



# Intact procedural motor sequence learning in developmental coordination disorder



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## ABSTRACT

The purpose of the present study was to explore the possibility of a procedural learning deficit among children with developmental coordination disorder (DCD). We tested 34 children aged 6–12 years with and without DCD using the serial reaction time task, in which the standard keyboard was replaced by a touch screen in order to minimize the impact of perceptuomotor coordination difficulties that characterize this disorder. The results showed that children with DCD succeed as well as control children at the procedural sequence learning task. These findings challenge the hypothesis that a procedural learning impairment underlies the difficulties of DCD children in acquiring and automatizing daily activities. We suggest that the previously reported impairment of children with DCD on the serial reaction time task is not due to a sequence learning deficit per se, but rather due to methodological factors such as the response mode used in these studies.

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## 1. Introduction

Developmental coordination disorder (DCD) is a developmental disorder mainly characterized by marked impairments in motor skills, in the absence of neurological or intellectual dysfunction (APA, 2000). Children with the disorder typically have problems acquiring and performing daily activities that require motor coordination, such as handwriting, drawing, eating with cutlery, dressing, tying shoelaces, and sports (throwing a ball, riding a bike, jumping, etc.) (Zwicker, Missiuna, Harris, & Boyd, 2012). These motor difficulties may lead to a high level of dependence on adults and cause the children affective and social discomfort. The mechanisms underlying this disorder, which can have a severe impact on children's daily lives, are still unknown.

One of the hypotheses relevant to DCD that has received some consideration is the idea of a dysfunction in the brain circuits (such as cortico-striatal and cortico-cerebellar circuits) that sustain procedural learning, i.e., the learning and automation of motor skills. This hypothesis has been initially proposed by Nicolson and Fawcett (2007). More specifically, these authors suggested a common impairment procedural learning system in developmental disorders which could explain especially the frequent comorbidity between these disorders. While some studies have reported results which support the presence of a procedural learning deficit in children with dyslexia (Vicari et al., 2005), specific language impairment (Lum, Conti-Ramsden, Page, & Ullman, 2012), and attention deficit hyperactivity disorder (Barnes, Howard, Howard, Kenealy, &

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Vaidya, 2010), contrasting results have also been obtained, showing for instance that children with specific language impairment are able to learn a new procedural skill as quickly and accurately as children without any developmental disorder (e.g., Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011).

In DCD, the hypothesis of a procedural learning deficit seems particularly relevant; indeed, several authors have highlighted problems with motor skill acquisition in DCD (e.g., Goodgold-Edwards & Cermak, 1990). Clinically, DCD children have been observed to experience difficulties automatizing their gestures: for instance, in contrast with peers, movements to tie shoes continue to require particular attention, even after a great deal of practice. In support of this procedural learning deficit hypothesis, some studies have showed that dysfunction of cerebellum and basal ganglia might be involved in the pathogenesis of DCD (Brookes, Nicolson, & Fawcett, 2007; Cherng, Liang, Chen, & Chen, 2009; Marien, Wackener, De Surgeloose, De Deyn, & Verhoeven, 2010; Piek & Dyck, 2004; Zwicker, Missiuna, Harris, & Boyd, 2011). For instance, Zwicker et al. (2011) explored brain activity during motor procedural learning (trail-tracing task using a joystick) in 7 children with DCD and 7 matched controls. DCD children showed significantly less activation than their peers in the cerebellar-parietal and cerebellar-prefrontal circuits. Interestingly, after three days of practice on this trail-tracing task, in children with DCD, contrary to control children, there was no improvement in tracing accuracy. Several behavioral studies have also demonstrated cerebellar dysfunction among children with DCD (Geuze, 2005). For instance, difficulties in motor adaptation learning have been demonstrated in DCD (e.g., Kagerer, Contreras-Vidal, Bo, & Clark, 2006).

