Brain-machine interfaces based on transcranial Doppler sonography

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PATIENTS suffering from severe motor disability due to neurological diseases and injuries such as amyotrophic lateral sclerosis, stroke, and traumatic brain injury are frequently unable to complete tasks required for independent living [1], [2]. Enabling these individuals to function independently would save health care systems millions of dollars annually [3]. The brain-machine interface (BMI) (also referred to as the brain-computer interface) is a hardware and software system providing a direct communication link between the neural activity of the brain and computer hardware/software components, without the involvement of peripheral nerves and muscles [2], [4]. There is a need for a non-invasive BMI that can accurately differentiate between intentional cognitive tasks and a resting state, while being portable. Such an instrument could easily be incorporated into daily routines of patients with severe motor disability.

Functional transcranial Doppler is a functional ultrasound imaging technique that measures cerebral blood flow velocity (CBFV) changes related to neural activation, comparable to fMRI [6]. In contrast to other neuroimaging procedures, fTCD provides a continuous measurement of cerebral blood flow and therefore a rapid designation of changes in brain activity [7].

In a proof-of-concept study of nine able-bodied participants (6 female; 3 male; mean age 25.6 years), we classified the CBFV changes associated with two cognitive tasks - a word generation task and a mental rotation task [7]. CBFV was measured simultaneously within the left and right middle cerebral arteries while subjects alternated between mental activity (i.e. word generation or mental rotation) and relaxation. Using advanced signal processing techniques for classification, word generation and mental rotation tasks were classified with respective average accuracies of over 80%. We also examined the transmission rates achievable with the proposed BMI [8]. We showed that data transmission rate was maximized at 1.2 bits per minute for 20-s state durations using a three-dimensional feature set, compared to a maximum rate of 0.3 bits per minute previously reported for an fTCD-based BMI [7]. These results are comparable to other metabolic BMI modalities with data transmission rates ranging from 0.6 to 1.3 bits per minute [9]. Our BMI places near the upper end of this range, indicating that fTCD is a worthwhile alternative to NIRS for metabolic BMIs. In [10], the authors have achieved data transmission rates approaching 3 bits per minute, a level that may be possible for fTCD when more powerful feature selection and classification algorithms are used.

Our future work will seek to design an improved classifier by expanding the context of fTCD-based BMIs beyond the laboratory settings. We will also explore the utility of adding raw cerebral blood flow velocity signals to the classifier considerations. We will also seek to obtain a larger sample of fTCD recordings from both healthy and clinical populations.

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