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Age-related differences in perceptuomotor procedural learning in children

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ABSTRACT

Procedural learning is generally considered to proceed in a series of phases, with cognitive resources playing an important role during the initial step. From a developmental perspective, little is known about the development of procedural learning or the role played by explicit cognitive processes during learning. The main objectives of this study were (a) to determine whether procedural learning performance improves with age by comparing groups of 7-year-old children, 10-year-old children, and adults and (b) to investigate the role played by executive functions during the acquisition in these three age groups. The 76 participants were assessed on a computerized adaptation of the mirror tracing paradigm. Results revealed that the youngest children had more difficulty in adapting to the task (they were slower and committed more errors at the beginning of the learning process) than 10-year-olds, but despite this age effect observed at the outset, all children improved performance across trials and transferred their skill to a different figure as well as adults. Correlational analyses showed that inhibition abilities play a key role in the performance of 10-year-olds and adults at the beginning of the learning but not in that of 7-year-olds. Overall, our results suggest that the age-related differences observed in our procedural learning task are at least partly due to the differential involvement of inhibition abilities, which may facilitate learning (so long as they are sufficiently developed) during the initial steps of the learning process; however, they would not be a necessary condition for skill learning to occur.

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Introduction

From an early age, children acquire many kinds of perceptuomotor skills; for example, they can learn how to eat with cutlery, manipulate a computer mouse, tie shoelaces, or use a variety of tools at school. Through repeated practice, these skills gradually become automated and can be performed without awareness or fatigue. They represent what one calls "routines"—that is, procedural skills. Procedural learning refers to the process in which new perceptuomotor, perceptual, or cognitive skills are acquired through long and repetitive training (Cohen & Squire, 1980; Willingham, 1998). Considering the early maturity of the brain structures underlying procedural learning, it is generally acknowledged that this system is present early in childhood and that, undoubtedly, it plays an important role in child development.

The process of learning a procedural skill is generally considered to proceed in a series of distinct learning phases, with cognitive resources playing an important role during the initial step of learning. Through repeated practice, the skill becomes progressively more automatic and the involvement of controlled cognitive functions progressively dwindles. This conception is formalized in the adaptive control of thought model (ACT model; Anderson, 1982, 2000), where knowledge is first stored in a declarative form and then converted into procedural knowledge. According to this top-down approach to learning, this transformation occurs in three stages; the first ("cognitive") stage requires a large amount of cognitive (e.g., working memory) resources, the involvement of cognitive functions is progressively reduced during the second ("associative") stage, and the last ("autonomous") stage is characterized by automation and no longer requires the involvement of explicit processes. Brain imaging studies in adults have confirmed the existence of distinct learning phases showing that different brain structures are active at the different stages in motor skill learning (Doyon & Benali, 2005; Hikosaka et al., 1999). The early stages of learning recruit the basal ganglia and cerebellum; the prefrontal, parietal, and limbic areas; and the motor cortical regions. When consolidation has occurred, performance becomes automatic and the circuits involved depend on the type of motor skill acquired (Doyon & Benali, 2005). The ACT model has received experimental support from a number of studies on perceptuomotor procedural learning that have highlighted the role of explicit cognitive processes during the first learning phase. More specifically, several studies have demonstrated that some procedural learning tasks require the intervention of nonprocedural functions, in particular executive functions. First, Kennedy, Partridge, and Raz (2008) showed that the effects of age on perceptuomotor skill acquisition (e.g., mirror tracing) may be mediated by the deterioration of cognitive resources (notably working memory) during aging. Second, Brosseau, Potvin, and Rouleau (2007) argued that the age-related difficulties observed in the learning of the mirror tracing task reflect mainly the involvement of executive functions (inhibitory control). Third, Schmidtke, Manner, Kaufmann, and Schmolck (2002) found that patients with prefrontal lesions experience some difficulties with adaptation during the initial phases of learning on the pursuit rotor task, confirming the involvement of the prefrontal cortex during the first phase of motor learning. To summarize, results obtained with adults and elderly people support the proposal that explicit cognitive processes play a key role during the first phase of procedural learning. These studies also demonstrate age-related differences in at least some procedural learning tasks where executive functions seem to play a key role.

Although the top-down approach to procedural learning (i.e., performance during the first learning stages is sustained by explicit high-level mechanisms) has received the most attention, some researchers have also proposed a bottom-up approach to skill learning, which postulates that explicit declarative knowledge is not necessarily involved in procedural skill learning and that the knowledge acquired could be stored in an implicit mode from the beginning of learning (Karmiloff-Smith, 1992; Liao & Masters, 2001; Sun, Merrill, & Peterson, 2001). Karmiloff-Smith (1992), for example, proposed the representational redescription model (RR model), which suggests that children shift progressively during development from a procedural learning mode (involving the formation of procedural knowledge) to a more declarative learning mode (leading to the formation of declarative knowledge). This view suggests the possibility that procedural learning in young children (whose explicit learning mechanisms have not yet fully developed) might work differently than the ACT model suggests without necessarily involving the intervention of explicit cognitive resources (e.g., working memory) during the first phase of learning.