 DOI:10.3217/978-3-85125-260-6-9

Objective Indication of Fatigue in SSVEP-Based BCI Through EEG Spectral Analysis

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Abstract. A critical problem in steady-state visual evoked potential (SSVEP)-based brain-computer interfaces (BCIs) is the fatigue that the users may suffer when staring at flashing stimuli. This paper studies an objective evaluation of the fatigue in SSVEP-based BCIs by EEG spectral analysis. The results show that the brain is slowing its activity as a result of the reduced cognitive capacity during fatigue, and the SSVEP amplitude as well as the signal-to-noise ratio (SNR) are influenced by fatigue level.

Keywords: BCI, SSVEP, EEG, Fatigue, Visual Stimulus

1. Introduction

Steady-state visual evoked potential (SSVEP) has been widely used as a non-invasive input for brain-computer interfaces (BCIs). The fatigue of the users when staring at flashing stimuli is one of critical problems in SSVEP-based BCIs. The repetitive visual stimuli usually make the users uncomfortable, tired and consequently reduce the performance, which is a limitation during the application of SSVEP-based BCIs. In order to apply SSVEP-based BCIs to a large number of users, a user-friendly stimulus to reduce fatigue should be considered, while firstly the evaluation of the fatigue and its influence on SSVEP properties should be investigated.

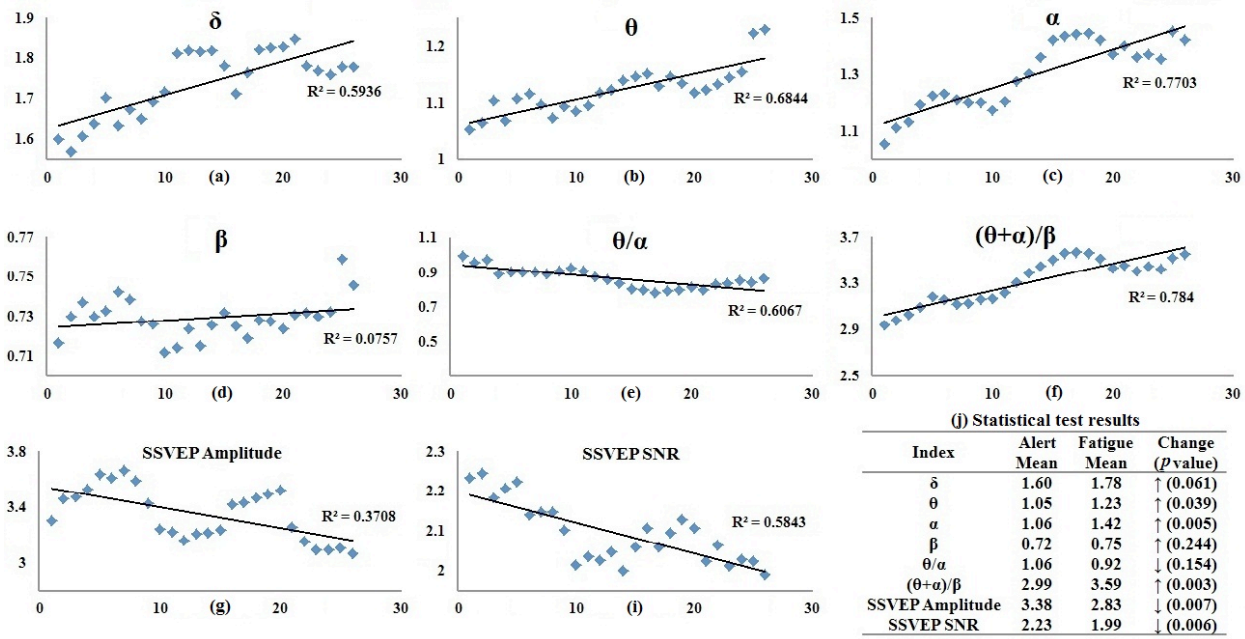
Some SSVEP literature mentioned to use questionnaires or subjects' feeling to describe the fatigue or comfort, which is unfortunately quite subjective and inaccurate [Allison et al., 2010; Bieger and Molina, 2010]. In the case of fatigue, the arousal level and cognitive capacity will be decreased, which are associated with reduced cortical arousal. More specifically, the increases in theta and alpha activity are related to generalized performance decrements on cognitive tasks and increased mental efforts to maintain vigilance level, respectively [Craig et al., 2012; Klimesch, 1999]. Therefore, it is certain that fatigue is associated with significant theta and alpha activity change. This paper proposes EEG spectral indices as objective fatigue measures to help the selection of optimal visual stimulus parameters for SSVEP-based BCIs.

