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DETECTION OF ATTENTION ALTERATION OF BCI USERS BASED ON EEG ANALYSIS

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ABSTRACT: In previous studies we have introduced a brain-computer interface (BCI) system based on movement related cortical potentials (MRCP). The performance of this system was shown to be significantly affected by the users' attention state. In the current study, we analyzed MRCP features (low frequencies) and features extracted at higher frequencies to determine the effect of variations in user's attention on EEG. Attention was modulated by a combination of auditory and visual stimuli that served as external distractors from the main task, which was a simple dorsiflexion. Time and frequency analysis was performed on EEG signals recorded from twenty-eight channels. The amplitude of the peak negativity and the slope of the negative deflection of the MRCP decreased and pre-movement variability increased with the distractors. Moreover, spectral analysis revealed an increment of theta power and alpha power due to attentional shifts. These results have implications for the design of real-life BCI systems, potentially allowing an increased robustness and adaptability with users' conditions.

INTRODUCTION

BCI systems provide a bi-direction interface with the human brain and can be used to modulate neural activity for rehabilitation (1, 2). For this purpose, the user's attention has an impact on the system performance. The effect of attention levels by the user was previously investigated for synchronous BCIs, where a cue was used as a source of information for the task execution (3, 4). However, the performance of asynchronous (self-paced) BCI in relation to attention variations remains unclear.

External stimuli can play the role of attention distractors and therefore drift the attention away from the target task (5, 6). Different types of attention activate various locations of the brain. While visual attention influences the parietal and occipital areas (7), auditory stimuli are directed to temporal and frontal locations (8).

Attention level modulates electroencephalography (EEG) signals. Event-related cortical potentials, steady–state evoked potentials and event-related (de)synchronization have been the most common types of signal modalities for the investigation of attention in BCI (9-11). In our previous work, we used features of the MRCP for detection of attention variations. We showed that temporal features of the MRCP are influenced by attention distractors (3).

In this study, temporal and spectral features of EEG signals were used for detection of attention variations. The main aim of this analysis is to make BCIs more robust for attention detection. Additionally, we aimed to identify which brain locations were more influenced by using each group of features.

MATERALS AND METHODS

Experimental set up

Nine healthy participants (4 females, 5 males) without hearing or visual impairments took part in the experiments. The experimental procedures were approved by the local ethical committee for the region of Northern Jutland (N-2016006).

EEG signals were recorded from twenty-eight channels by using an active EEG electrode system (g.GAMMAcap^2, Austria) and two synchronized g.USBamp amplifier (gTec, GmbH, Austria). EEG channels corresponded to AF3, AFz, Af4, F3, F1, Fz, F2, F4, FC3, FC1, FCz, FC2, FC4, C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2 and P4 of the international 10-20 system. Two electromyography (EMG) electrodes were placed on the tibialis anterior (TA) muscle of the dominant foot to get information about movement execution.

Paradigm and task

Participants were asked to sit on a comfortable chair placed approximately one meter away from a computer screen, which showed the visual oddball task. An auditory oddball was played from a conventional headphone.

The experiment consisted of two phases.

Control Level (CL): Participants were asked to perform 60 repetitions of self-paced ankle dorsiflexion divided into two blocks, each with 30 repetitions. They were instructed to perform the movement rapidly and forcefully and to hold the position for approximately 2 s after which they were asked to rest for 5-10 s.

Diverted Attention Level (DAL): participants had to focus on the oddball stimuli and count the number of target sequences while performing the same movements as in the first phase (dual-tasking).

The oddball used in this experiment was a combination of visual and auditory oddballs. For the visual oddball, two Gabor masks with an orientation of 60º and 30º, each with a probability of 25%, were used. For the auditory oddball, two auditory tones with frequencies of 1200 and 1900 Hz (middle and high pitch), each with a probability of 25%, were applied. All stimuli were randomized with an inter-stimulus interval of 1-2 s. Participants were asked to count the number of Gabor 30º followed by the middle pitch sound or the number of high pitch sounds following the Gabor 60º mask.

Signal analysis

The correlation of EMG envelopes in each block was computed to quantify the consistency of movement execution. EMG signals were rectified and low-pass filtered (10 Hz) to extract the envelopes. The correlation between averaged envelopes was calculated among trials of each block. In addition, the movement onsets were computed in each block with using a threshold for EMG signals to provide information about the timing of movement execution.

EEG signals were filtered in the bandwidth [0.05 10] Hz using a 2nd order Butterworth filter. MRCPs were extracted in the time interval [-3 3] s with reference to the movement onset, as estimated from the EMG signals.

Ten temporal features were extracted from the MRCPs: amplitude and timing of the peak negativity (APN and TPN), first derivatives (slopes) for the time intervals [-2 0] s, [-2 -1] s, [-1 0] s, and [0 1]s, and the standard deviations of the signal amplitude in the same time intervals. Figure 1 illustrated these features on a representative case.

