues were visually presented. They showed a higher parieto-occipital ~10 Hz activity in preparation for anticipated auditory input as compared to visual input which reflects a disengaged visual attentional system while focusing on auditory input. This fits to Birbaumer and Schmidt (2006) who reported that afferents and efferents of the prefrontal cortex anatomically select momentarily important parts of gathered information, i.e. only acoustic information can pass via medial geniculate nucleus. The interaction between the thalamus and the cerebral cortex, which are widely and complexly interconnected anatomically, phylogenetically and functionally (Reinoso-Suárez et al., 2011), plays an important part in shifting attention.

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A different approach to measure alpha activity has been proposed by Simon et al. (2011). The authors reported a method to automatically detect so-called alpha spindles and analyzed several properties of this EEG component. Driver fatigue had a long-term effect on the alpha spindle rate (occurrence rate per minute), but there were also short-term variations, indicating additional influences of other cognitive processes. Even though alpha activity is partially generated in the cortex (Bollimunta et al., 2011), alpha spindles are assumed to be largely controlled by the interplay between thalamic relay cells and the thalamic reticular nucleus, as well as thalamo-cortical interactions. This thalamo-cortical gating serves as a relay for incoming information and values information by acting as an integration system for the transfer of sensory information (Pfurtscheller, 2003). Adjusting attention by projecting arousal from reticular activation to specific cortical processing systems plays an important role for the process of selective attention (Cohen, 1993). These selection mechanisms weight information coming from different modalities, depending on the attended stimuli. Therefore, alpha activity, in particular alpha spindles, might serve as an indicator of the current attentional focus.

1.2. Gamma band activity

Previous studies reported that EEG activity in the gamma band can be modulated by attention. Landau et al. (2007) showed that voluntary shifts of spatial attention are linked to a gamma-band response. Fell et al. (2003) also reported findings indicating synchronized gamma activity to be involved in selective attention. Jensen et al. (2007) noted that human gamma-frequency oscillations play an important role in neuronal communication and synaptic plasticity and therefore are associated with attention and memory processes. Gruber et al. (1999) reported higher power in a lower gamma band (35–51 Hz) on parieto-occipital electrode sites contralateral to an attended rotating stimulus. When shifting attention to the left or to the right the lower gamma band response changed from a broad posterior distribution to an increase of power only at contralateral parieto-occipital sites. Generally, gamma band power increased for subjects attending to a certain stimulus as compared to ignoring the same stimulus (Müller et al., 2000). These findings support the idea that induced gamma band activity is closely related to visual information processing and attentional perceptual mechanisms.

However, results from the above described studies mostly rely on experiments with little ecological validity, since they often depict isolated stimuli out of complex scenarios. It remains open whether these results can be replicated in a more realistic setting such as performing in a simulated driving task with less controlled conditions and possibly more influences of noise and artifacts.

1.3. Hypothesis

The aim of this study is to identify correlates of inattentive driver states that are induced by executing secondary tasks. These mental states are described by EEG parameters that are robust to ocular, muscular and technical artifacts which typically occur during driving.

Alpha spindle rate and *alpha band power* are expected (a) to increase while performing on an auditory secondary task indicating inhibited visual information processing and (b) to decrease while performing on a visuomotor secondary task indicating increased visual information processing. *Gamma band power* should increase during the visuomotor secondary task indicating a higher level of visual information processing.

2. Methods

2.1. Participants

A total of 29 employees participated in this study (20–42 years, mean: 28.0 years), 17 male and 12 female. A subgroup of 20 participants had no experience in driving simulators. 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 time. All experimental procedures were conducted in accordance with the ethic guidelines of the German Psychological Society (Deutsche Gesellschaft für Psychologie) and the German Psychologists' Professional Association (Berufsverband deutscher Psychologen) from 1998. All assessments were performed by the same research personnel, who were well trained and had relevant experience in rehabilitation research. Subjects were recruited from an in-house database, in which voluntary participants are listed for experiments. Data were collected anonymously. Informed consent was obtained after the task had been explained. Participants were informed that they could stop participating in the experiment at any time without any monetary or other penalties. For participation they received compensation in form of a gift worth approximately € 10.

Due to technical problems one dataset had to be excluded from further analysis; in total 28 datasets were statistically analyzed.

2.2. Simulator

The study was conducted in a simulator localized in a laboratory at Daimler AG in Sindelfingen, Germany. The simulator was rebuilt from a Mercedes-Benz C-Class (type W203, automatic transmission) that created a natural environment with a conventional brake and accelerator pedal, a steering wheel, a complete dashboard and an adjustable car seat position. The driving task was coded with STISIM Drive V2.0 (Systems Technology Inc.). The driving scene was projected by an Epson EMP7800 on a 2.05 m × 1.05 m screen 1.00 m above the ground in 1.95 m distance from the seat.

2.3. Driving task (primary task)

Participants were instructed to always prioritize the primary task and drive in accordance to official traffic regulations. The maximum speed of the vehicle was 100 km/h (~60 mph) and the difficulty of the course was very low, so participants could easily follow the street. They drove about 80 km (two rounds of 40 km) interrupted by a short break after the first round. This driving task lasted about 60 min and was subdivided into two sets of three different blocks, one set for each round. In each of the total six blocks participants had to react to critical situations (red traffic lights, stop signs). A stop sign suddenly appeared over the entire screen, while the traffic light was announced by a sign 800 m earlier and could be seen 400 m before arriving. It turned to red four seconds before the driver would have passed the stop line with the current speed.

In each block four traffic lights (two of them turned red, two stayed green) and four stop signs appeared. These critical situations appeared at varying times within a block. Participants were instructed to perform a full stop brake when they perceived a red light or a stop sign. This resulted in a total of 54 full stop brakings, 18 for each task (visuomotor secondary task, auditory secondary task, driving task only).

2.4. Visuomotor secondary task

During the visuomotor task (Visual Task v2.20, developed by Daimler AG, 2008) a 3 × 3-matrix with 9 Landolt rings was presented on a separate 18-inch LCD-TFT display. The display was located at the central console where it replaced the navigation system. The 3 × 3 matrix contained eight identical rings and one distractor with the gap at a different position (Fig. 1). Participants had to determine the position of the distractor by pushing the matching button on an external number keypad (1–9) that was positioned at the actual position of the manual delivery of the lower central console. After pushing a button the next matrix appeared immediately. This secondary task