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Deficit in implicit motor sequence learning among children and adolescents with spastic Cerebral Palsy

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ABSTRACT

Skill learning (SL) is learning as a result of repeated exposure and practice, which encompasses independent explicit (response to instructions) and implicit (response to hidden regularities) processes. Little is known about the effects of developmental disorders, such as Cerebral Palsy (CP), on the ability to acquire new skills. We compared performance of CP and typically developing (TD) children and adolescents in completing the serial reaction time (SRT) task, which is a motor sequence learning task, and examined the impact of various factors on this performance as indicative of the ability to acquire motor skills. While both groups improved in performance, participants with CP were significantly slower than TD controls and did not learn the implicit sequence. Our results indicate that SL in children and adolescents with CP is qualitatively and quantitatively different than that of their peers. Understanding the unique aspects of SL in children and adolescents with CP might help plan appropriate and efficient interventions.

1. Introduction

The acquisition of motor skills is an essential component of development for all children (Haibach, Reid, & Collier, 2011). Motor skill learning (SL) refers to the cognitive process by which movements are executed more quickly and accurately with practice (Willingham, 1998). There is abundant and strong evidence for two separate motor learning systems in the brain: an explicit system that relies on strategies like instructions, feedback and demonstrations to generate performance while the process can be verbally described, and an implicit system that generates skilled motor performance unintentionally and often without awareness (Reder, Park, & Kieffaber, 2009; Squire, 2004).

The evidence supports the notion that the two systems are operating independently, by different neural networks, in the normal brain while acquiring a skill. A crucial anatomic difference between the two is the involvement of the medial temporal lobe (MTL) structures (i.e. the hippocampus and surrounding structures) in the explicit network and extra-MTL structures in the implicit system (Reder et al., 2009).

A simple task that has been thoroughly studied as a model of implicit skill acquisition is the serial reaction time (SRT) task, first reported by Nissen and Bullemer (1987). The task requires learning a sequence of motor responses to visual cues. Typically, four cue locations are shown on a computer screen with four possible keyboard button responses aligned underneath. Participants are asked to produce a motor response to a concealed *repeated sequence* presented in different spatial locations on a computer screen using corresponding buttons. After several *repeated sequence* blocks a *new sequence* is

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presented, followed by the *repeated sequence* once again at the end of the task. A gradual reduction in reaction time (RT) that takes place across the sequential blocks provides a measure of participants' mastering of the task – what Ferraro, Balota, and Connor (1993) termed "generalized skill". However, a more specific measure of skill acquisition is obtained by contrasting RT's for the *repeated sequence* against those of the *new sequence*. If following the replacement of the *new sequence*, participants implicitly continue to anticipate that the visual cues will occur at the same positions as in the *repeated sequence*, an implicit learning of the sequence has occurred (Vakil, Kahan, Huberman, & Osimani, 2000). This anticipation will inflate RT's in the *new sequence* trail, increasing the difference between responses to the *repeated* and *new* sequences. Tacit knowledge of the repeating sequence occurs even when participants are unaware of the existence of the sequence, and learning occurs at a normal rate in patients with memory disorders (Nissen & Bullemer, 1987). Studies of implicit learning patterns evaluating the SRT task in typically developing (TD) children showed that beyond typical patterns of decreasing reaction time throughout the task blocks and delays after introducing the new sequence, overall response time also decreased throughout childhood and adolescence (Janacsek, Fiser, & Nemeth, 2012).

Performance on SRT task has also been reported in children with atypical development, including children with autism (Barnes et al., 2008), ADHD (Barnes, Howard, Howard, Kenealy, & Vaidya, 2010), Williams and Down syndromes (Vicari, Verucci, & Carlesimo, 2007), and in children with structural brain anomalies involving the cerebellum (Vakil et al., 2000) and basal ganglia (Mayor-Dubois, Maeder, Zesiger, & Roulet-Perez, 2010), however findings were fairly inconsistent partially due to the different SRT methodologies used.

Cerebral Palsy (CP) is an umbrella term that describes a group of heterogeneous movement and posture disorders with varying etiologies and severity, attributed to non-progressive brain disturbances. These motor disorders are often accompanied by impairments in sensation, cognition, perception, and behavior (Bax et al., 2005).

As a result of motor disorders and accompanying impairments, children with CP manifest difficulties in executing various activities of daily living (ADL's) (Fauconnier et al., 2009). As with children who do not have neurological motor impairments, children with CP need to learn these activities in order to adequately function in the real world. Although visible motor difficulties like spasticity and limited range of motion are defining characteristics of the impairment in CP, it has been recently acknowledged that higher-order motor planning and motor learning deficiencies also exist (Bar-Haim et al., 2010; Steenbergen & Gordon, 2006). Considering intensive efforts invested in teaching motor skills to children with CP with only limited results (Liptak & Accardo, 2004), it has been suggested that the implicit system might offer a better avenue for improvement (Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010). This necessitates investigation of the implicit system in children with CP.

Implicit forms of motor learning in this population have seldom been studied. In a series of experiments, Gagliardi, Tavano, Turconi, Pozzoli, and Borgatti (2011) and Gagliardi, Tavano, Turconi, and Borgatti (2013) examined SL in children with CP using the Corsi block test. Overall, compared to TD children, children with CP were less accurate and needed more attempts to learn. SL skills were unrelated to CP severity as defined by the Gross Motor Function Classification System (GMFCS) level (Palisano et al., 1997). In the follow up study, Gagliardi et al. (2013) found that SL skills are independent of age in TD and CP children. While these studies demonstrated how children with CP learn visuo-spatial sequences, their conclusions about SL abilities of children with CP should be considered with caution since they did not address the implicit learning component underlying their performance. This differentiation is crucial for understanding the cognitive processes of motor SL and can be achieved by using a more sensitive task, such as the SRT.

General intellectual abilities, measured as IQ, correlate with performance on explicit learning tasks but not with performance on implicit SL task when examined among TD children (Kaufman et al., 2010). Only a few studies addressed this relationship among children with developmental disabilities. For example, when assessing the relationship between non-verbal intelligence and performance on the SRT task in children with Down and Williams syndromes, Vicari et al. (2007) found IQ was independent of performance on the SRT task.

Given the importance of motor SL for children, the extensive clinical investment in this area for children and adolescents with CP yielding only moderate results, and the lack of knowledge about the performance of the implicit system in this population, our goal was to examine the explicit and the implicit components of motor SL among children and adolescents with CP compared to their TD peers, using the SRT task. In addition, we evaluated whether performance in the SRT task was related to individual differences such as age, cognitive ability and level of motor impairment.

2. Methods

2.1. Participants

Twenty-two children and adolescents (9 boys) diagnosed with spastic CP, aged 9–20 years (M = 13 y 2 mo, SD = 3 y 7 mo) and 23 TD controls (11 boys) aged 9–18 years (M = 13 y 1 mo, SD = 3 y 6 mo) volunteered to participate in the study. The participants were recruited from several mainstream schools, through special education schools and from the Department of Pediatric Rehabilitation in central Israel. All participants were tested in a quiet room either at their school or at the rehabilitation unit.

Inclusion criteria were a minimum age of 9 years, sufficient motor skills to press computer keys (the ability to tap on two adjacent keys on the computer keyboard), no major visual impairments that might interfere with performance on a computer task and comprehension of study instructions. Each participant's level of motor impairment was evaluated by