Alpha and Theta Power in Repeated Take-over Requests

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INTRODUCTION

It is demanding to sustain high levels of vigilance over long durations (Warm et al., 2008). Nonetheless, this is often required of users of automated vehicles who are still expected to intervene in case of unexpected emergencies. Oscillatory activity, often with a focus on alpha (8-12 Hz) and theta (4-7 Hz) bands, are typically treated as indices for cognitive states such as mental workload, attention, or fatigue (Lohani et al., 2019). High alpha power can be inferred as attentional withdrawal or task disengagement (Wascher et al., 2014; Wascher et al., 2016), while frontal theta power typically increases with higher task demands (Diaz-Piedra et al., 2020; Jensen & Tesche, 2002). Time on task, which is the length of time spent actively involved in a task, was also associated with increasing theta activity (Arnau et al., 2017; Wascher et al., 2014). For instance, Arnau et al. (2017) assumed that theta activity reflects the mental effort required to maintain high performance over time. Zhao et al. (2012) found that both alpha and theta rhythms increase after a long period of driving in a driving simulator. In contrast, Kamzanova et al. (2011) did not find a 'time-on-task effect' on theta activity. This study evaluates changes in the relative frontal midline theta and the relative parietal midline alpha power during repeated take-over requests (TORs) while driving in a highly automated vehicle. We hypothesize an increase in relative alpha and relative theta power due to the 'time-on-task effect'.

METHOD

The sample consisted of 10 participants (8 female) with an average age of 22.91 years (SD = 3.70) with normal or corrected to normal vision, no neurological or psychiatric disease, and a valid driver's license.

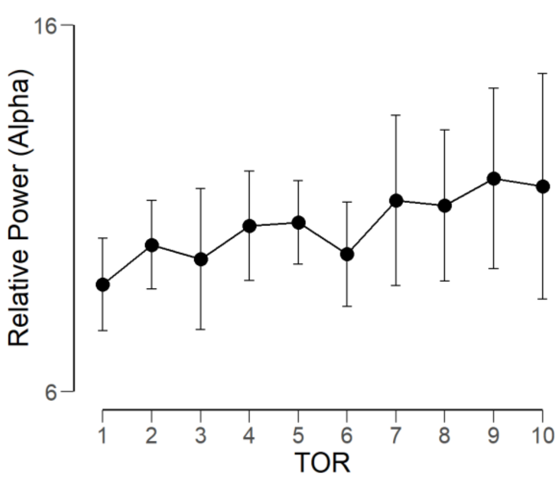
Participants drove in an automated vehicle through four driving scenarios (approx. 10 mins each) in a fixed-base, high immersive driving simulator with a 190 ° field of view. The order of the scenarios was counterbalanced using the balanced Latin square. The scenarios were similar regarding the environment, and each track consisted of a 17 km long rural road. The vehicle was traveling in an autonomous mode with a set speed of 100 km/h, and there was mild oncoming traffic. While monitoring vehicle automation, participants performed a secondary task (the Visual Search Task; Treisman & Gelade, 1980) on a dashboard screen. During the experiment, participants experienced ten slow-moving vehicles on the road ahead that individually triggered auditory TORs. The TORs prompted participants to disengage from the secondary task, deactivate the automation, manually overtake the slow vehicle, activate the automation, and return to the secondary task. The TORs appeared randomly every one to six minutes, and there were two or three TORs in each of the four scenarios.

The EEG was recorded using 32 Ag/AgCl active electrodes placed according to the International 10/20 System. Horizontal and vertical eye movements were recorded using six electrodes. Data were recorded with a sampling rate of 500 Hz using a LiveAmp amplifier (BrainProducts). The signal was re-referenced to a common average reference; the noisy channels were removed from the average. A bandpass filter between 0.5 and 40 Hz was applied, as well as a 50 Hz notch filter. The eye movement artifacts were removed using the *ICA*, and the data was segmented (-3 to 10 s relative to the auditory TOR onset). The spectral power density was analyzed in the theta band (4-7 Hz) on the frontal electrodes (Fz, F3, F4) and in the alpha band (8 to 12 Hz) on the parietal electrodes (P3, P4, Pz). The relative power of the alpha and theta bands was calculated as a percentage of the absolute power of the signal (0.5-40 Hz).

