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Effects of practice and delays on learning and retention of skilled tool use in Parkinson's disease

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ABSTRACT

Previous research has shown that individuals with Parkinson's disease (PD) show preserved learning of tool-related motor skills, while retention was impaired after a three-week delay, possibly as a result of striatal dysfunction. The goal of the current study was to identify if shorter delays and more extensive practice might reduce retention deficits related to complex tool use in PD. PD participants and healthy age and education-matched controls were trained to use novel tools across four sessions, spaced one-day, one-week, and three-weeks apart. Recall of tool attributes (e.g., function) and skilled motor performance using tools was investigated by examining patterns of learning and forgetting over time. Results showed that tool attribute recall was unimpaired in PD participants relative to controls. For motor skill performance, PD participants were unimpaired in motor skill learning within sessions, but they did not retain these skills across one-week and three-week delays between sessions. This dissociation suggests that the striatum plays a critical role in retention of motor skills needed in skilled tool use performance. Finally, in spite of forgetting, individuals with PD still demonstrated improvement across sessions with additional training, suggesting that people with PD may benefit from extensive practice when learning motor skills.

1. Introduction

Parkinson's disease (PD) is traditionally characterized by motor difficulties, but a variety of cognitive impairments may also be present even in non-dementing individuals (Lewis et al., 2003; McFadden et al., 1996). In terms of memory performance, individuals in the early stages of PD have impaired procedural memory (Knowlton et al., 1996; Shohamy et al., 2008; Werheid et al., 2003) while their declarative memory remains relatively intact (Robbins and Cools, 2014; but see Cohn et al. (2010)). Recently it was shown that procedural memory impairments extended to motor skill performance using novel complex tools in PD (Roy et al., 2015). Complex tools are defined as objects that transform motor output into advantageous mechanical actions to achieve a goal when acting on an object (e.g., using a knife to slice bread; Frey, 2007). In our daily activities, we often rely on familiar complex tools, and when new tools are encountered it is critical to learn about the properties of these tools and the actions associated with their skilled use (Goldenberg, 2013).

Roy et al. (2015) showed that individuals with PD demonstrated intact learning of motor skills involved in the skilled use of a novel tool within a session, but unlike healthy controls, PD participants did not retain these skills after a 3-week delay. Although this pattern of preserved within-session learning but impaired retention after a delay has been previously reported in individuals with PD (Bedard and Sanes, 2011; Marinelli et al., 2009), these motor adaptation tasks differ considerably from skilled tool use. Motor adaptation tasks require participants to adjust their movements in response to environmental changes, and patients with cerebellar damage show impairment on these tasks. In contrast, skilled use of tools and motor sequence tasks involve the production of a sequence of movements, and patients with PD and Huntington's disease can be impaired on these tasks (for a review, see Doyon et al., 2009). At this point, it is unknown whether this pattern of intact learning but impaired retention with skilled tool use would be observed after a shorter delay and with additional practice, and the neurocognitive processes responsible for the pattern of performance are unclear. Thus, the general goals of the current study were to determine whether individuals with PD would have impaired motor skill retention after shorter delays including a one-day delay. In addition, the experiment investigated whether more extensive practice across four sessions would result in an overall improvement in tool-related motor skills in spite of reduced retention.

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1.1. Memory systems in tool use

Research aimed at understanding praxis and apraxia has shown that a variety of knowledge and skills are required in the skillful use of complex tools (Boronat et al., 2005; Buxbaum and Saffran, 2002; Kellenbach et al., 2003; Stanley and Krakauer, 2013). For example, it has been argued that human tool use relies on the ability to use technical reasoning based on perceptual characteristics of the tool to infer its function (Goldenberg, 2013; Osiurak et al., 2011). However, these studies did not carefully assess the cognitive and neural underpinnings associated with the acquisition and retention of the different aspects of tool use.

This issue was investigated in a previous experiment in our lab. In an amnesic individual, D.A., who had severe declarative memory impairments as a result of extensive bilateral hippocampal damage, Roy and Park (2010) examined how declarative and procedural memory systems mediate novel complex tool use. Similar to familiar tools (e.g., tool, hammer; recipient, and nail), the novel tools used in this study required participants to grasp the tool and perform a sequence of actions that acted on a recipient object in order to achieve the goal associated with that tool. Results showed that D.A. and controls improved with practice when motor skill performance was assessed immediately after viewing a video that demonstrated the correct use of the tool. This improved motor skill performance was retained by D.A. and controls after a 3-day and 3-week delay between sessions. The finding of preserved learning and retention of motor skills with D.A. is consistent with previous research showing that individuals with amnesia have intact skilled motor performance (e.g., Milner, 1962), procedural memory (Squire, 1992), and retain motor skills after long delays (Gabrieli et al., 1993). In contrast to intact learning and retention of motor skills, D.A. was severely impaired in using tools when there was a delay between viewing a video and attempting skilled use of the tool. Further results showed that D.A. was also impaired in recalling the attributes, function, and grasp of the tool, showing that declarative memory is necessary for these tasks. Based on these findings, Roy and Park (2010) concluded that declarative memory is necessary to recall a tool's attributes, function, and grasp, but that the motor skills associated with the tool were primarily mediated by procedural memory.