Sixteen spectral features were extracted from the spectrogram of EEG signals in the delta [0 3] Hz, theta [4 8] Hz, alpha [8 13] Hz and beta [15 31] Hz bands, and at the four time intervals T1= [-1 -.6] s, T2= [-.8 -.4], T3= [-.6 -.2] s, and T4= [-.4 0] s.

Statistics

Three-way ANOVA was applied to compare the temporal or spectral features among the two attention levels (CL and DAL) and channel placement. The fixed factors were 'attention level' with two states (CL and DAL), 'channel lobe' with six levels (Anterio-frontal, Frontal, Centro-frontal, Central, Centro-parietal and parietal lobes), and 'channel hemisphere' with three levels (Right, midline and left). Wilcoxon matched-pair sign rank test was used to analyze the differences in EMG envelopes between two attention levels. Significant was set to $p<0.05$.

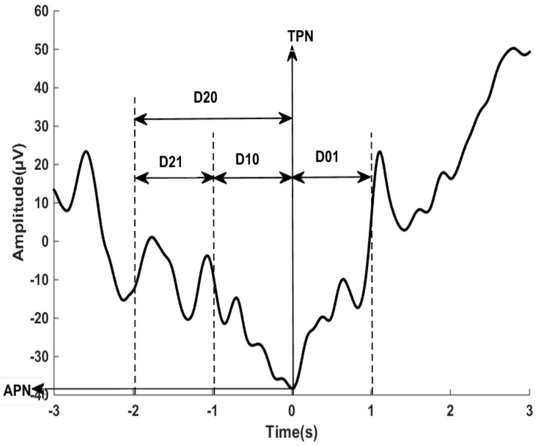

Figure 1: Schematic of temporal features extracted from single-trial MRCPs. 'D' indicates the range of time domains for slope and variability extraction. D21 shows [-2 -1] s, D10 represents [-1 0] s, D20 means [-2 0] s and D01 is for [0 1] s.

RESULTS

EMG Analysis

The EMG envelope and the time interval between movements were not significantly different between CL and DAL ($p>0.05$). The duration between movements was also greater in the diverted attention level (CL: 9.9s, DAL: 11.5s) but not significantly different.

Temporal Features

APN, slope and variability in the range of [1 0] s (S10 and Var10) were significantly different between CL and DAL. Table 1 shows the values for these variables and the associated significance levels based on the three independent factors.

APN and S10 were significantly reduced from CL to DAL (APN: $F_{(1,412)}= 6.4$, $p=0.01$; S10: $F_{(1,412)}= 37.3$, $p<0.001$). Figure 2 illustrates the average MRCP signals across all subjects and each channel for both conditions. Both the MRCP amplitude and slopes were reduced from CL to DAL for most channels.

APN was significantly different between the three channel hemispheres ($F_{(2,412)}= 7.9$, $p<0.001$). The *Bonferroni post-hoc* test revealed that the midline locations were significantly different compared to the right ($p= 0.03$) and left channel placements ($p=0.001$). Var10 was increased significantly from CL to DAL ($F_{(1,412)}= 125.2$, $p<0.001$) although it did not show statistical differences with regards to the channel lobe or channel hemisphere.

Table 1: Three temporal features of MRCPs as a function of the three independent factors, with corresponding p values.

	Attention Level			Hemisphere placement				Lobe Placement						
	CL	DAL	P	Left	Midline	Right	P	AF	F	FC	C	CP	P	P
APN	-20.1 µV	-17.2 µV	0.01	-17.8 µV	-21 µV	-19 µV	<.001	-19.6 µV	-19.9 µV	-18.4 µV	-19.8 µV	-18.8 µV	-19.2 µV	0.9
S10	-10.5 µV/s	-4.1 µV/s	<.001	-9.6 µV/s	-9.2 µV/s	-7.5 µV/s	0.2	-9.9 µV/s	-9.1 µV/s	-9.8 µV/s	-9.4 µV/s	-9.9 µV/s	-9.5 µV/s	0.7
Var10	0.013	0.016	<.001	.014	.014	.015	0.4	.015	.014	.015	.014	.014	.014	0.2

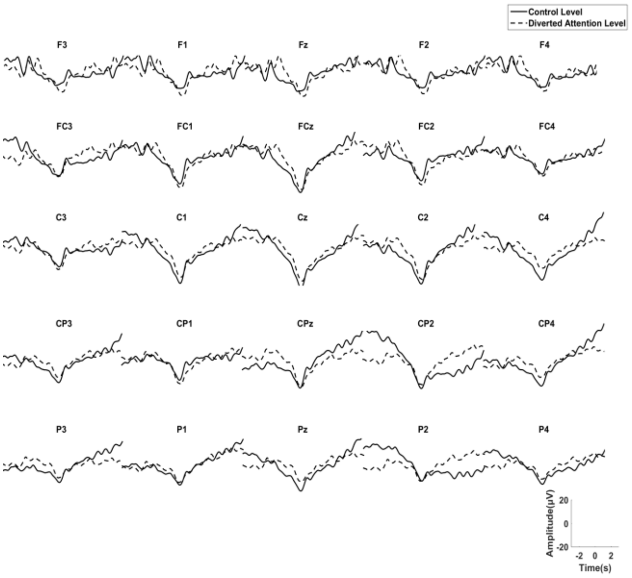

Figure 2: Grand average of the MRCP signals in different channel locations based on the two attention levels. CL is shown as a solid black line and DAL as the dotted black line. Data are the average across all subjects (n=9).

