Modeling the Role of the Basal Ganglia in Natural Motor Control and Motor Programming

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The Problem: What are the roles of the basal ganglia in 1) low-level kinematic control of movement and posture and 2) high-level motor programming and cognitive functions?

Motivation: It is recognized that the basal ganglia and associated regions of the frontal cerebral cortex contribute to control of movement speed and posture as well as to regulation of motor sequencing and even the organization of higher motor behavior and cognitive processes. In some sense, these structures embody at least “motor intelligence”. Dysfunction of the basal ganglia results in movement disorders such as Parkinson’s and Huntington’s disease and dystonia that are marked by involuntary slowness, muscular rigidity, tremor, abnormal postures, disorganized, jerky movements and subcortical-type dementia. Recently, some of these have been corrected by deep brain stimulation [7]. Still, the precise mechanism by which these structures operate remains unclear. Accurate quantitative models would provide us with insights into normal human brain function and the possible development of advanced clinical techniques for the diagnosis and treatment of neurological diseases. At the same time, the study of biological control strategies of the basal ganglia would likely identify valuable principles for the design of self-learning motor behavioral control systems for robots and intelligent embedded systems

Previous Work: Prior models of basal ganglionic function have focused either on its low-level motor function (e.g. [2]) or its possible role in decision making (e.g. [1], [3]) or behavioral learning (e.g. [4]). However, we are in the process of developing a unified model of cortical - basal ganglionic interaction in both low-level kinematic control of movement and posture and higher level motor behavior [6],[5]. This model seeks first to explain basal ganglionic function in the generation of “cruise” (constant velocity) movements. The model assumes several parallel cortico-basal ganglionic-thalamocortical (CBGTC) circuits or “channels” that serve agonist and antagonist motor pathways. Each CBGTC functional loop includes a thalamocortical integrator whose activity is allowed or disallowed by basal ganglionic direct and indirect pathway action [2] resulting in speed control. The model is thus consistent with others that describe a possible role of the basal ganglia in the sequencing and switching of brain states [1],[3]. It is then demonstrated that certain disorders of motor control may be understandable in terms of faulty switching between such channels. Simulation of certain alterations of dopamine-dependent gains in the putamen (entry nucleus for lower motor control basal ganglionic channels) results in excessive and less selective basal ganglionic output activity. This produces model representations of the 5-Hz rest tremor, slowness and rigidity characteristic of Parkinson’s disease (PD). Other modeled alterations of putamenal integrity result in representations of dystonia. Simulated selective impairment of STN units (assumed effect of therapeutic deep brain stimulation) reverses most of the motor dysfunctional features of simulated PD and dystonia. Finally, application of the same model to motor programming control affords plausible simulations of simple motor behavioral learning in animals

Approach: The research involves analysis of the stability neural dynamics of the cortico-basal ganglia-thalamocortical circuits and their synaptic plasticity under both normal and abnormal conditions. The modeling is constrained to adhere closely to known or highly plausible neuroanatomical connections, neuronal dynamics and molecular biology. Models are developed in MATLAB to afford rapid prototyping and analysis within a systems engineering framework.

Difficulty: A central difficulty is that ultimate validation of internal model mechanisms depends on the availability of recordings from multiple brain neurons in non-human animals or humans during behavior. For this reason, we are establishing collaborations with experimental neurophysiologists, neurologists and neurosurgeons to acquire this data.
**Impact:** The research proposes a functional neuroanatomic model that attempts to provide a unified explanation for the roles of the basal ganglia in motor control and higher-level cognitive functions. The model subsumes within a broader framework, prior conceptions of the roles of the basal ganglia in controlling movement speed and posture, acquiring and generating sequences of single actions, and in the selective sustenance of activation in working memory regions of frontal cortex. In so doing, it provides specific predictions regarding the activity of internal circuits in health and disease. It also provides a computational foundation for designing artificial autonomous agents capable of acquiring flexible behaviors through behavioral reinforcement.

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**References:**


