Brain-computer interface training fosters perceptual learning

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Introduction Perceptual learning improves our ability to make decisions amidst ambiguous sensory information by intense training [1]. Given the established evidence associating the amplitude of the error positivity (Pe) component of error-related potentials (ErrP) with conscious awareness [2], we conjecture that there is a casual relationship between the Pe amplitude and humans perceptual ability to detect visuo-motor errors (Fig. 1a). We predict that participants cannot improve their ability to perceive small errors by conventional perceptual learning training. For these small perceptual errors that subjects failed to learn to detect, we expect Pe amplitudes to remain small. Furthermore, we hypothesize that providing BCI feedback on the presence/absence of ErrP during perceptual training will enhance the Pe component, and thus augment perceptual abilities of participants in comparison to a conventional perceptual learning protocol without BCI feedback.

Material, Methods and Results Thirty-two healthy participants used a joystick to control a cursor from a start to an end location in a computer screen following a straight, continuous trajectory (Fig. 1a). An experimental session consisted of 10 training runs, each with 32 reaching trials. In each trial, the normal joystick-cursor mapping can be violated by applying a rotation magnitude. To control the levels of difficulty to perceive errors, we used four magnitudes of rotation: 3, 6, 9 and 12 degrees. Participants in the BCI and the control groups (16 each) completed perceptual training over 5 consecutive sessions, where they received feedback at the end of each trial. The control group pressed joystick buttons to indicate whether they perceived a rotation and received the correct answer. Feedback for the BCI group was the output of their BCI (detection of an ErrP) together with information about an eventual rotation. The results show that BCI intervention fostered perceptual learning at small rotation magnitudes of 3° and 6° (Fig. 1b). The BCI group also showed significantly enhanced Pe amplitudes at Cz across sessions, which mirrored the behavior improvement in perceptual abilities (Fig. 1c).

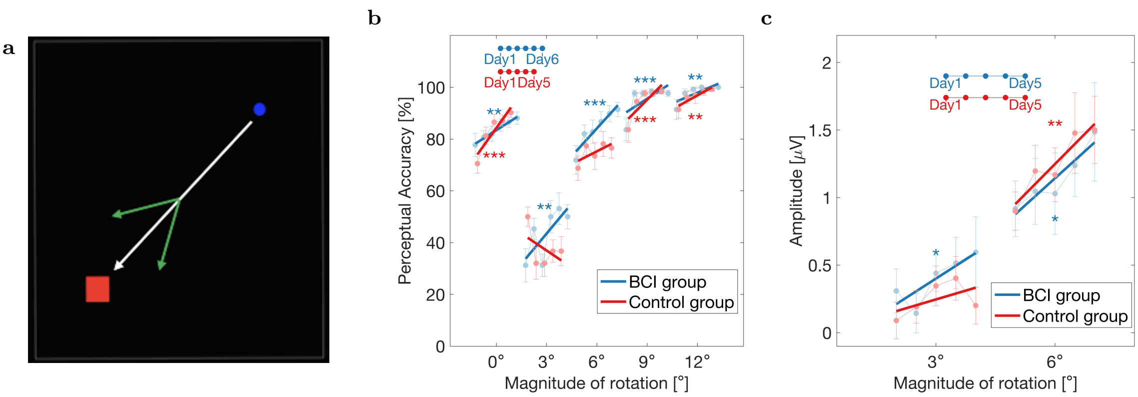

Figure 1: **a** *The cursor control task, the green arrows indicate directions where the cursor could be rotated.* **b** *The accuracy of subjects' perception to rotations (No rotation, 3°, 6°, 9°, 12°) over sessions.* **c** *The change in Pe amplitudes at Cz across sessions in 3° and 6°.* $*$: $p < 0.05$, $**$: $p < 0.01$ *and* $***$: $p < 0.001$

Discussion and Significance Our results revealed that humans' perceptual abilities to identify errors during cursor-reaching movements is closely related with ErrPs, and such cognitive brain function is, in part, governed by Pe amplitude of ErrPs. The proposed BCI-based approach can provide foundations for future non-pharmacological, non-invasive interventions for perceptual impairment in elderly and clinical populations, which avoids the adverse effects of pharmacological interventions and accelerates perceptual learning in comparison to time-consuming, conventional methods.

References

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