Ongoing Multifaceted Electrophysiological Signatures of Error Precursors Unraveled by Independent Component Analysis

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ERROR commission has been ascribed to malfunctions in distinct neuronal processes, e.g., attention and cognitive control. Accordingly, suitable levels of ongoing brain states in these neuronal processes are indispensable, as suggested by a growing body of literatures that highlight a role of pre-stimulus brain states in perceptual and cognitive performance [1-2]. However, previous studies always focus on one of the brain systems in terms of task demands, and the patterns are usually identified at the channel space, which have mixed signals from multiple brain substrates. Therefore, the goal of the present study is to examine ongoing brain states in distinct neuronal electrophysiological signatures for error commission by means of high-density electroencephalography (EEG) and independent component analysis (ICA).

Twenty-six healthy right-handed participants (20-36 years, three females) performed a speeded color-word matching Stroop task [3]. Eight participants were excluded due to less number of error trials (less than 36, i.e., 5% of trials) or bad performance at the chance level. Written informed consent was obtained before experiment, which was approved by the University of Oklahoma Institutional Review Board.

The preprocessed EEG data were segmented into epochs with 1500 ms before and 2300 ms after stimulus onsets. Response time matched correct trials to error trials within participants were selected, and trials from all participants were temporally concatenated to a group-wise ICA process [4]. From 32 group-level ICs, five ICs that had typical spatio-temporal-spectral patterns generated by certain brain substrates were selected as ICs of interests that linked to frontal, parietal, left and right occipital, and motor cortices. Ongoing rhythmic activities, i.e., power and phase, calculated from these ICs using Morlet wavelet at 700 ms pre-stimulus period were statistically compared between correct and error trials by a resampling test [5].

In total, four aspects of ongoing preparatory brain activations in three ICs were significantly highlighted to differentiate error from correct responses: (1) ongoing oscillatory alpha/theta (4~13 Hz) power in right occipital IC (higher for error trials); (2) momentary phase of ongoing alpha/theta (6.74 Hz) in right occipital IC (opposite between response types); (3) ongoing theta (4~8 Hz) power in frontal IC (higher for error trials); (4) ongoing alpha/beta (8~30 Hz) power in posterior parietal IC (higher for error trials). In addition, a short (~70 ms) ongoing beta power in motor IC (lower for error trials) was also detected. Interestingly, three ICs with significant pre-stimulus EEG oscillatory patterns are well fit to the three networks involved in attention system [6] in terms of their spatio-temporal-spectral characteristics, i.e., the alerting (or vigilance) network with right occipital IC, the orienting network with parietal IC, and the executive network with frontal IC. Therefore, the observed significant differences in ICs can be uniformly interpreted as the lapse of preparatory attention in distinct neuronal processes, which also suggest the importance of pre-stimulus brain states are not simply "noise", rather playing an important role in the imminent behaviors as top-down constraints to subsequent sensory, cognitive, or motor activities.

In conclusion, we successfully characterize ongoing multifaceted electrophysiological signatures in distinct brain substrates that differentiate error from correct trials. Our results extend the reported effects of ongoing alpha oscillatory activations to theta and beta bands in a conflict task. Of the greatest importance, the identification of multiple ongoing EEG patterns in distinct neural mechanisms demonstrate that errors can be independently or jointly triggered by different neural mechanisms from sensory, cognitive and motor functions, which is also in line with a recent study that address two different kinds of errors from the post-error EEG activities [7].

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