Spectral Features

The alpha and theta range had more variations in specific time windows. Alpha power was increased statistically in T1 ([-1 -.6]) s between the CL and DAL condition ($F_{(1,412)}$= 4.7, p= 0.03). In addition, channel lobe had a significant effect on alpha power distribution in four time intervals (T1[-1 -.6]: $F_{(5,412)}$= 4.6, p<0.001; T2[-8 -.4]: $F_{(5,412)}$= 3.6, p= 0.03; T3[-.6 -.2]: $F_{(5,412)}$= 2.8, p= 0.02; T4[-.4 0]: $F_{(5,412)}$= 3.1, p= 0.009). The *Post-hoc* test revealed that the Parietal and Anterio-Frontal lobe channels led to significantly different features compared to the other lobes.

Theta power was also increased in the time interval [-1 -.6] for CL versus DAL condition ($F_{(1,412)}$= 32.3, p< 0.001). Similar to the alpha power, the factor ‘lobe’ had a significant effect on theta power distribution (T1[-1 -.6]: $F_{(5,412)}$= 16.8, p<0.001; T2[-.8 -.4]: $F_{(5,412)}$= 15.8, p= 0.03; T3[-6 -.2]: $F_{(5,412)}$= 12.4, p= 0.02; T4[-.4 0]: $F_{(5,412)}$= 9.8, p= 0.009). The factor ‘channel hemisphere’ revealed a significant effect in T1[-1 -.6] ($F_{(2,412)}$= 6.8, p= 0.001) and T2[-.8 -.4] ($F_{(2,412)}$= 8.3, p< 0.001). The post-hoc test indicated that channels located on the midline led to different features compared to those located in the other two hemispheres. Figure 3 shows the topographic plots of the power distribution in T1 [-1 -.6] for one representative subject. Regarding to all subjects, the signal power increased in the theta and alpha range, particularly in the channels placed on left hemisphere, with attention diversion.

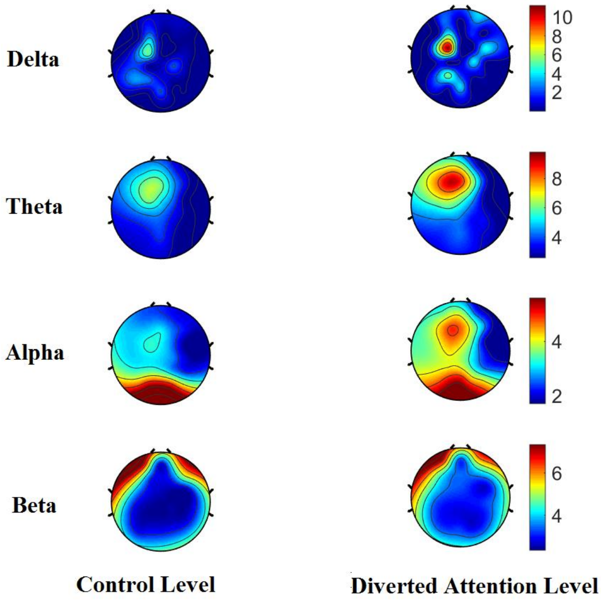

Figure 3: Power distribution in four frequency ranges for T1 [-1 -.6] with respect to the dorsiflexion onset. Data are for n=1.

DISCUSSION

We studied time and frequency features of EEG signals with attention variations. The results suggest that among ten temporal features, the amplitude of peak negativity and pre-movement slope in the late negativity phase before movement onset decrease in DAL by comparison with CL. Our previous studies support that by dividing the attention (dual-tasking), the EEG signal associated to movement preparation is reduced in amplitude and thus detection of movement intention delayed (3). One of the possible reasons for this effect is a reduction of attention to the main task in dual-task conditions in comparison with the single task. Therefore, the majority of attention is diverted to the secondary task and causes a reduced motor cortex excitability for the main

movement preparation and execution (12). Nonetheless, the movement execution was not significantly influenced, as quantified by EMG activity.
Moreover, we observed significant increases in theta and alpha power with reduced attention. Although theta power enhancement particularly in the frontal lobe suggests an increment in the working memory or focused attention to the target task, in this study it is presumably due to an increased task demand in the dual-task conditions (13-15). This supports previous studies which revealed an inverse relation between attention demand in multi-tasking and alpha power (16) and the same relation between task demand and alpha power in the frontal, central and parietal lobes (17, 18).

CONCLUSION

For designing robust and reliable BCI systems, it is important to adapt the system to the users' attention variations. Here we demonstrate that attention influences the temporal and spectral features of EEG signals. These results may have potential application in the design of systems for detecting the attention level from EEG features.

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