ERPs and EEG oscillations, best friends forever: comment on Cohen et al.

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In their recent Opinion article, Cohen and colleagues discuss the relative strengths of the event-related brain potential (ERP) and time-frequency (TF) techniques for investigating cognitive function [1]. Their discussion pivots on the example of an ERP component called the feedback-related negativity (FRN), which we have proposed reflects the impact of dopamine-dependent reward prediction error (RPE) signals on anterior cingulate cortex (ACC) for the purpose of reinforcement learning [2]. We disagree with several of the authors’ arguments in [1], as we explain below.

First, the authors question the validity of the RPE-FRN theory on the basis of the fact that FRN amplitude is sometimes seen to vary along a binary rather than continuous scale. This argument confuses a graded response to reward probability with a binary response to reward magnitude: the FRN reflects revisions of an ongoing probabilistic estimate of future reward (the RPE) [3], where the reward itself indicates whether or not a goal is achieved (a binary outcome) [4].

Second, the authors suggest that the theory is difficult to falsify or confirm. Nevertheless, the theory is in fact testable. In line with common practice in cognitive neuroscience [5], our argument is supported by a wealth of converging evidence from multiple experimental techniques [6]. Animal models provide a particularly promising avenue for testing the theory further. For example, a homolog of the FRN has been identified in the monkey ACC [7], the scalp manifestation of which is sensitive to a dopamine antagonist [8].

Third, the authors suggest that the RPE algorithm cannot account for high-level cognitive function because it is overly simplistic. However, our theory holds that the ACC implements a high-level decision-making mechanism that uses the RPE signals to choose between action plans [2], a position that we have recently developed in terms of a formal theoretical framework called ‘hierarchical reinforcement learning’ [6]. This contrasts with the authors’ own emphasis on the learning of simple stimulus-response associations [1].

Fourth, the authors question whether the brain can – even in principle – produce the fast, phasic deflections that characterize the ERP. Yet in the case of the FRN, we have proposed that negative [2] and positive [9] phasic dopamine RPE signals respectively disinhibit and inhibit electrophysiological activity at the apical dendrites of ACC motor neurons, and have provided arguments in support of the plausibility of this hypothesis [2,6].

Finally, the authors propose that frontal-midline theta reflects a neural mechanism for learning from negative feedback. However, we (unpublished observations) as well as Cavanagh, Cohen and colleagues [10] have found that unexpected task-relevant events – not errors in particular – elicit theta. Thus this theta response cannot index error processing per se.

We applaud the authors for highlighting the advantages of the TF technique. Our own ongoing research on frontal-midline theta, parahippocampal theta [11] and reward-related gamma [12] attests to our belief in its utility. But as the authors themselves point out, TF suffers from an array of methodological concerns [1]: uncertainties related to source localization and volume conduction, complex and sometimes questionable assumptions underlying the application of specific TF procedures, and dangers inherent in drawing conclusions about long-term neural plasticity, as well as in inferring causality from correlations. In our view, the mysteries of the brain will be elucidated by harmonious application of both TF and ERP approaches; celebrating the successes of any one experimental technique need not come at the expense of equally solid work in other domains.

References

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