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Mathematical difficulties in developmental coordination disorder: Symbolic and nonsymbolic number processing

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A B S T R A C T

At school, children with Developmental Coordination Disorder (DCD) struggle with mathematics. However, little attention has been paid to their numerical cognition abilities. The goal of this study was to better understand the cognitive basis for mathematical difficulties in children with DCD.

Twenty 7-to-10 years-old children with DCD were compared to twenty age—matched typically developing children using dot and digit comparison tasks to assess symbolic and nonsymbolic number processing and in a task of single digits additions.

Results showed that children with DCD had lower performance in nonsymbolic and symbolic number comparison tasks than typically developing children. They were also slower to solve simple addition problems. Moreover, correlational analyses showed that children with DCD who experienced greater impairments in the nonsymbolic task also performed more poorly in the symbolic tasks.

These findings suggest that DCD impairs both nonsymbolic and symbolic number processing. A systematic assessment of numerical cognition in children with DCD could provide a more comprehensive picture of their deficits and help in proposing specific remediation.

1. Introduction

Developmental Coordination Disorder (DCD) is defined as an impairment in motor coordination which interferes with academic achievement and daily life activities (DSM-IV-TR, American Psychiatric Association, 2000). DCD impairs gross and fine motor functions, as well as balance (Visser, 2003). For instance, children with DCD have difficulties with throwing and catching a ball, tying their shoelaces, or buttoning their clothes. Among neurodevelopmental disorders, DCD is one of the less studied (Bishop, 2010) despite its high prevalence (from 1.4 to 19.0% of children aged 5 to 11; Lingam, Hunt, Golding, Jongmans, & Emond, 2009; Tsiotra et al., 2006; Wright & Sugden, 1996) and its association with persistent academic difficulties. At school, handwriting difficulties are very common in these children (Bo et al., 2014; Chang & Yu, 2010; Prunty,

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Barnett, Wilmut, & Plumb, 2013; Prunty, Barnett, Wilmut, & Plumb, 2014; Rosenblum & Livneh-Zirinski, 2008; Rosenblum, Margieh, & Engel-Yeger, 2013). Importantly, they also experience particular difficulties with mathematics learning.

A recent study (Vaivre-Douret et al., 2011) reported that, among 43 children with DCD, 88% showed academic underachievement in mathematics. Yet, and surprisingly, the learning difficulties in mathematics experienced by children with DCD have received very little attention in the literature. Pieters, Desoete, Van Waelvelde, Vanderswalmen, and Roeyers (2012) suggested that number fact retrieval and procedural calculation were impaired in children with DCD but their study was inconclusive regarding the mechanisms underlying these impairments. Other studies investigated how working memory affects mathematical performances in children with DCD (Alloway, 2007; Alloway & Archibald, 2008). Alloway (2007) showed that children with DCD with low visuospatial memory skills performed significantly worse on numerical operations (addition, subtraction, division, multiplication, fractions, and algebra) and in mathematical reasoning (from Wechsler Objective Numerical Dimensions) subtests than those with high visuospatial memory skills. They suggested that visuospatial working memory plays a critical role in the learning difficulties experienced by children with DCD. However, an intervention that improved visuospatial working memory of children with DCD, identified as having learning difficulties, failed to enhance their math scores (Alloway & Warner, 2008). Overall, these studies showed that difficulties in mathematics do exist in children with DCD but they do not provide sufficient functional insights about the basic numerical skills of these children. However, studying these basic numerical skills is as essential as identifying low level deficits for reading difficulties. Indeed, identifying low level deficits in numerical cognition is critical to help children with DCD and like Ansari and Karmiloff-Smith (2002), we think that there is "an urgent need to explore low-level, number-relevant causes" of mathematical difficulties in developmental disorders. Only a methodical psychophysical approach that taps into elementary numerical processes can achieve this goal. In the present study, we will examine the foundational, numerical representations, as they have been defined in the field of numerical cognition, in children with DCD compared with typically developing children. Indeed, subtle impairments in a foundational system should affect higher-level numerical competencies like addition.

