FUNCTION AND DYSFUNCTION OF THE BASAL GANGLIA IN DIFFERENT ASPECTS OF MOTOR LEARNING

M. Felice Ghilardi, Ioannis U. Isaias^, Clara Moisello, Bernardo Perfetti

SMILab, Dept. of Physiology & Pharmacology, CUNY School of Medicine, New York, NY
^ Parkinson Institute, Istituti Clinici di Perfezionamento, Milano

Motor learning encompasses complex and highly integrated processes that allow for the planning, acquisition, retention and retrieval of motor skills. It has been studied with experimental tasks designed either to measure acquisition of sequential movements into a well-articulated behavior, or to test the ability to compensate for environmental changes. The learning of motor skills generally follows several phases, including an initial acquisition phase in which considerable improvement in performance occurs fast, usually within a single training session, followed by a phase in which further gains take place slowly, usually over several sessions of practice. The final stage is automaticity that can be reached when the learned task or behavior can be executed with minimal cognitive resources. Performance enhancement can also occur after sleep or after a latent period, without further practice taking place. Thus, through several processes, a motor skill can be retained, becoming resistant to interference and to time, and can be retrieved so it can be executed readily, even after long delays without further practice on the task.

There are fundamental differences in the processes and the neural substrates that are involved in visuomotor adaptation and in the acquisition of sequences and during. For instance, visuomotor adaptation usually occurs implicitly, without awareness, as subjects cannot describe the process or the nature of what they learned; moreover, errors are signaled by a continuous - or analog – stream of visual and proprioceptive information.

On the other hand, while learning ordered sequences of events or movements, subjects are usually aware of errors and successes, they can describe what they learned verbally or through other sign systems: thus, in this type of explicit learning, feedback is typically discrete and available only at the completion of individual responses or of the entire sequence. Imaging studies also have highlighted some other differences. Although basal ganglia play a role in both types of learning, the cortico-striatal systems are differentially involved: for example, the dorsolateral pre-frontal cortex loop is engaged in sequence learning but not in the implicit visuomotor adaptation. In summary, cortico-striatal and cortico-cerebellar systems are active depending on the cognitive processes required by the specific type of learning but also on the different phases of learning, as these systems are crucial for consolidating, retrieving and maintaining a learned behavior. Since cortico-striatal circuits play a
crucial role in forming, maintaining and retrieving motor memory, disorders of the basal ganglia affect the processes involved in motor learning and motor planning. Here we review recent evidence on the processes and the neural correlates of motor learning in Parkinson’s disease (PD), Huntington’s disease (HD) and dystonia. In particular, we will focus our attention on sequence learning.

Sequence learning, that is the ability to acquire and link together single events or movements, represents an interesting case as different aspects of learning processes are involved. In fact, sequence learning encompasses two distinct learning components: the acquisition of the order of the elements in the sequence, and the ability to combine these elements in a single, smooth, automatic skilled behavior. We have recently used an intentional learning paradigm in an arm-reaching task to identify and measure these two components (Ghilardi et al. 2003, 2007, 2008, 2009; Moisello et al., 2009). With this task, we assessed the acquisition of the sequence order with the number of the correct anticipatory movements, a discrete variable that is defined by changes in reaction times, and with declarative scores. We have also determined the achievement of the automatic, skilled execution, by evaluating kinematic characteristics that are indicative of increased efficiency, greater accuracy and significant energy saving: anticipatory movements are more accurate, with longer duration as well as with lower peak acceleration and velocity than non-anticipatory movements. The implicit switch of the kinematic strategy is an optimization process and a fundamental part of skill acquisition: it represents a form of adaptation and a transition from the unknown, or unpredictable, to the known, or predictable, allowing subjects to save energy when possible.

The basal ganglia play a significant role in this type of behavioral learning is confirmed by the finding that patients with basal ganglia disorders exhibit deficits in these aspects. In fact, we have recently found that PD patients exhibit a learning deficit that is more evident for the declarative component: they are slower in learning both visual and visuo-motor sequence order and use different neural networks than normal controls. Interestingly, dopaminergic therapy decreases both network activity and the acquisition of the sequence order, while deep brain stimulation increases both measures. As for the implicit component of sequence learning, we have found that patients with PD have down-regulated ability to switch the kinematic strategy and thus, they have difficulty in increasing energy when it is required. The energy regulation impairment significantly correlates with UPDRS motor scores. We have also studied sequence learning in two populations of subjects without clinically evident motor symptoms, but with possible involvement of the basal ganglia: non-manifesting carriers of the DYT1 gene and subjects in the pre-symptomatic stages of HD (pHD). DYT1 carriers show reduced declarative scores than in con-
trols with an increase in the left ventral prefrontal cortex, and lateral cerebellum. However, these subjects were able to switch kinematic strategy and to modulate energy consumption like normal subjects. Despite the absence of clinical motor symptoms, pHD subjects showed a significantly lower number of correct anticipatory movements and lower declarative scores than controls in a visuo-motor sequence learning task, with an significant improvement in the learning scores in a purely visual task. However, pHD subjects have a decreased ability to decrease energy with a general up-regulated energy consumption.

The neural counterparts of the declarative and the implicit learning attributes are basal ganglia loops: the first is likely based on the DLPFC loop that encompasses the anterior striatum, while the second includes SMA and the putamen loop and involves the primary motor cortex, the prefrontal cortex and pre-SMA.

We conclude that abnormalities in energy regulation, a form of implicit adaptation process, may be part of a general impairment in trajectory formation in both early stages of PD and pHD, also when motor impairment is minimal. All these data suggest that basal ganglia are involved in the regulation of movement energetic expenditures, although the different cortico-striato-cortical loops and/or neurotransmitter systems are likely to play different roles in such a regulation.
REFERENCES:


