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Virtual Reality-Based Investigation of Error-Related Potentials in ADHD for BCI applications

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Introduction: Error-related potentials (ErrPs) represent specific brain activity patterns elicited when individuals recognise errors during task performance, measurable via electroencephalography (EEG), and have been linked to executive functions and self-monitoring processes. In individuals with Attention Deficit Hyperactivity Disorder (ADHD), atypical cognitive and brain functions include reduced amplitudes of error-related negativity (ERN), (McLoughlin et al., 2022) and affected self-monitoring. To better understand potential biomarkers and treatment targets, we developed and tested a virtual reality (VR) environment of an adapted Wisconsin Card Sorting test to study ERN in ADHD and neurotypical populations (Figure 1) in a more ecologically valid way, using machine learning to classify the ErrPs.

Material and Methods: Participants (N=20) were divided into ADHD and neurotypical groups based on Conners' Adult ADHD Rating Scales. A VR-based task inspired by the Wisconsin Card Sorting Test (Berg, 1948) required sorting study-related objects by colour or shape, with feedback indicating correct or incorrect actions. Two error types were simulated: feedback errors (intentional incorrect feedback) and tracking errors (object manipulation failures). EEG data was recorded and processed to identify ErrPs. Machine learning classifiers were trained to distinguish between error types and participant groups.

Results: Behavioural and EEG data analysis revealed a trend towards a reduced ERN amplitude in the ADHD group compared to controls, aligning with prior meta-analytic findings (e.g., Bellato et al., 2021). However, this reduction was not statistically significant. Machine learning classifiers successfully distinguished error types and participant groups, with all tested models outperforming a dummy classifier, emphasizing the potential use of ErrPs in Brain-Computer Interface applications.

Conclusion: This study demonstrates the feasibility of using VR to investigate ErrPs in ADHD and control groups. While the reduction in ERN amplitude in ADHD was not significant, the medium effect size suggests the potential for further exploration with larger samples. Machine learning-based classification supports the future development of various BCI applications, such as adaptive self-corrective systems leveraging real-time brain data.

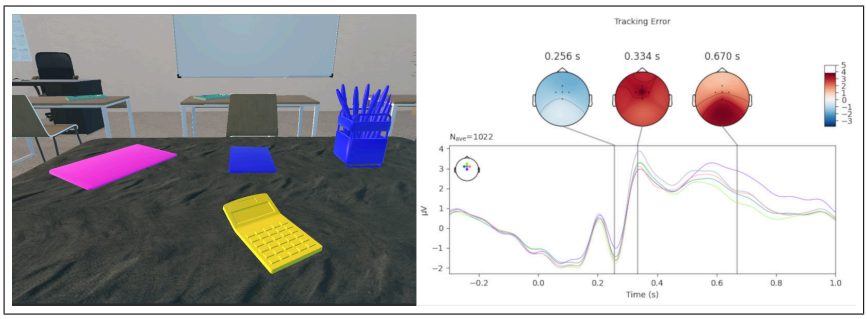

Figure 1: *Left: VR-based task environment. Right: Grand average ErrP and topoplot in the "Tracking Error" condition in the area of interest.*

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