

A Computational Neural Model of Anterior Cingulate Cortex Learns to Estimate Context-Dependent Behavioral Risk

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Recent evidence (Brown and Braver, 2005) demonstrates that Anterior Cingulate Cortex (ACC) and pre-SMA show activity consistent with learned predictions of error likelihood, of which conflict and error detection are special cases. The finding was predicted by a computational neural model of ACC and subsequently verified with fMRI. Here we report new results from further simulations with the same model. The model (implemented in RNS++) performs a modified stop-signal task in which one stimulus color predicts a high-error condition (50% errors), while another color predicts a low-error condition (5% errors). First, we parametrically manipulated not only the likelihood of error but also the magnitude of the consequences (if an error occurs) by manipulating the strength of the error signal. Manipulations of error consequence magnitude lead to a predicted positive linear relationship between ACC activity and the product of error likelihood and consequence magnitude. Thus, ACC may monitor the “riskiness” of behavior in terms of the expected “negative utility” of a particular decision. This suggests a fundamental link between ACC activity and microeconomic theories of decision making under risk. Thus, error-likelihood detection by ACC may be a special case of a more general risk detection model of ACC. Second, we added a prefrontal cortex (PFC) working memory representation of the error likelihood predicting cue and added a projection from the model PFC to ACC. We then introduced a delay between the onset of the error likelihood cue and the target stimuli. The model ACC activity again learned to signal the likelihood of an error. This result suggests how error likelihood predicting cues stored in working memory might contextualize learned predictions of error likelihood in ACC. The results provide clear, testable predictions regarding the role of ACC and its reciprocal interactions with prefrontal cortex and the dopaminergic midbrain. Ongoing studies aim to test these predictions.

Supported by: ONR

Keywords: dopamine, cognition, modeling, plasticity

CCN Conference submission:

Unified computational neural modeling of behavior, fMRI, and neurophysiological data with RNS++

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Cognitive computational modeling increasingly requires integrated treatment of multiple types of empirical data. Long-standing cognitive measures of reaction time and error rate are complemented by an extensive literature on the neurophysiology of awake, behaving non-human primates as well as the burgeoning human fMRI literature. The most powerful models will simultaneously address data from all of these and other modalities in a unified computational framework. The RNS++ (Real-time Neural Simulator) software models rate-coded and spiking neural activity. Time is simulated in real units of seconds, which provides a unifying factor that allows simulation of diverse data types in a single model. RNS++ shares a common user interface with its parent PDP++ software. Parameter fitting is automated with a noise-tolerant gradient descent algorithm. A case study of cognitive control mechanisms demonstrates the power and functionality of the simulator. Specifically, we fit a model of cognitive control to reaction time and error rate data. The model successfully predicted subsequent fMRI findings and captured neurophysiological data as well.

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