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Review article

Motor skill learning in children with Developmental Coordination Disorder

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ABSTRACT

Children with Developmental Coordination Disorder (DCD) are characterized as having motor difficulties and learning impairment that may last well into adolescence and adulthood. Although behavioral deficits have been identified in many domains such as visuo-spatial processing, kinesthetic perception, and cross-modal sensory integration, recent studies suggested that the functional impairment of certain brain areas, such as cerebellum and basal ganglia, are the underlying causes of DCD. This review focuses on the "motor learning deficits" in DCD and their possible neural correlates. It presents recent evidence from both behavioral and neuroimaging studies and discusses dominant neural hypotheses in DCD. Given the heterogeneity of this disorder, a successful intervention program should target the specific deficits on an individual basis. Future neuroimaging studies are critical steps in enhancing our understanding of learning deficits in DCD.

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1. Introduction

Children with Developmental Coordination Disorder (DCD), sometimes known as "clumsy children," demonstrate motor difficulties (Bo, Bastian, Kagerer, Contreras-Vidal, & Clark, 2008; Henderson, Barnett, & Henderson, 1994) and learning impairment (Alloway & Archibald, 2008; Dewey, Kaplan, Crawford, & Wilson, 2002; Kagerer, Bo, Contreras-Vidal, & Clark, 2004) that interfere with academic achievement (Henderson & Sugden, 1992; Tucha & Lange, 2004) and activities of daily living (e.g., dressing, playground skills and handwriting; Kennedy et al., 2007). If without appropriate intervention during childhood, these deficiencies may last well into adolescence (Cousins & Smyth, 2003) and adulthood (Kirby & Sugden, 2010). Up to 6% of American school children are thought to be affected by DCD (American Psychiatric Association (APA), 2000) and as high as 87% of these children will not "grow out" of their difficulties (Cousins & Smyth, 2003).

Although a number of terms have been used to describe children with motor difficulties in the literature (see review in Henderson & Henderson, 2003), we use the term Developmental Coordination Disorder (DCD) in this review in accordance with the Diagnostic and Statistical Manual of Mental Disorders IV-TR ([DSM IV-TR]; APA, 2000) to avoid confusion among terms and potential bias on causality. Based on DSM IV-TR, criteria for the diagnosis of DCD include (1) performance in daily activities that require motor coordination that is substantially below that expected given the person's chronological age and daily living; (2) the motor disturbance (significantly) interferes with academic achievement or activities of daily living; and (3) the motor disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet the criteria for a Pervasive Developmental Disorder (APA, 2000).

In this review, we focus on the "motor learning" aspect of DCD due to its classification as a "learning disorder," although behavioral deficits have been identified in many other domains such as visuo-spatial processing, kinesthetic perception, and cross-model sensory integration (see Wilson & McKenzie, 1998, for detailed review). It has been suggested that DCD may be related to central nervous system pathology (Ivry, 2003; Querne et al., 2008; Zwicker, Missiuna, Harris, & Boyd, 2011). Therefore, the purpose of this review is to present a synopsis of the current literature on the motor learning deficits in DCD and their possible neural correlates, discuss dominant hypotheses, and suggest a direction for future research.

2. Motor learning deficits in children with DCD

The ability to learn a variety of motor skills is critical for many daily activities throughout the lifetime (e.g., dressing oneself, writing letters, or communicating via computers). Here, the term "motor learning" refers to relatively permanent behavioral changes associated with practice or experience (Schmidt, Sherwood, & Walter, 1988). Wolpert, Diedrichsen, and Flanagan (2011) have recently provided an extensive review on the principles of motor learning as we adapt to changes in our environment, manipulate new objects, and refine existing motor skills. Although there are multiple ways to classify motor learning (e.g., error-based learning, reinforcement learning, and use-dependent learning in Wolpert et al. (2011)), the current review focuses on two broad experimental categories: sensorimotor adaptation and sequence learning (Doyon & Benali, 2005; Willingham, 1998). In sensorimotor adaptation paradigms, participants modify movements to adjust to changes in either sensory input or motor output characteristics. For sequence learning, individuals learn to combine isolated movements into one smooth, coherent action (Bo, Langan, & Seidler, 2008).

2.1. Sensorimotor adaptation

Sensorimotor adaptation tasks are used to gain insight into how humans represent their environment, the mechanics of the body, and interactions between the two during movement planning and production (Bo, Block, Clark, & Bastian, 2008). A useful experimental approach to understand adaptation is to investigate how motor performance changes through repetition or practice when the relationship between the hand movements and the sensory feedback of those movements is altered. In this case, participants have to adaptively adjust their movement to compensate for the changed environment.

In the literature, there are two broad types of sensorimotor adaptation. One is kinematic adaptation, where the sensory feedback of movements is distorted through the use of computer programs (e.g., Cunningham, 1989; Pine, Krakauer, Gordon, & Ghez, 1996) or the use of laterally displacing prisms (e.g., Held & Bossom, 1961; von Helmholtz, 1962). The other is dynamic (or kinetic) adaptation, where the anticipated proprioception is altered by having participants move their limb through an opposing force field (e.g., Izawa, Criscimagna-Hemminger, & Shadmehr, 2012; Shadmehr & Holcomb, 1997, 1999).

A real-world example of sensorimotor adaptation is driving a rental car that is a different model from one's own car. The magnitude of vehicle movement in response to the amount of wheel turn and accelerator depression varies across vehicles. Thus, the driver must learn the new mapping between his or her actions and the resulting vehicle movements. Experimentally, a sensorimotor adaptation task consists of three phases: (1) baseline with normal visual feedback of the hand movements (e.g., you drive your own car without making errors), (2) learning trials (i.e., distorted trials) where the visual feedback of the hand movement is changed (e.g., you drive a rental car for the first time and make mistakes since the scale of the wheel turn is not the same), and (3) post-learning trials where the visual feedback of the hand movement is changed back to normal. Successful learning can be measured by the presence of an after-effect during post-learning trials (e.g., making errors when you change back to your own car after driving a rental car for quite a long period of time).