An Integrated Cerebellum Model Explaining Associative Learning, Timing Prediction, and Motor Control

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Abstract:

Early models of cerebellar function have emphasized the role of the cerebellum in motor control and timing. In addition to the well documented role of the cerebellum in motor function, studies have shown that the cerebellum is also required for certain associative learning tasks and that cerebellar lesions are correlated with various cognitive impairments. These additional roles of the cerebellum are not well explained by models dedicated to motor control and timing.

Here we present a model of the cerebellum capable of replicating and explaining a broader range of capabilities, encompassing associative learning, timing prediction, and motor control. In this system-level model, the cerebellum is not considered in isolation. This model depends upon known relationships of the cerebellum with the inferior olive, the deep nuclei, the red nucleus, the pontine nuclei, the cerebral cortex, the spinal cord, and other afferents. The model hypothesizes a critical role in learning and cortical prediction for the 1 to 3 Hz firing rate of complex spikes emanating from the inferior olive. This firing rate can be thought of as the reference signal in a control system that adapts by changing the integration rate of Purkinje cells through synaptic modification. This modulates a point-to-point feedback loop starting and ending in the cerebral cortex that passes through the red nucleus, the inferior olive, the cerebellar cortex and deep nuclei, and the thalamus. This modulates cortical activity, which directly and indirectly affects motor function.

Finally, the aforementioned capabilities of associative learning, timing prediction, and motor control are demonstrated using computer simulations.

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