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Review

The many facets of motor learning and their relevance for Parkinson's disease

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H I G H L I G H T S

- Retention of motor skills is impaired in Parkinson's disease, despite preserved on-line learning.
- Declarative learning is impaired even in the early stage of Parkinson's disease.
- Exercise, but not levodopa can improve motor learning and plasticity in Parkinson's disease.

A B S T R A C T

The final goal of motor learning, a complex process that includes both implicit and explicit (or declarative) components, is the optimization and automatization of motor skills. Motor learning involves different neural networks and neurotransmitters systems depending on the type of task and on the stage of learning. After the first phase of acquisition, a motor skill goes through consolidation (i.e., becoming resistant to interference) and retention, processes in which sleep and long-term potentiation seem to play important roles. The studies of motor learning in Parkinson's disease have yielded controversial results that likely stem from the use of different experimental paradigms. When a task's characteristics, instructions, context, learning phase and type of measures are taken into consideration, it is apparent that, in general, only learning that relies on attentional resources and cognitive strategies is affected by PD, in agreement with the finding of a fronto-striatal deficit in this disease. Levodopa administration does not seem to reverse the learning deficits in PD, while deep brain stimulation of either globus pallidus or subthalamic nucleus appears to be beneficial. Finally and most importantly, patients with PD often show a decrease in retention of newly learned skill, a problem that is present even in the early stages of the disease. A thorough dissection and understanding of the processes involved in motor learning is warranted to provide solid bases for effective medical, surgical and rehabilitative approaches in PD.

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1. Introduction

Motor learning in Parkinson's disease (PD), defined as the ability to learn and refine skills, has been the subject of investigations and debate for more than two decades. In fact, studies have produced controversial results, as whether or not motor skill formation is impaired in PD. Confounding factors are many, starting from the use of a variety of tasks that tap into different cognitive and motor aspects to the influence of drugs and therapies used in PD. Another important problem in deciphering those results is the range of terminology used in defining the type of learning involved in the different motor tasks. The study of motor learning, a special category in the field of learning and memory, is a relatively recent, but rapidly growing field that has borrowed, sometimes inaccurately, nomenclature and definitions from neuropsychology. Briefly, neuropsychological research has proposed a major distinction between *explicit* and *implicit* learning (Tulving, 1985; Squire and Zola-Morgan, 1991). Explicit (or *declarative*, *noetic*) learning is the capacity for *conscious*, declarative learning and memory about facts and events that can be expressed through recollection, and constitutes a sort of memory register for facts and notions, be they general or autobiographical. Implicit (or *non-declarative, procedural*, *anoetic*) learning, on the other hand, refers to a heterogeneous collection of *unconscious*, non-declarative memory abilities, which includes procedural learning and thus, all motor skill and habit formation. From an operational point of view, while implicit processes are usually measured by continuous variables, explicit learning is more likely to involve discrete changes and variables. Moreover, factors such as instructions, selection of performance measures, contextual cues as well as motivation might be implicit or explicit in nature and differentially influence the use of implicit or explicit "channels" and attentional resources. One must not assume that all the processes that occur during motor learning are *implicit*; in fact, motor learning is a multistep operation, involving both declarative and procedural mechanisms, usually at different stages (Moisello et al., 2009). In the following review, we will first address general concepts and ideas about motor learning; we will then summarize the results of motor learning studies in PD focusing on the type of tasks used and the effect of drugs and other therapeutic interventions. Finally, we will review the few studies that have investigated retention of motor skills in PD. Dissecting motor learning is highly relevant in PD: as illustrated in this review, motor learning encompasses the formation and retention of motor skills and, in particular, the achievement and the use of automaticity in daily routines, which are both impaired in PD. Detailed knowledge of the learning processes in this context is important to enhance and maximize the effects of rehabilitation and compensation strategies to overcome the motor deficits and the disabilities imposed by PD.

2. Different stages of motor learning: Explicit and implicit processes are both present

Explicit or declarative processes are important for most motor skill learning. In fact, many of the actions that we learn or we perform daily can be described, to some extent, verbally and the initial stages of learning new motor routines, the *what to do*, often rely on verbal and visual information. An example is when volleyball players first learn to hit the ball: following the coach's instructions, they learn to take three steps, jump, raise the arm and then hit the ball. However, despite as much detail one can provide in a verbal or visual description, this does not guarantee that performance will be flawless and effective: extensive hands-on practice needs to follow to obtain winning actions. Thus, explicit information and actual performance must coexist in variable degrees at different stages of practice, depending on the task, on the instructions and also on individual differences such as genetic predisposition, age, experience, motivation and personality.

The classic view on the development of motor skills (Fitts, 1964; Anderson, 1982, 1995; Logan, 1988) posits that motor learning generally occurs in three main phases: *cognitive*, *associative* and *autonomous* phases (Fig. 1). In the first, the *cognitive* phase, the learner is usually new to a task and the primary concern is to understand *what* needs to be done mostly through the interpretation of verbal instructions, a declarative process (Anderson, 1982). In this phase, performance is usually effortful, tentative, slow and inaccurate, but dramatic gains in proficiency, generally larger than at any other time, are noted. Declarative and attentional processes as well as cognitive strategies mediate most of the improvement, with major advances in terms of *what to do*, rather than in the refinement of motor patterns themselves (*how to do*). The duration of this "verbal-motor" stage (Adams, 1971) usually depends on the clarity of the instructions (see also the end of this part) and on the complexity of the task. Indeed, very simple tasks, like the repetitive flexion of the index finger, have a very short *cognitive* phase that can be captured only focusing on the first few movements. The second phase of learning, also known as *slow learning stage*, or *motor stage* (Adams, 1971), starts when subtle performance adjustments, imperceptible to the subject, occur: movements become more consistent and improvements more gradual. In this phase, which might persist for days or weeks, performance becomes more accurate and automatic with small changes in the motor patterns, as the declarative aspects have completely or largely dropped out and *implicit* mechanisms have taken over. Finally, after a longer time of practice, perhaps as long as months or years, in the third phase, the skill becomes largely automatic, as it can be performed with little deployment of attentional resources and less interference from other simultaneous activities. In this "automatization" phase, extended practice establishes a direct condition-action association: the result is that performance is faster, effortless,