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Procedural learning and automatization process in children with developmental coordination disorder and/or developmental dyslexia

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ABSTRACT

Objective: There is increasing evidence to suggest that developmental dyslexia (DD) and developmental coordination disorder (DCD) actually form part of a broader disorder. Their frequent association could be justified by a deficit of the procedural memory system, that subtends many of the cognitive, motor and linguistic abilities that are impaired in both DD and DCD. However, studies of procedural learning in these two disorders have yielded divergent results, and in any case no studies have so far addressed the issue of automatization (dual-task paradigm).
Methods: We administered a finger tapping task to participants aged 8–12 years (19 DCD, 18 DD, and 22 with both DD and DCD) to explore procedural learning and automatic movements in these three groups of children, comparing motor performances at the prelearning stage, after 2 weeks of training, and in a post-training dual-task condition.
Results: First, results indicated that all the children were able to learn a sequence of movements and even automatize their movements. Second, they revealed between-groups differences in procedural/automatization learning abilities, setting the DCD group apart from the other two. Third, contrary to our expectations concerning comorbidity, they suggested that the DD + DCD association does not have an additional impact on behavioral performances.

1. Introduction

Neurodevelopmental disorders such as developmental dyslexia (DD), developmental coordination disorder (DCD), specific language impairment (SLI), and attention deficit hyperactivity disorder (ADHD) frequently co-occur, even if precise percentages may vary (Kaplan, Crawford, Cantell, Kooistra, & Dewey, 2006). Some of these comorbid associations have attracted considerable attention, as they raise the question of shared aetiological bases. These include the DD and SLI association, as regards the phonological deficit hypothesis (Catts, Adlof, Hogan, & Weismer, 2005; Ramus, Marshall, Rosen, & van der Lely,

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2013), and DCD and DD co-occurrence, given the cerebellum/procedural deficit hypothesis (Nicolson & Fawcett, 1990, 2007, 2011). It is the latter that we explored in the present study.

1.1. DD, DCD and the overlap between the two

DD is a persistent disorder that affects a sizeable proportion (5–10%) of the school-age population (Peterson & Pennington, 2012). Children with DD (or specific reading disability) have reading deficits despite adequate intelligence, normal sensory abilities, conventional instruction, sociocultural opportunity and school education (World Health Organization, 1993). DD is widely acknowledged to be a language-based disorder characterized by difficulties in phonological processing (Ramus & Szenkovits, 2008). Substantial evidence has also established the neurobiological origin of DD (Peterson & Pennington, 2012).

DCD, or specific developmental disorder of motor function, is a persistent disorder affecting 2–7% of school-age children (Lingam, Hunt, Golding, Jongmans, & Emond, 2009) in whom the acquisition and execution of coordinated motor skills is below that expected for a given age and opportunity for skill learning, in the absence of intellectual disability (APA, 2013; Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). Children with DCD have both gross and fine motor skill difficulties that include difficulty with postural control, motor learning and sensorimotor coordination. These interfere considerably with activities of daily life (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013).

The aetiology of DD and DCD has yet to be elucidated, probably because both disorders have multifactorial origins. That said, motor impairments in DD were observed long ago (Denckla, 1985; Haslum, 1989), and there is a substantial overlap between the two disorders, with over half of all children with DD having DCD and vice versa (Chaix et al., 2007; Haslum & Miles, 2007). This, of course, raises the question of shared aetiological bases.

1.2. Cerebellum/procedural deficit hypothesis

Supported by the fact that the cerebellum is centrally involved in language, reading-related activities and motor skills, the cerebellum deficit hypothesis (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001) provides a plausible explanation for the co-occurrence of DD and DCD, or in any case of DD and motor impairments. This theoretical framework, initially centered around DD, has been continually revised, expanded and improved over the past 20 years, recently gravitating toward a neural system typography for learning difficulties (Nicolson & Fawcett, 2007, 2011). In this typology, the authors contrast general learning disabilities secondary to an impairment of the declarative learning system (i.e., intellectual developmental disorder) and developmental disorders secondary to an impairment of the procedural learning system (i.e., ADHD, SLI, DD, DCD). Their hypothesis is based on the fact that some children with learning disorders have particular difficulty acquiring skills related to procedural learning or automaticity, including impairments of motor or language functions, working memory, executive functions (attention, planning), visuospatial regulation, oculomotor and visuoperceptual functions. For the authors, this tangle of different procedural learning impairments in specific developmental disorders is crucial for understanding learning disabilities. Brain imaging studies have shown that the automaticity and procedural learning system depends largely on corticostriatal and/or corticocerebellar circuits (Doyon et al., 2009). Authors therefore suggest that impairments in these circuits explain deficits mainly associated with learning disorders, procedural impairment in these disorders and the overlap between them. According to this view, children with learning disorders fail to automate new cognitive and/or motor procedures. In the special case of DD and/or DCD, procedural impairment may therefore explain difficulties in both language and motor skills – a view supported by experimental data and neuroimaging studies revealing cerebellar and/or striatal abnormalities in both disorders (Bo & Lee, 2013; Brookes, Nicolson, & Fawcett, 2007; Stoodley & Stein, 2011, 2013).

1.3. Acquisition of procedural motor skills

Procedural learning is usually defined as a process in which new skills (motor, perceptual, or cognitive) are acquired through repetitive training. This acquisition, especially of a new motor skill, can be divided into three distinct stages originally described by Fitts (1964), and since renamed and modeled by Doyon et al. (2009). In the first, early fast learning stage, in which the individual is first exposed to a task that involves training and repeated engagement with the procedure being learned (Rattoni, Escobar, Pawlik, & Rosenzweig, 2000). Performance greatly and rapidly improves in the course of a single training session, with an improvement being observed within a matter of minutes or even seconds (online learning). This improvement follows a power function curve, and performance gradually reaches asymptote, reflecting saturated learning (Hauptmann, Reinhart, Brandt, & Karni, 2005). In the second, slow learning phase (consolidation), incremental gains in performance can be observed over several sessions of practice, and may be seen within days if not hours, sometimes even without further practice (phenomenon referred to as *offline learning*; Hauptmann et al., 2005). These memory traces become increasingly robust and resistant to disruption (Walker, 2005). Following successful completion of the acquisition and consolidation stages, a third, autonomous stage (automatization) is believed to occur without intent or awareness (Stickgold & Walker, 2005). This automatic stage allows for the transition from controlled to more efficient performance: the skill becomes fluent and even more resistant to interference, allowing it to be performed in a range of contexts with limited demands on attentional resources (Seger & Spiering, 2011; Stefanidis, Scerbo, Korndorffer, & Scott, 2007). Automaticity, which probably relies on sleep (Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005), refers in this context to a shift in the brain