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Cortico-Muscular-Coupling and Covariate Shift Adaptation based BCI for Personalized Neuro-Rehabilitation of Stroke Patients

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Introduction: Every year an estimated 17 million people get affected by stoke among which 30% to 60% of stroke survivors may suffer from permanent upper limb paralysis [1], which may significantly impact their quality of life and employability. Often the upper limb paralysis becomes chronic due to lack of active and engaging rehabilitation exercises over a prolonged period. This research investigates advanced approaches to devising EMG and EEG based brain-computer interface (BCI) systems, which provide neuro-feedback to the patients and/or operate powered exoskeleton to facilitate active and engaging upper limb rehabilitation exercises. The feasibility of the BCI assisted motor imagery (MI) training has successfully been established for post-stroke patients, in reorganizing the neuronal connections around the affected areas of the brain, which is also termed as neuro-plasticity [2]. In this paper, we devised a novel feature extraction approach using a correlation between the variations of signal power of EEG and EMG signals in time domain, which is termed here as Power-Level-Correlation (PLC). As a part of BCI-based neuro-rehabilitation system, this PLC acts as a measure of cortico-muscular-coupling. The PLC index is used to decide the movement intension of a user (e.g., whether a user is making an effort to move the fingers), and accordingly the hand exoskeleton is triggered to help perform motor exercises and provide a neuro-feedback to the user. However during post-stroke acute phase, the EMG activity may be very little or none, and hence PLC index is not suitable for determining user intension. Therefore, we have also analyzed the EEG signals alone, using covariate shift-detection (CSD) based adaptive classification, as it detects the non-stationary brainwave changes (often occurring due to neuronal re-organization and other known/unknown causes), and accordingly a new classification decision boundary is obtained by re-training a pattern classifier on the newly acquired features. We have tested our single-trial based online BCI paradigm on 17 healthy subjects to classify the hand at rest state (class 1) and grasp attempt (class 2) of the user and the results are found to be promising over the conventional EEG-based non-adaptive BCI.

Material, Methods and Results: EEG signals have been acquired using C3, Cz, and C4 channels and EMG signals have been extracted from the forearm muscles (i.e., Flexor-Digitorum-Superficialis (FDS), and Flexor-Policus-Longus (FPL)). Consenting healthy participants were asked to undergo two training sessions and one feedback session. Each session consisted of 40 trials and subjects were asked to perform either a grasp attempt or stay at rest according to the appearance of the cue in each trial. Using training dataset, a classifier has been trained on three different approaches. The first method is an EEG-based non-adaptive classifier (EEG-NAC); the second method is an EEG-based adaptive learning classifier (EEG-ALC); and third method is a PLC based NAC. Unlike EEG-NAC, EEG-ALC uses CSD test [3] to detect the covariate shift in the EEG features, and update the classifier parameters to adapt to the data distributional changes. In, PLC-NAC, we correlate the power distribution in EEG and EMG in a particular trial over a suitable time-window to get an index, which can be used to discriminate the two classes. Here, a support vector machine based pattern classifier has been used for the single-trial binary classification. During the evaluation phase, the following classification accuracies have been achieved; EEG-NAC (78.53%), EEG-ALC (80.44%), and PLC-NAC (94.85). Moreover, by comparing the results of the EEG-NAC method with the other proposed methods using a Wilcoxon signed rank test, the EEG-ALC gives a p-value=0.0078 and PLC-NAC gives a p-value=0.0028, which are statistically significant.

Discussion and Conclusion: From the results, it is evident that the PLC-NAC and EEG-ALC methods have a clear advantage over the EEG-NAC method. These two modes (PLC-NAC and EEG-ALC) also help in monitoring the improvement in brain-muscle coordination throughout the neuro-rehabilitation process. It is expected that by regularly using this system for a specific period of time, patients could increase their finger mobility to perform grasping action of their hand for activities of daily life.

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