Procedural learning is usually defined as a process in which new visuomotor, perceptual, or cognitive skills are acquired through repetitive training (Cohen & Squire, 1980; Willingham, 1998). An experimental paradigm frequently used to explore procedural learning is the serial reaction time paradigm (SRT; Nissen & Bullemer, 1987). In this task, subjects are asked to respond as quickly and accurately as possible to stimuli appearing at different locations on a computer screen by pressing corresponding keys on the keyboard; participants are not told that the stream of stimuli corresponds to a repeating sequence. Learning is demonstrated by improvement in the speed of response across trials and, more specifically, by the difference in response latency between a random block of stimuli and the repeating sequence block, indicating clearly that skill learning was sequence-specific. Neuroimaging studies have demonstrated that procedural sequence learning is supported by the basal ganglia and the cerebellum (e.g., Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994), and the SRT paradigm has been widely used to explore memory abilities in various neurological pathologies characterized by impairments in these regions, such as Parkinson's disease (e.g., Helmuth, Mayr, & Daum, 2000). In children, the SRT task has also been used to explore procedural learning in developmental disorders (e.g., Lum et al., 2012; Vicari et al., 2005).

To our knowledge, only two studies have investigated the motor difficulties of children with DCD with the SRT paradigm. First, Wilson, Maruff, and Lum (2003) explored motor sequence learning with a 10-element long sequence SRT task and noted normal results in 10 children with DCD. Unfortunately, the interpretation of this finding is problematic due to some methodological flaws, such as the absence of structural equivalence between random and repeated sequence blocks. Recently, Gheysen, Van Waelvelde, and Fias (2011) used the sequence of Wilson et al. to explore SRT performance in a larger sample of children (18 DCD and 20 control children). These authors matched the random block to the sequence block (i.e., the four locations appeared with the same frequency in the random and sequence blocks) and added another sequence block (administered after the random block) in order to control for the effects of fatigue. In this way, they assured that the increase in reaction times observed for the random block was due to the impossibility of using sequence-specific knowledge with these randomly presented items. Interestingly, in this study, implicit sequence learning seemed to be impaired in children with DCD. However, one question remains unanswered: did these results reflect a deficit in procedural learning as such, or rather a motor deficit? Subjects had to use a response box to press the key corresponding to the target: the possibility remains that the DCD children's impaired performance on the SRT task could have been caused by the perceptuomotor difficulties that characterize DCD. As described by Gabriel, Stefaniak, Maillart, Schmitz, and Meulemans (2012), performance on an SRT task can be affected by deficits in manual dexterity and/or by difficulties matching the location of the target on the screen to the corresponding key. These cognitive and perceptuomotor constraints may affect specific-sequence learning. Indeed, considering the deficits in eye-hand coordination and in sensorimotor and visuospatial processing (Savelsbergh, Whiting, Pijpers, & van Santvoord, 1993; Wilson & McKenzie, 1998), but also in working memory (Alloway, Rajendran, & Archibald, 2009) present in DCD, it might be hypothesized that using a keyboard or a response box is too complex for DCD children.

In this context, the aim of our study was to explore motor sequence learning in children with DCD in an adaptation of the SRT task that reduces (or even eliminates) the cognitive and perceptuomotor constraints associated with the classical SRT task. For this purpose, we used a modified version of the SRT task devised by Gabriel et al. (2012), in which the standard keyboard is replaced by a touch screen. With the touch screen, the motor and cognitive constraints of the task are minimized, because subjects can simply use their dominant hand to touch the target directly on the screen. In addition, a quadrant presentation was employed; with this arrangement the locations can be better separated into large spatial domains (Thomas & Nelson, 2001). On the basis of the procedural deficit hypothesis, we predicted that even with the touch screen as response mode, children with DCD should present difficulties in sequence-specific learning relative to normal controls. Conversely, the observation that the performance levels of children with DCD on the touch screen-based SRT task are similar to those of control children would challenge the procedural deficit hypothesis on the difficulties of DCD children in learning new motor skills.

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