2. Material and Methods

An LCD monitor was used as the visual stimulator (ViewSonic 22", refresh rate 120 Hz, 1680×1050 pixel resolution) and the stimulus was programmed under Microsoft Visual Studio 2010 using Microsoft DirectX SDK (June 2010). EEG was collected from Oz channel by an amplifier (g.USBamp, Guger Technologies, Graz, Austria) during 30 flashing periods (3 s for each). 11 subjects (aged from 22 to 28 years old, 6 males and 5 females) participated in the experiments and were asked to complete a validate self-reported fatigue questionnaire before and after the task work, which was called the Chalder Fatigue Scale (CFS) [Chalder et al., 1993]. The CFS had high reliability and validity, and it was used in this study as a standard reference for fatigue levels. Several EEG spectral indices (δ, θ, α, β), ratio indices (θ/α, (θ+α)/β), SSVEP indices were calculated during flashing periods, and paired sample *t* test was employed to compare the differences for EEG and SSVEP indices at alert and fatigue states.

3. Results

The CFS score was significantly increased ($p < 0.001$) with pre-mean CFS score = 14.91, standard deviation (*SD*) = 1.22; post-mean CFS score = 25.73, *SD* = 4.98; which indicated the fatigue level is significantly increased after SSVEP-based BCI experiments. For the EEG measurement of fatigue, Fig. 1 showed the average amplitude of EEG and the SSVEP indices as well as the statistical test results. Significant increases were found in θ ($p = 0.039$), α ($p = 0.005$) and the ratio index (θ+α)/β ($p = 0.003$). No significant change was observed in δ ($p = 0.061$), β ($p = 0.244$) and the ratio index θ/α ($p = 0.154$). SSVEP indices, including both SSVEP amplitude ($p = 0.007$) and the signal-to-noise ratio (SNR) ($p = 0.006$) were significantly decreased.



(j) Statistical test results

Index	Alert Mean	Fatigue Mean	Change (*p* value)
δ	1.60	1.78	↑ (0.061)
θ	1.05	1.23	↑ (0.039)
α	1.06	1.42	↑ (0.005)
β	0.72	0.75	↑ (0.244)
θ/α	1.06	0.92	↓ (0.154)
(θ+α)/β	2.99	3.59	↑ (0.003)
SSVEP Amplitude	3.38	2.83	↓ (0.007)
SSVEP SNR	2.23	1.99	↓ (0.006)

Figure 1. *(a)-(i). Average amplitude of EEG and SSVEP indices vs flashing periods; vertical axis: amplitude (μV); horizental axis: flahsing period. (j). Statistical test results; Alert Mean: average amplitude at the begin of experiment; Fatigue Mean: average amplitude at the end of experiment; ↑: increase; ↓: decrease.*

4. Discussion

This study adopted EEG measurements for an objective evaluation of fatigue and the influence of fatigue on SSVEP in SSVEP-based BCIs. The experimental results are consistent with previous research on fatigue monitoring by EEG that the increased θ and α power are associated with the decreased vigilance level and cognitive capacity due to the increased fatigue level [Craig et al., 2012; Klimesch, 1999]. The ratio index (θ+α)/β provides an accurate and quantitative measure of fatigue in SSVEP-based BCI. In addition, it is observed that the SSVEP amplitude and SNR are influenced by fatigue levels. Future study may include an investigation on the fatigue due to other design factors (e.g., visual stimulus frequency, duty cycle, color, etc.) and accordingly a better design of the visual stimuli and the whole BCI system to alleviate the users' fatigue with minimal influence on SSVEP properties.

Acknowledgements

This work was supported in part by the Macau Science and Technology Development Fund (Grant FDCT/036/2009/A) and the University of Macau Research Fund (Grants RG059/08-09S/FW/FST, RG080/09-10S/WF/FST and MYRG139 (Y1-L2)-FST11-WF).

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