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Temporal and Spatial Distribution of Workload-Induced Power Modulations of EEG Rhythms

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Abstract. Changes of workload are correlated with power modulations of certain frequency bands in the human EEG. In order to be able to detect these changes, it is of avail to know the temporal relationship, shape and spatial distribution of EEG band power modulations induced by the workload. Here, we suggest a novel approach that allows to identify the temporal structure of the function that is maximally correlated with power modulations of the theta and alpha frequency bands. We present findings from a case study which demonstrate the validity of the suggested method.

Keywords: EEG, Workload Detection, Alpha, Theta

1. Introduction

A reliable assessment of mental workload of human operators can be used as an adaptive mechanism in brain-computer interfaces (BCIs). Previous studies have shown that the power of oscillatory activity in the human electroencephalogram (EEG) [Buzsáki and Draguhn, 2004] in the theta (4–8 Hz) and alpha (8–12 Hz) frequency bands is modulated by changes in workload during task engagement [Gevins and Smith, 2003; Holm et al., 2009]. In order to improve the decoding of those power modulations, it is crucial to find optimal spatial filters. The Source Power Correlation (SPoC) analysis [Dähne et al., 2012] finds a spatial filter such that power modulations are maximally correlated with a given target function. Here, we present preliminary results of employing an extension of SPoC that, given an initial set of basis functions, simultaneously finds the optimal shape of the target function.

2. Material and Methods

Subjects ($N = 10$) carried out a task on a touch screen, where the aim was to tag and catch objects falling from the top of the screen before they hit the bottom. Every 90 seconds the task difficulty alternated between two conditions: In the low workload condition (L) the interval between objects was constant, subjects reported the task as demanding but not stressful. In the high workload condition (H) the intervals were shorter and varied randomly, resulting in an increased sense of stress and in higher error rates. Each subject performed 4 blocks of 24 minutes each. EEG data were recorded at 1 kHz from 64 electrodes, downsampled to 100 Hz and segmented into epochs of 10 seconds length, ocular artifacts were removed via ICA. Prior to SPoC analysis the dimensionality of the data was reduced via PCA retaining 90 % of the variance. In addition to EEG, heart rate and skin conductivity were recorded during the experiment.

3. Results

As Figs. 1A–C show, the workload paradigm of the experiment clearly modulated the task performance, skin conductance and heart rate of the subjects. Based on the time course of those quantities for the SPoC analysis we chose three initial target functions (Fig. 1D). The scalp maps of the SPoC components (patterns) shown in Fig. 1E-H clearly reflect the known impact of workload on the human EEG as described in the literature [Holm et al., 2009]. On the one hand, variance of the theta frequency band power (Figs. 1E,F) correlated with the optimized target function (right panels) occurs predominantly at mid-frontal electrodes and shows a decrease during low workload condition and an increase during high workload condition. As for the alpha frequency band (Figs. 1G,H), the power variance correlated with the target function is located at mid-central and -parietal electrodes and is negatively correlated with the paradigm, i. e. showing an increase in condition L and a decrease in condition H. The shape of the target functions optimized by SPoC, suggests that the power modulations induced by the experimental paradigm are more of a smooth nature, lacking rough jumps. Finally, we evaluated our results by calculating the correlation between the optimized target

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function and the band power variance estimated by the optimized spatial filter, and compared with the correlation we obtain by analogously employing a Canonical Correlation Analysis (CCA). Results show that SPoC outperforms CCA and that correlations are significant in all four cases.

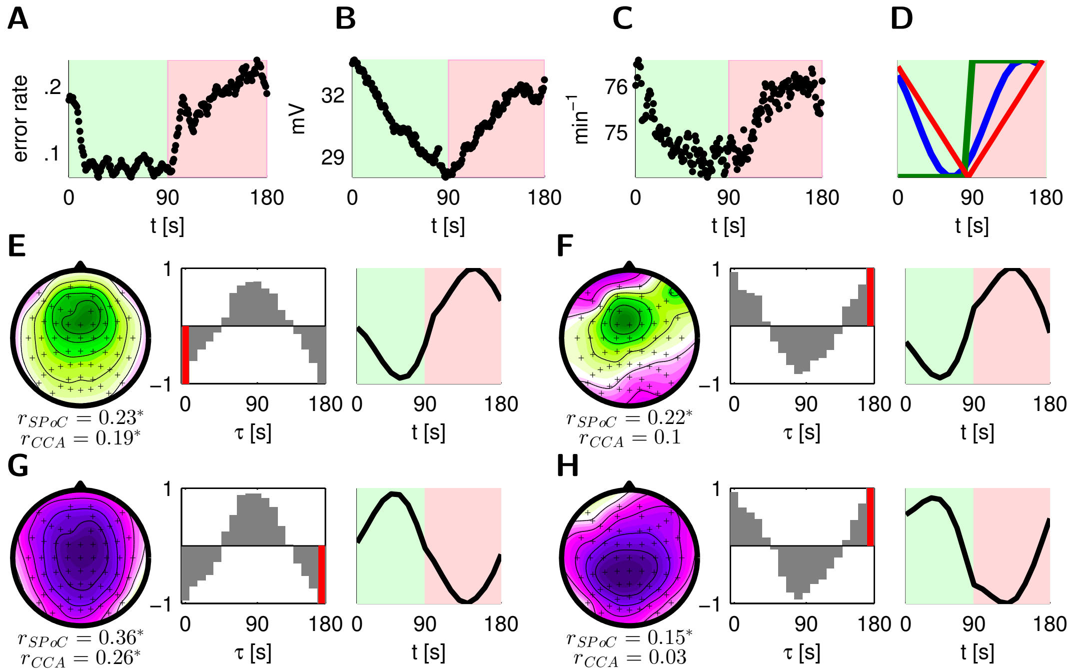

Figure 1: *A–C: Task performance (A), skin conductance (B) and heart rate (C), averaged over all subjects and all L-H-condition-pairs, where L is coded green and H red. D: One period of the set of basis functions used in the analysis. E-H: SPoC results for the theta band and subject 'lh' (E) and subject 'icd' (F) and for the alpha band and subject 'lh' (G) and subject 'bad' (H). Left panel: Scalp map of the SPoC component for which the band power modulation correlates maximally with the target function. Below scalp map: Cross-validated correlations (see text), asterisk indicates* $p < 0.01$. *Middle panel: Temporal filter (optimized by SPoC) which transforms the ongoing power modulations such that the correlation with the target function is optimized. The highest absolute value and its sign (indicated in red) shows the approximate best time shift and sign of the target function, correspondingly. Right panel: One period of the optimal linear combination of the initial target functions after time shifting and sign multiplication.*

4. Discussion

Previous studies have aimed at using EEG in order to develop BCIs that can detect mental workload of humans with the goal of enhancing performance in operator tasks [Kohlmorgen et al., 2007]. In this case study we present an approach in which a spatial filter and a target function are simultaneously optimized via an extension of the SPoC analysis. Our findings confirm the validity of our approach and suggest that further refinements of this approach will provide a valuable improvement for the development of BCIs for workload detection.

Acknowledgments

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