A related study investigated novel tool use in a sample of individuals with mild-moderate PD and healthy age and education-matched controls (Roy et al., 2015). Participants were evaluated on various components of tool use, during two sessions, spaced three weeks apart. Individuals with PD were selected because previous research demonstrated that this group was impaired on the serial reaction time test (Siegert et al., 2006; Wilkinson et al., 2009), a task used to investigate the cognitive processes associated with motor sequence learning. Most relevant to the current study was skilled motor performance using novel tools in the training condition. In this condition, individuals with PD, similar to D.A. and healthy controls, showed improved performance within sessions. However, unlike D.A. and healthy controls, individuals with PD were impaired in their performance of motor skills after a 3-week delay.

Based on these findings Roy et al. (2015) proposed that both declarative memory, mediated by the hippocampus and related structures, and procedural memory, mediated by a frontal-striatal network, interact in novel tool use. However, their relative contribution varies during within-session testing and retesting after a delay because the properties of these two memory systems differ. Declarative memories can be acquired quickly, but are susceptible to interference, whereas in many situations procedural memories are robust and tend to be retained for long periods of time (Gabrieli et al., 1993; Squire, 2009). According to this proposal, intact within-session learning by individuals with PD reflected performance mediated by a relatively intact declarative memory system. In contrast, it was hypothesized PD participants had impaired retention because the striatum was more important in the retention of skilled actions after a three-week delay.

The hypothesis that the hippocampus and striatum interact is supported by neuroimaging studies of motor sequence (for a review, see Albouy et al., 2013) and probabilistic learning (Poldrack et al., 2001). In studies of motor sequence learning, hippocampal and striatal activation were observed during within-session training in healthy young adults. With practice, hippocampal activation decreased, whereas striatal activation increased. In addition, there was an antagonistic relation between the hippocampus and the basal ganglia within a session (Albouy et al., 2013; see also Poldrack et al., 2001). Other research has also showed that PD participants might compensate for impaired striatal functioning by relying more heavily on medial temporal lobes for some tasks (Gobel et al., 2013; Moody et al., 2004).

1.2. Role of executive function in motor learning

An alternative possibility is that motor skill performance declined after a 3-week delay in the Roy et al. (2015) study because PD participants had impaired executive function. Previous research showed that as a result of disruptions in frontal-striatal circuitry, individuals with PD may have deficits in executive functioning, which may in turn affect motor performance (Robbins and Cools, 2014: Sullivan et al., 1989). It has also been proposed that impairments in probabilistic motor sequence learning by PD participants may be indicative of a dysexecutive syndrome (Wilkinson et al., 2009), and results from neuroimaging studies of motor sequence learning revealed prefrontal cortical activation, particularly during the early stages of learning (Albouy et al., 2013). Further neuroimaging findings showed that spaced learning increased activation in the prefrontal cortex and related structures compared to massed learning (Wagner et al., 2000; Zhao et al., 2015). Taken together, these findings suggest that in the Roy et al. (2015) study, executive functions might have been required to a greater extent after a 3-week delay in Session 2 than on the preceding training trial, which was carried out immediately after the first trial in Session 1, similar to findings reported for spaced learning. As a result, performance deteriorated after a 3-week delay for PD participants, but not for controls, because PD participants had impaired executive function due to dysfunctional frontal-striatal circuitry.

1.3. Motor skill learning and retention in PD

Although intact motor learning within a session has been reported in previous studies of individuals with PD (for a review, see Nieuwboer et al. (2009)), fewer studies have examined the effects of delay on motor skill retention, and findings have been less consistent. For instance, some studies reported unimpaired retention after delays of 48 h or longer in PD participants (Behrman et al., 2000; Smiley-Oyen et al., 2006), whereas other research found impaired retention at longer delays of three months or more on motor (Mochizuki-Kawai et al., 2004) and striatally-mediated tasks (Cohen and Pourcher, 2007; Poldrack and Gabrieli, 2001) Currently, it remains unclear why inconsistencies in retention performance have been observed in PD participants on tasks that rely primarily on procedural memory or striatal activation. Factors such as task differences, the amount and type of training, and the duration of retention interval varied across studies, so mixed results could be attributable to such differences.

The degree to which procedural memory mediates performance may also depend upon the amount of practice an individual receives. Studies using probabilistic learning demonstrated that individuals with PD had intact performance during early learning, but were impaired during later learning, as these stages of learning are thought to be mediated by declarative and procedural memory, respectively (Shohamy et al., 2004; Wilkinson and Jahanshahi, 2007). A computational model of probabilistic cueing observed that after extensive practice, PD participants relied to a greater degree on procedural memory than during earlier trials (Shohamy et al., 2008). Thus,