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Detection of errors using multiple spectro-temporal features related to distinct post-error neural processes

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Introduction: Detection of different types of errors (e.g., user's own errors (or execution errors), interaction errors, and feedback errors) based on brain signals immediately following errors, has been increasingly studied in brain-computer interface (BCI) community [1], with the aim to improve the performance of BCI devices or developing novel BCI systems [2]. Here, we focused on the detection of execution errors using noninvasive electroencephalography (EEG) signal. Beyond the well-known error-related negativity (ERN) in previous studies [3-4], the present study investigated multiple spectro-temporal EEG features related to distinct post-error neural processes, given that different neural and behavior responses could be triggered by errors under the performance monitoring system [5-6]. We expected better detection of execution errors can be achieved by including as many as error-related EEG patterns.

Material, Methods and Results: 128-channel EEG data from 18 healthy subjects was previously recorded in a color-word matching Stroop task (details of the experiment and data, as well as preprocessing procedures, can be found in [7]). Subjects made 73 (±29) error responses out of 720 trials. To extract distinct neural processes, a group-wise independent component analysis (ICA) procedure was applied on preprocessed EEG data that were temporally concatenated across all subjects [6]. Spectro-temporal features were extracted from four neural processes (i.e., independent components, ICs; Fig. 1) that were characterized with well-known event-related potentials (ERPs) [6]. Statistical comparisons demonstrated that errors show significantly enhanced theta power at early time (around 0-300 ms) and decreased alpha/beta power at late time (around 150-500 ms), at all four ICs (Fig. 1). Thereafter, single-trial classification of error or correct responses was performed using a linear discriminant analysis (LDA) classifier by using different combinations of features. With features selected from spectro-temporal signals from 0 to 300 ms post-response after band-pass filtering from 1 to 10 Hz and down-sampling (25 Hz) for all four ICs, LDA achieved a mean accuracy of 93.6% (error: 70.0%; correct: 96.2%) and a mean area under curve (AUC) of 0.88.

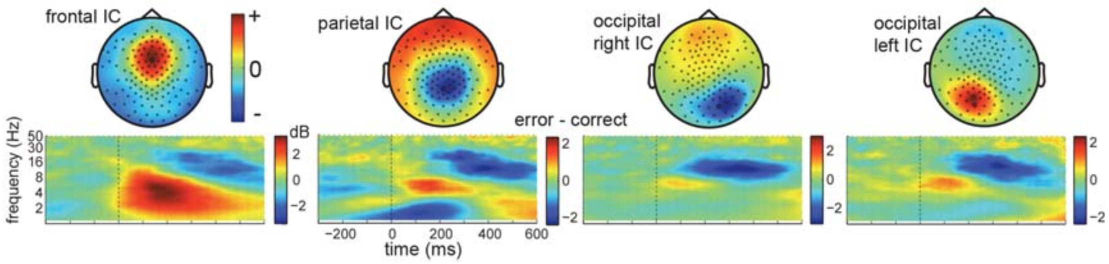

Figure 1. *Four ICs represented post-error neural adaptation. Top: scalp maps; bottom: response-locked time frequency representations of the difference between error and correct responses.*

Discussion: A series of EEG spectro-temporal patterns related to distinct cognitive and sensory neural processes were uncovered following error responses made by subjects. By combining as many as features related to post-error neural responses, better detection of execution errors has been achieved.

Significance: This study unveiled multiple spectro-temporal features over distinct neural processes related to errors, which can potentially be used to improve the single-trial detection of errors in the application of BCI.

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