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EEG-Predictors of Covert Vigilant Attention

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Abstract. A brain computer interface (BCI)-based cognitive state monitoring system able to determine the current, and predict the near-future development of the brain's attentional processes would bear great theoretical and practical implications. The present study investigated the evolution of neurophysiological signals preceding an omission error during a covert sustained attention task. The findings confirm the presence of characteristic EEG signals anteceding inadequate levels of attention by up to 10 s.

Keywords: EEG, BCI, vigilant attention, cognitive state monitoring, covert attention, P300, N200, α-rythm

1. Introduction

Many work environments, especially in safety critical environments require the continuous and consistent attention of a human operator. The monotonous nature of these tasks often leads to momentary inattention which can result in errors and have serious consequences. Brain computer interfaces (BCI) offer a powerful insight into the mental states of users and an additional channel of information, which can be exploited by devices able to dynamically adapt to the user's mood or state [Blankertz et al., 2010]. Several studies have already demonstrated that brain activity carries information presaging the outcome of behavioral responses [Eichele et al., 2010; O'Connell et al., 2009] in attention task using stimuli in the foveal field. The present work aimed at obtaining analogous results in a covert vigilant attention task which more closely mimics a real-world environment where rare critical stimuli may appear on the periphery of the visual field.

2. Material and Methods

Twelve healthy subjects (4 female; 27.4 ± 2.9 years) volunteered for participation in this study. Participants performed a modified "Mackworth Clock test" [Mackworth, 1948], consisting in identifying and reacting to rare double jumps of a pointer that produces regular small jumps every second across dots arranged in a circle. The dots formed a circle with a diameter spanning 10° of the visual field around the center of the fixation cross. Participants were instructed to gaze at the cross in the center of the screen, keep track of the pointer using covert attention and to react as fast as possible to the rare double jumps by pressing a button. The task was designed to impose great strain on cognitive resources [Warm et al., 2008], especially endogenously directed attention, and was chosen to encourage attentional drifting. Participants completed four blocks à 15.5 min each with an average of one double jump every 10 s equating to a total of 360 double jumps over the course of the whole experiment. Neurophysiological data was gathered using surface EEG with 64 electrodes arranged according to the international 10/20 system.

3. Results

The average response time (RT) of the participants included in the analysis was 560 ± 166 ms with an overall accuracy of 65.5 ± 10%. Behavioral data revealed a strong decline in performance and a steady increase in reaction time over the course of each block. The blocks were divided into 5 bins of 3 min and 4.4 s each and two 4×5 repeated measure ANOVA were conducted on the dependent variables performance and RT. A highly significant time-on-task effect on performance, $F_{(4, 36)}$=14.483, $p < 0.001$, and RT were found, $F_{(4, 36)}$=3.458, p=0.017, confirming the efficacy of the paradigm in inducing a rapid decrease in vigilant attention.

The grand average ERP waveform and the contrast in P3 amplitude between hits and misses, expressed in terms of *sgn* r^2 (Fig. 1), show a gradual decline of the amplitude of P3 for trials preceding misses. First signs of the amplitudinal decline of P3 can be observed on the sixth trial preceding a miss. Examination of the N2 suggests an increase in amplitude for trials preceding hits. Moreover, a propensity towards an inadequate attentional cognitive state is also reflected in an increase of α activity over occipital central areas up to 10 trials before target onset. Linear regression analyses of peak amplitude differences between classes revealed a significant positive correlation for the P3 component over channel Cz and a significant negative correlation of α activity over channel POz.

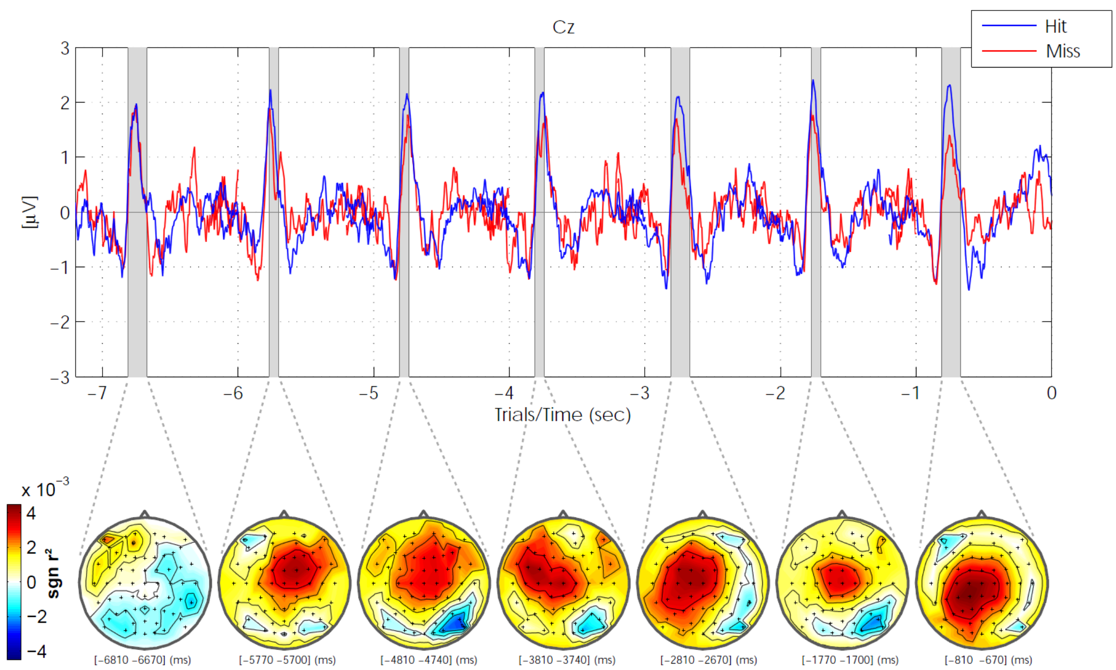

Figure 1. *Grand Average ERP waveform and associated sgn r² scalp topographies for the 6 trials preceding a hit or miss.The sgn r² scalp topographies show the contrast between the peak of the P3 of hit- and miss-preceding trials (marked in grey).*

4. Discussion

The results of this study confirm that neurophysiological signals harbor information pertaining to the subject's current attentional state. ERP features, especially the P3 component, and spectral features of the EEG data seem to possess predictive value up to ten trials before the occurrence of a critical stimulus. In contrast with Eichele et al.'s [Eichele et al., 2010] results, this study did not observe a gradual decline in N2 amplitude preceding errors or misses. This is most likely due to the fact that N2 predominantly reflects visual processing whereas P3 is related to cognitive processing. Therefore an attenuated N2 and a more discriminative P3 is to be expected in a covert attention paradigm. Our results clearly show a decrease in P3 amplitude over central areas and an increase of α activity over central occipital areas for trials preceding misses, corroborating O'Conell et al.'s [O'Connell et al., 2009] findings.

These results are of particular interest with regard to the fact that the P3 and spectral amplitude divergences between trials preceding misses and hits carry anticipatory information in a covert attention paradigm. This strengthens the theoretical feasibility of a BCI-based attention surveillance system in a visually complex environment (e.g. driving, security or medical screenings, cockpit monitoring etc.). Furthermore, the fact that the discussed ERP and spectral features are spatially consistent and confined could be exploited in the form of a reduced subset of electrodes sufficient to predict lapses of attention. Taken together, these findings encourage further investigation towards a BCI-based attention state monitoring system that would possibly prove beneficial to a wide range of work environments and human-machine interfaces. Future studies should investigate whether the propensity towards task disengagement can be detected on a single-trial basis.

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