 DOI: 10.3217/978-3-99161-050-2-014

Asynchronous Voluntary Self-regulated Near-infrared Spectroscopy Brain-Computer Interface for Children with Cerebral Palsy

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Introduction: Brain-computer interfaces (BCI) hold promise as an access method for children with cerebral palsy (CP) [1]. Challenges such as distinguishing control states with an fNIRS BCI is a challenging task, which involves addressing issues like overlapping neural signals, variability in brain responses, and maintaining a good signal-to-noise ratio to ensure accurate detection and classification of intentional control (IC) versus non-control (NC) states. Previous studies, including Koo et al.[2] developed a hybrid electroencephalography (EEG)-functional near-infrared spectroscopy (fNIRS)-BCI system for self-paced motor imagery, and Millán et al.[3] used an EEG-BCI system with a mixture of Gaussian generative models of multiple IC states. However, none have combined self-regulation with asynchronous algorithms for fNIRS-BCI systems. This research aims to develop an intuitive and user-driven asynchronous fNIRS-BCI for voluntary self-regulation for children with CP.

Material, Methods and Results: Four participants (3 males and 1 female, aged 13-18 years, GMFCS levels III-V) with CP completed four self-regulation sessions on different days. The first two sessions were offline, while the last two sessions used an NIRS-BCI to control a toy car during the online sessions. fNIRS channels were placed on the prefrontal cortex using a wireless Artinis Brite fNIRS headset (Elst, The Netherlands) at 25 Hz. Data from self-regulation and rest tasks were converted into hemoglobin concentrations based on the Beer-Lambert law and baseline correction with noise reduction applied through a third-order Chebyshev type II low-pass filter (passband: $<$6 dB). Features (signal mean, signal slope, signal variance, and root mean square values) were selected through ReliefF. Seven classifiers were tested using a 1000-fold permutation test with 10 by 5-fold cross-validation for each fold, with hyperparameters tuned through grid search (Fig. 1). The offline and online cross-validation achieved average classification accuracies of 85.3±7.17% and 77.2±5.83%, respectively.

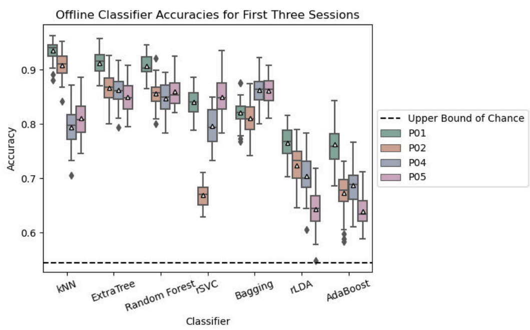

Figure 1: *Classifier accuracies evaluated using 10 by 5-fold cross-validation. White triangles represent the mean accuracy value. The dashed line marks the upper bound, corresponding to the maximum 97.5th percentile of the chance level across all classifiers and participants.*

Conclusion: Our findings show that self-regulated asynchronous real-time fNIRS-BCI is feasible for children with CP. Personalized approaches for channel selection, feature extraction, and classifier optimization may effectively address individual differences. These advances emphasize the potential for translating BCI into clinical or home settings as an access technology.

Acknowledgments and Disclosures: The authors thank all volunteers who participated in this study. The authors express their gratitude to members of the PRISM lab for their continuous support. The authors did not report any potential conflict of interest.

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