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Toward Hybrid BCI: EEG and Pupillometric Signatures of Error Perception in an Immersive Navigation Task in VR

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Introduction: Brain-Computer interfaces (BCIs) frequently incorporate the detection of erroneous events to improve their performance. This detection is usually exclusively based on electroencephalographic (EEG) correlates of error perception [1, 2]. Head-mounted displays (HMDs) with built-in pupillometric sensors allow for access to additional physiological data with the potential to improve error detection [3].

Material, Methods and Results: We used an HP Reverb G2 Omnicept HMD to display the virtual reality (VR) flight simulation and to measure the pupil size of 19 participants. Additionally, we measured EEG signals using 61 active electrodes. The participants were asked to navigate a glider through targets in VR (see Fig. 1), as three different types of erroneous events were randomly triggered: (i) the target suddenly changed its position (condition *target*), or (ii, iii) a torque was applied to the glider resulting in an unexpected rotation of it. The last could happen either while the participants actively steered the glider (*active*) or were in a passive state (*passive*). In *correct* trials, no error was triggered. EEG data preprocessing included filtering (non-causal, 1-10 Hz), eye-artifact correction, rejection of corrupted trials, and common average referencing. After we applied the false discovery rate procedure to correct for multiple testing, we found statistically significant differences in the EEG and pupillometric data. Fig. 1 shows the averaged evoked responses calculated from the participant averages.

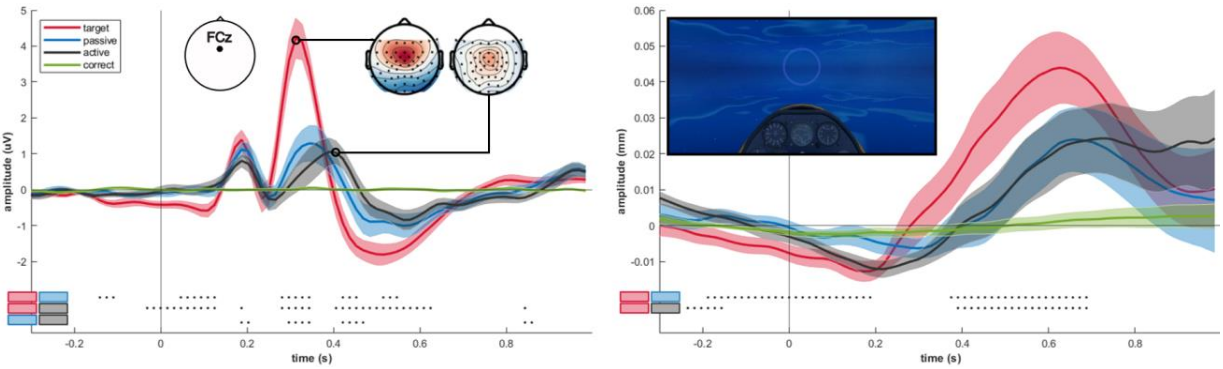

***Figure 1**. Grand average results. Left: Error-related potentials (± standard error) for the three error conditions and the correct condition. The dots below the signals show significant samples ($p < 0.05$) for the comparisons indicated by the rectangles. Errors were triggered at $t = 0$ s (vertical line). Right: Baseline-corrected pupil dilation (like on the left) and the flight simulation (glider approaching a target).*

Discussion: In the evoked EEG responses, we found that performing a task delays the error perception (*passive* vs. *active*), illustrated by the significant differences in the corresponding error-related potentials. Additionally, we found a dilation of the pupil induced by the erroneous event with a similar delay.

Significance: We argue that, based on our results, pupillometric correlates of error perception have the potential to improve the performance of BCIs in immersive virtual environments.

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