RESULTS

Figure 1 illustrates the mean relative power of alpha and theta bands across the presentation order of TOR. Using the ANOVA with repeated measures with a Greenhouse-Geisser correction, no significant effect was observed neither for the alpha activity ($F(3.435, 30.912) = 1.195$, $p = .330$), nor for the theta activity ($F(3.625, 32.621) = 1.117$, $p = .363$).

Given the characteristics of our data, we applied further analyses. Using the linear trend estimation, we observed a significant negative linear trend in theta power ($t(9) = -2.30$, $p = 0.02$) and a positive linear trend in alpha power ($t(9) = 2.91$, $p = 0.005$). Next, we performed exploratory post-hoc analyses, namely Bayesian t-tests, to determine potential differences between the presentation of the first TOR and subsequent ones. Interestingly, there was substantial evidence for a difference in alpha power between TOR1 and TOR5 (*BF10* = 4.76). There was no evidence favoring either the null or test hypothesis for all other comparisons between TOR1 and subsequent TORs for theta and alpha power measurements. Moreover, a strong negative correlation ($r(8) = -.74$, $p = .01$) was observed between the mean alpha and theta power.



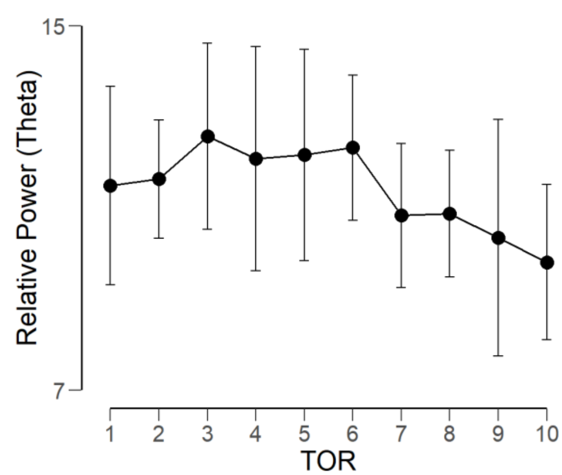


Figure 1 Mean relative alpha power and mean relative theta power for each of the ten TORs. Error bars represent the standard deviation.

DISCUSSION

In this study, ten participants experienced four highly automated driving scenarios in a driving simulator of approximately 45 minutes in total. They had to take over control over the vehicle ten times during this period. We hypothesized an overall increase in both alpha and theta relative power due to the time-on-task effect. Our current data do not directly support this hypothesis. Instead, we identified a potential increase in alpha power halfway through our experiment relative to the first TOR. This increase might indicate a change in vigilance over time that results in a mid-experiment impairment, followed by a recovery. Another explanation might be substantial variance in our data due to the sample size. Follow-up studies are designed to study the dynamics of vigilance and resource demands over time.

Interestingly, theta power did not increase over time. It seemed to have decreased. This finding is in contrast with most previously published studies (Arnau et al., 2017; Wascher et al., 2014; Wascher et al., 2016; Zhao et al., 2012), but compliant with the results of Kamzanova et al. (2011). Thus, the time-on-task effect may not be strongly manifested in the EEG indices over a relatively short period of time, namely over the 45 minutes long drive. However, given the relatively small sample size and a low number of repetitions resulting in 100 trials only, the observed variance in our data is relatively large.

In future studies, we recommend addressing the limiting factors. A larger sample size should be recruited. Moreover, a comparison with other psychophysiological data would be interesting, e.g., with the skin conductance response or the heart rate variability. We also recommend addressing rather the dynamic than the global changes of alpha and theta power.

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