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An Audiovisual BCI for Awareness Evaluation in Patients with Disorder of Consciousness

Yuanqing Li[1*], Jiahui Pan[1], Fei Wang[1], Ronghao Yu[2], Qiuyou Xie[2], Yanbin He[2]

[1] School of Automation Science and Engineering, South China University of Technology, China; [2]Centre for Hyperbaric Oxygen and Neurorehabilitation, Guangzhou General Hospital of Guangzhou Military Command, China

*381 Wushan Road, Tianhe District, Guangzhou, China. E-mail: auyqli@scut.edu.cn

Introduction: Currently, clinical diagnosis and awareness evaluation of patients with disorder of consciousness (DOC), such as vegetative state (VS) and minimally conscious state (MCS), relies mainly on behavioral observation scales such as the Coma Recovery Scale-Revised. There exists a high misdiagnosis rate (ranging from 37% to 43%) because these patients cannot provide sufficient behavioral responses. Brain-computer interfaces (BCIs) may represent a potential solution, as they can directly detect the endogenous brain activities. However, there are large differences in both recognition levels and brain signals between healthy subjects and DOC patients with severe brain injuries, it is thus a challenging task to design effective BCIs for these patients.

Material, Methods and Results: In the GUI of our audiovisual BCI, there are two number buttons (two numbers randomly drawn from 0-9) located on the left and right sides, and two speakers are placed laterally to the monitor. The two buttons flash in an alternative manner. When a number button is visually intensified, the corresponding spoken number is presented from the ipsilateral speaker. In this way, the user is presented with a temporally, spatially and semantically congruent audiovisual stimulus that lasts for 300 ms, where the inter-stimulus interval is randomized from 700 to 1500 ms. Ten healthy subjects participated in the first experiment, which consisted of three sessions administered in a random order, corresponding to the visual-only, auditory-only, and audiovisual conditions. In each session, the subject first performed a training run of 10 trials, and then a test run of 30 trials. The online average accuracies across all healthy subjects were 95.67%, 86.33% and 62.33% for the audiovisual, visual-only and auditory-only sessions, respectively. The audiovisual BCI thus significantly outperformed the visual-only and auditory-only BCIs. As shown in Fig. 1(a), the ERP waveforms at the electrode "Pz" indicated that for the target stimuli, there were stronger P100, N200 and P300 responses in the audiovisual condition than in the visual-only and auditory-only conditions. It followed from Fig. 1(b) that there were more discriminative features for the audiovisual condition than for the visual-only and auditory-only conditions. The enhanced ERP components associated with audiovisual stimuli, such as P100, N200 and P300, improved the performance of the audiovisual BCI system.

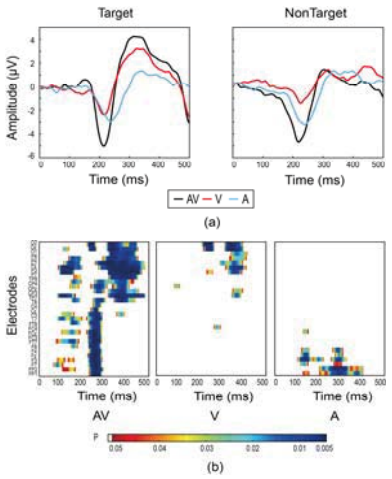

Figure 1. *(a) Average ERP waveforms in each stimulus condition from the "Pz" electrode for all subjects. (b) Point-wise running t-tests compared the target responses with the non-target responses in multisensory and unisensory stimulus conditions across all subjects for 30 electrodes. Significant differences were plotted when data points met an alpha criterion of 0.05.*

This system was then applied to detect the awareness of seven DOC patients in the second experiment. Each patient first performed a calibration run of 10 trials. The test run contained five blocks, each of which was composed of 10 trials and was conducted on separate days because the patients were easily fatigued. In the seven patients involved in our experiment, the online accuracies for five patients (1 VS and 4 MCS) were significantly higher than the chance level. For each of the five patients, the ERP waveforms measured at the electrodes "Fz" and "Oz" showed a robust P300 response elicited by the target stimuli. Our experimental results demonstrated the presence of command following and residual number recognition ability in the five DOC patients.

Discussion: In this study, we designed an audiovisual BCI for awareness detection in DOC patients. Our results for healthy subjects indicated that improved target detection can be achieved by integrating multiple sensory modalities. That is, the audiovisual BCI performed better than the corresponding visual-only or auditory-only BCI. The underlying mechanism is: multiple ERP components including P100, N200 and P300 were enhanced by audiovisual stimuli, and this enhancement was associated with audiovisual integration. There seldom reported similar results for online audiovisual BCIs in existing references. As a clinical application, this hybrid BCI was successfully used for awareness evaluation in patients with DOC.

Significance: To our knowledge, this study is the first attempt to test an audiovisual BCI in this challenging patient population. Furthermore, no results from other groups indicated that VS patient could use an online BCI system with a significant accuracy, and the online accuracy rates for VS and MCS patients in our study were higher than those reported in the existing references.