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The effect of gamified calibration environment on P300 and MI BCI performance in children

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Introduction: A major challenge with BCI use is the requirement for subject-specific training, which is often tedious and unengaging for the user, but necessary to improve efficiency [1]. This is especially true for children, who's limited attention and motivation pose pressing challenges for the implementation of BCI. Games present clear objectives with short-term goals that confer rewards and act as external motivators to provide a seamless sense of advancement [2]. Several studies have shown that the addition of scoring systems, prizes, and awards to tasks, a process known as "gamification", can increase motivation, attention, and task performance in children [3]. This randomized prospective cross-over study aimed to address this challenge by comparing the effects of gamified versus non-gamified calibration environments on classification accuracy and BCI performance on utility-driven tasks.

Materials & Methods: Thirty-two typically developing children (14 female, mean age 11.9 years, range 5.8-17.9) attended two sessions lasting between 1.5-2 hours. Two standard BCI paradigms well-established in adults were studied: spelling using visual P300 event-related potentials (P300) (3x3 T9-style speller) and cursor control using motor imagery (MI). Gamified and non-gamified calibration paradigms were generated using BCI Essentials. Research-grade EEG-based BCI systems were utilized for signal acquisition at 256Hz (g.tec medical engineering GmbH, Schiedlberg Austria). Frequency filtering was done with 5th order Butterworth bandpass filters with bands of 0.1-15Hz and 5-30Hz for P300 and MI, respectively. P300 covariance matrices were constructed with XDawn spatial filtering, the tangent space representation of these matrices was classified using linear discriminant analysis (LDA). Tangent space representations of MI covariance matrices were classified with logistic regression. The MI classifier was iteratively retrained in-session to provide user feedback. Motivation, tolerability, and mental workload (NASA-TLX) were evaluated following each paradigm.

Results: For the P300 paradigm, mean classification accuracy was 96% with both gamified and non-gamified calibration. For the MI paradigm, mean classification accuracy was 62% with gamification and 60% without gamification. Mean online BCI accuracy for the MI task was 63% for both conditions. For the P300 task, differences in online BCI accuracy were only observed below 4 flashes per row/column for both conditions. Motivation and tolerability scores across all four paradigms were high. Mean total workload as a percentage of the possible score ranged from 34-39% for the four paradigms, which is between a low-moderate workload. Females perceived gamified tasks as having a lower mental workload ($p<0.05$). There were no significant differences found between classification accuracy, online BCI accuracy, motivation, tolerability, or workload. Three children verbalized that they did not enjoy the gamified MI environment because it was frustrating. Further analysis will investigate the potential effects of age, order and factors affecting performance, such as fatigue, mood, and regular video game play.

Discussion: Our results reinforce the ability of typical children to control advanced BCI systems with performance comparable to adults. Gamified calibration environments may not enhance BCI classification and performance in children. It is possible that the gamified environments utilized in this study were not engaging enough.

Significance: To our knowledge, this is the first study that investigates the effects of gamified calibration paradigms on classification accuracy and BCI performance in children. Future research on optimizing BCI training paradigms for children is necessary for implementation of BCI in this population.

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