Movement and reward are encoded in the cerebellar signals to the substantia nigra dopamine neurons

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Learning involves multiple brain regions that process sensory input, evaluate outcomes and generate movement. A recent in vivo study characterized functional monosynaptic projections from the cerebellum (Cb) to the substantia nigra (SNc) dopaminergic nucleus and demonstrated the involvement of these Cb-SNc projections in both movement generation and reward-based functions during learning (Washburn, Onate et al, Nat Neurosci 2024). However, the information content of these signals and how they relate to function is still unknown. Moreover, decomposing neural signals into components that encode different predictors and their kinetics, particularly during a learning process remains mathematically and computationally challenging. Standard methods such as generalized linear models (GLM) can provide link functions that estimate the contribution of each predictor to the total signal, but do not estimate the associated signal kinetics.

In this work, we develop and use an optimization technique to decompose the Cb-SNc activity, recorded in a Pavlovian conditioning task, into three components: (i) movement-related, (ii) sensory, and (iii) reward-related. This method produces the respective contributions (kernels) of each predictor component, based on a priori assumptions (such as linear decomposition), which can then be examined to estimate how each predictor changes during the learning process.

Because these kernels are time-dependent, they provide an estimate of both the amplitudes and the kinetics of the signal components contributed by each predictor. Notably, the time-dependent kernels can be interpreted as the output of dynamical systems (solutions to

ordinary differential equations) in response to inputs. Therefore, these kernels are interpretable in terms of a systems' building blocks. We build firing rate models of cerebellar output neurons, SNc dopamine neurons and inhibitory GABAergic neurons and simulate this activity using parameter estimation tools. These models are used to examine how the cerebellum may contribute to dopaminergic signaling in the process of conditioned learning.
