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Fatigue Evaluation through EEG Analysis Using Multi-scale Entropy in SSVEP-based BCIs

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Introduction: Fatigue is a big challenge when moving a steady state visual evoked potential (SSVEP) based brain-computer interfaces (BCIs) from laboratory into real-life applications [1], as it not only harms the system performance, but also causes users' discomfort. Towards eventually fatigue reduction, an accurate and objective evaluation of fatigue level is the first and also a crucial step. On the other hand, multi-scale entropy (MSE) can describe the complexity of physical and physiologic data and has been successfully applied to the analysis of human health states. Inspired by [2–4], we proposed an index based on MSE of electroencephalography (EEG) signals, for fatigue evaluation when a user is operating a SSVEP-based BCI. Experimental results showed that it performed better than other objective indices based on EEG spectral analysis.

Material, Methods and Results: 12 subjects performed a standard SSVEP-based BCI test. During the experiment, they were asked to gaze at the flashing stimuli for 30 trials in 6 sessions with EEG signals recorded. All participants finished a self-reported fatigue questionnaire based on the Chalder Fatigue Scale (CFS) before and after the visual task, to provide a subjective reference. Meanwhile, their fatigue levels in 6 different sessions evaluated by several methods, were calculated as the objective indices. The change between the first and sixth session is shown in Table 1, and the correlations between the subjective index and different objective indices are given in the third row.

Table 1. Comparison between the subjective index and objective indices of fatigue level changes between the first and sixth sessions.

Index	δ	θ	α	β	θ/α	θ/β	α/β	(θ+α)/β	θ+α	θ+α+β	SNR	Entropy	MSE
Change in percent	31%	-18%	-35%	-44%	20%	32%	12%	24%	-25%	-29%	-25%	-58%	-75%
Correlation to subjective scores (R^2)	0.001	0.012	0.020	0.034	0.014	0.022	0.021	0.030	0.036	0.007	0.424*	0.106*	0.369*
Number of fatigue levels distinguished	6	2	6	6	3	4	2	4	6	6	2	6	6

From Table 1, it can be seen that the index based on MSE performed better than the others. It provided the largest change during experiment, which could make fatigue evaluation more sensitive. Moreover, it distinguished all six levels of fatigue and has the second largest correlation coefficient to subjective fatigue score.

Discussion: Fatigue is a serious problem related to SSVEP-based BCIs, however there is no systematic study on this topic. A common practice is to evaluate the fatigue using self-reported questionnaires provided to the users for feedback about the feelings of fatigue in operating the systems, which are subjective and cannot be done in real time. MSE, as a new approach to measuring the complexity of physical and physiologic signals, may provide us a promising alternative to evaluate the fatigue related to SSVEP-based BCIs.

Significance: A new objective index based on multi-scale entropy was proposed to evaluate the fatigue when using SSVEP based BCIs. Experiments proved its effectiveness in comparison with other commonly-used EEG-based objective indices.

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