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From numeracy to arithmetic: Precursors of arithmetic performance in children with cerebral palsy from 6 till 8 years of age

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ABSTRACT

Children with cerebral palsy (CP) are generally delayed in arithmetic compared to their peers. The development of early numeracy performance in children with CP is not yet evident, nor have the factors associated with change over time been identified. Therefore, we examined the development of numeracy in children with CP over a two year period and studied which cognitive factors were predictive of arithmetic performance. A longitudinal study with three measurement waves separated by one year was conducted. 56 children participated (37 boys, $M = 6.0$ years, $SD = .58$). Standardized tasks were used to assess verbal- and visual–spatial working memory, executive functioning, fine motor skills and early numeracy performance. In addition, experimental tasks were developed to measure counting and arithmetic. The results showed that early numeracy performance of children with CP increased between 6 and 8 years of age. Structural equation modelling showed that early numeracy was strongly related to arithmetic performance at the consecutive year. Working memory, counting and fine motor skills were all positively related to early numeracy performance a year later. Furthermore, working memory and fine motor skills were precursors of the development of early numeracy. Considering the importance of numeracy and arithmetic in daily life and in academic and work success, children with CP could substantially benefit from intervention programs aimed at increasing working memory and early numeracy performance.

1. Introduction

Participation in age-appropriate activities contributes to a healthy social, emotional, and physical development for all children. Especially for children with disabilities, participation has been described as a core developmental feature (WHO, 2007). Children with neurodevelopmental disabilities are as a group at risk to develop participation difficulties (Mâsse, Miller, Shen, Schiariti, & Roxborough, 2013). Cerebral palsy (CP) is the most frequent cause for physical difficulties among children (Cans, 2000). The main characteristic of the diagnosis of CP is an atypical development of movement and posture that leads to activity limitations which is attributed to a non-progressive injury to the foetal or infant brain. Commonly, the

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motor difficulties are accompanied by additional disturbances of perception, sensation, communication, behaviour and cognition (Rosenbaum et al., 2007). Liptak and Accardo (2004) reported that it is estimated that 75% of the children with CP are slow learners or have disorders of higher cortical functioning. Among children with CP who follow mainstream education, around half of the children (46%) were found to have a specific learning difficulty (Schenker, Coster, & Parush, 2005). Previous research showed that this group of children are more likely to encounter difficulties in learning mathematics compared to reading (Frampton, Yude, & Goodman, 1998).

Arithmetic performance is assumed to develop in a hierarchical manner. Although there is still an ongoing debate on the role of the approximate number system in developing adequate numerical representations (Butterworth, 2010), the more fundamental idea of basic skills, such as counting and comparing quantities, that influence the later development of more complex abilities, such as multiplication and divisions, still holds (Butterworth, 2005). Hence, the capability to comprehend and process numerical magnitudes is suggested to play a fundamental role in the development of arithmetic (e.g. Brankaer, Ghesquière, & De Smedt, 2013; Butterworth, 2011). For instance, using a longitudinal design the early numeracy skills, especially counting, have been found to function well as a discriminator for later mathematics attainment (Aubrey & Godfrey, 2003). In addition, numeracy skills in kindergarten were more predictive of arithmetic performance in first grade than demographic characteristics (Aunio & Niemivirta, 2010).

At present, there is no consensus on the developmental trajectories of cognitive skills of children with CP. Previous studies have shown that intelligence scores of this group of children decline during primary school (e.g. Gonzalez-Monge et al., 2009; Levine, Kraus, Alexander, Suriyakham, & Huttenlocher, 2005). However, others have reported opposite results in showing an improvement in non-verbal intelligence performance of children with CP over a two year period. Smits et al. (2011) found that the raw scores of two age cohorts (i.e. 5–7 and 7–9 years of age) on the Raven non coloured progressive matrices increased. However, there was no statistical significant change in quotient scores. Regarding arithmetic performance, Jenks, de Moor, and van Lieshout (2009), using a longitudinal design, showed that the ability of a group of children with CP to solve simple addition and subtraction tasks ameliorated between 1st and 3rd grade. However, the developmental trajectory of early numeracy performance of children with CP has not been studied yet. Due to the eminent role of early numeracy knowledge for arithmetic performance, we will examine the development of early numeracy performance of children with CP from 6 till 8 years of age.

Solving an addition and subtraction task often relies on keeping in mind, that is, in working memory the results of operations that have already been performed and need to be used in subsequent calculations. Working memory capacities were repeatedly shown to influence the arithmetic performance of primary school children (see Raghubar, Barnes, & Hecht, 2010 for a review). Moreover, visual short term and working memory measured at kindergarten were predictive of mathematical achievement at 7 years of age (Bull, Espy, & Wiebe, 2008). Recent brain imaging data has also shown an association between working memory and numerical processing (Gullick, Sprute, & Temple, 2011).

For children with CP, working memory appears to play a similar fundamental role in mathematical performance (e.g. Jenks et al., 2009). Administering a broad range of working memory tasks, it was found that especially updating was strongly related to a standardized mathematical achievement test for children with CP in primary education (Jenks, van Lieshout, & de Moor, 2012). In a previous cross-sectional study, we found that working memory as a construct consisting of verbal, visual–spatial and updating task was by far the strongest associated with early numeracy performance of children with CP compared to other cognitive factors such as non-verbal intelligence and language (Van Rooijen, Verhoeven & Steenbergen, 2015).

Recent studies found that not only domain-general capabilities, like working memory, but also domain-specific abilities, such as counting, can be considered important for arithmetic achievement of typically developing children at primary school. For instance, working memory and counting ability assessed at kindergarten are the most discriminating factors for mathematical achievement in the first years of primary school (Passolunghi & Lanfranchi, 2012). Moreover, number knowledge assessed at kindergarten predicted functional numeracy outcomes in adolescence (Geary, Hoard, Nugent, & Bailey, 2013). In other words, children need well developed early numeracy skills to become successful in mathematics (Gersten & Chard, 1999).

According to the approximate enumeration hypothesis, infants from 6 months of age are already capable of distinguishing different amount of dots (Xu & Spelke, 2000). Around 4 years of age children are able to judge the number of a small amount of dots (i.e. 1–5) that are presented too short to make counting feasible, also labelled subitizing (Schleifer & Landerl, 2011). Le Corre, Van de Walle, Brannon, and Carey (2006) showed that performance on subitizing and counting tasks of typically developing children is closely related. Only 15% of the 4 till 6 year-old children with CP have been found to be efficient in subitizing, which might be due to difficulties with visual–spatial processing (Arp & Fagard, 2005). Therefore, we constructed a dot counting task that all children would be able to perform to study whether specific numerical skills are predictive of early numeracy and arithmetic performance of children with CP.

Children in almost all cultures use their fingers when first learning to count (Butterworth, 2005). Domahs, Moeller, Huber, Willmes, and Nuerk (2010) found that finger counting habits influence the structure of number representations of adults, which supports the idea that cognitive ideas might be partially based on bodily experiences and which exemplifies a form of embodied cognition. Next to behavioural data, neuroimaging studies also indicate that a common area in the parietal cortex is activated by finger representation and mental arithmetic (Andres, Michaux, & Pesenti, 2012). Moreover, gesturing has been indicated as an example of an additive tool for learning novel arithmetic tasks (Goldin-Meadow, Cook, & Mitchell, 2009). Nine-year-old children who were shown the correct gestures to solve an addition task they were unfamiliar with