The study of numerical cognition has considerably progressed during the past years. A prevalent theory has posited that numerical cognition is based on two systems of representation: an analogue-like, approximate, language-independent system, called the approximate number system (ANS), and an exact, symbolic, language and education-dependent system (e.g. Feigenson, Dehaene, & Spelke, 2004). For the numerical quantity 5, for example, the former would convey the approximate cardinal of a set of 5 objects or a sequence of five tones whereas the latter would convey the specific meaning attached to the symbol 5, or the spoken and written word "five". Both systems could play a foundational role in mathematics learning.

The ANS codes in an abstract and approximate way a broad range of numerosity starting from the first year of life (for reviews see Dehaene, Molko, Cohen, & Wilson, 2004; Dehaene, 1997; Feigenson et al., 2004; Piazza & Izard, 2009). The ANS supports an intuitive perception of numerical quantities that does not depend on language and which is shared by animals and preverbal infants alike (Dehaene, 1997; Nieder & Dehaene, 2009). In typical development, the ANS acuity follows a trajectory with a sharp increase during the first year of life and continues to increase at a slower rate until it reaches adult-like levels during the preteen years (Dehaene, Dehaene-Lambertz, & Cohen, 1998; Halberda & Feigenson, 2008; Izard, Sann, Spelke, & Streri, 2009; Piazza, Pica, Izard, Spelke, & Dehaene, 2013; Spelke, 2000; Xu & Arriaga, 2007; Xu, Spelke, & Goddard, 2005). The ANS obeys Weber's law stating that the ability to discriminate between two numerosities depends on their ratio (Dehaene, 2003). Therefore, the acuity of the ANS can be measured by the minimal percent change in numerosity that enables a fixed level of discrimination performance, referred to as the Weber fraction (w). Lower values of w correspond to greater ANS acuity.

Recently, the relationship between nonsymbolic abilities and formal mathematics was empirically tested. For instance, when 14-years old teenagers had to indicate which of the blue or yellow array of dots contained the largest number of dots, the observed Weber fraction was related to their past academic math scores (Halberda, Mazzocco, & Feigenson, 2008). Similarly, the ANS acuity of college students correlated with their scores in mathematics on a standardized college-entrance exam (Libertus, Odic, & Halberda, 2012). In kindergarten children, performance in nonsymbolic additions was shown to predict mathematics achievement at the end of the school year (Gilmore, McCarthy, & Spelke, 2010). In the same way, performance on mathematics at 6 years of age correlated with ANS acuity measured at preschool (Mazzocco, Feigenson, & Halberda, 2011b) and mathematical abilities at 3.5 years of age were related to ANS acuity at 6 months of age (Starr, Libertus, & Brannon, 2013). Moreover, training on approximate nonsymbolic additions and subtractions improves adults' performance on symbolic additions and subtractions (Park & Brannon, 2013). Overall, these results suggest that math proficiency is related to ANS acuity. Therefore, difficulties in mathematics at school experienced by children with DCD could be related to a lower ANS precision as has been reported in dyscalculia (Mazzocco, Feigenson, & Halberda, 2011a; Mussolin, Mejias, & Noël, 2010; Piazza et al., 2010; Price, Holloway, Räsänen, Vesterinen, & Ansari, 2007).

In contrast, some studies failed to find a link between math skills obtained at school and ANS acuity; rather, studies showed that it was the scores on symbolic number tasks which best predicted children' mathematics achievement (Holloway & Ansari, 2009; Rousselle & Noël, 2007; Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013). Holloway and Ansari (2009) used both symbolic (Arabic digits) and nonsymbolic (arrays of squares) numerical comparisons associated with standardized mathematics achievement measures in typically developing children of 6 to 8 years old. Their results showed a link between performance when comparing symbolic numbers (but not nonsymbolic) and fluency to solve single-digit operations. The performance of children with mathematics learning difficulties was shown to be impaired when they