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Numerical estimation in individuals with Down syndrome

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ABSTRACT

We investigated numerical estimation in children with Down syndrome (DS) in order to assess whether their pattern of performance is tied to experience (age), overall cognitive level, or specifically impaired. Siegler and Opfer's (2003) number to position task, which requires translating a number into a spatial position on a number line, was administered to a group of 21 children with DS and to two control groups of typically developing children (TD), matched for mental and chronological age. Results suggest that numerical estimation and the developmental transition between logarithm and linear patterns of estimates in children with DS is more similar to that of children with the same mental age than to children with the same chronological age. Moreover linearity was related to the cognitive level in DS while in TD children it was related to the experience level.

1. Introduction

Down syndrome (DS) is caused by abnormalities of chromosome 21, and affects about 1 in 1000 live births (McGrowther & Marshall, 1990). The great majority of individuals with DS have mild to severe levels of intellectual impairment and a wide range of associated physical, medical, and cognitive deficits (e.g., Silverman, 2007). Previous research has shown specific deficits in language, while visuo-spatial abilities are relatively preserved (e.g., Dykens, Hodapp, & Finucane, 2000, for a review). Deficits in working memory (Lanfranchi, Baddeley, Gathercole, & Vianello, 2012) and executive functions (Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010) have also been detected. Importantly, several studies have also reported that individuals with DS have difficulties in mathematics (e.g., Gelman & Cohen, 1988; Nye, Fluck, & Buckley, 2001; Porter, 1999). The origin of these difficulties is a debated topic. Some researchers support the *developmental hypothesis* (Zigler, 1969), suggesting that the mathematical difficulties of individuals with DS stem from their low general cognitive level (e.g., Caycho, Gunn, & Siegal, 1991). Others support the *difference hypothesis* (e.g., Gelman & Cohen, 1988; Nye et al., 2001) by showing poorer performance of individuals with DS in comparison to typically developing (TD) children of same mental age (MA). Gelman and Cohen (1988), for example, found that children with DS had lower performance compared to preschoolers matched for MA in both counting and cardinality tests. Similarly, Porter (1999) found that children with DS were unable to detect errors violating counting principles. Nye et al. (2001) reported that children with DS produced fewer words and shorter counting sequences, as well as counted smaller arrays of objects, than typically developing children

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matched for MA. Finally, numerosity discrimination is less efficient in individuals with DS than in MA controls for small numerosities (i.e., within the subitizing range; Paterson, Girelli, Butterworth, & Karmiloff-Smith, 2006; Sella, Lanfranchi, & Zorzi, 2013) but not for larger numerosities (Camos, 2009; Paterson et al., 2006; Sella, Lanfranchi, et al., 2013).

Numerical estimation is a central part of mathematical understanding, requiring integration of conceptual and procedural knowledge of numbers (Siegler, Thompson, & Opfer, 2009). Indeed, numerical estimation is a process of translating between alternative quantitative representations, at least one of which is inexact and at least one of which is numerical (Siegler & Booth, 2005). Numerical estimation tasks have proved particularly useful for providing insights into children's numerical development and their understanding of numerical magnitudes (Siegler & Opfer, 2003; Siegler et al., 2009). A widely used numerical estimation task is Siegler and Opfer's (2003) number-to-position task, which requires translating a number into a spatial position on a "number line". In this task, children are shown a visual line flanked by a number at each end (e.g., 0 and 1000) and they have to indicate where a given number (e.g., 75) would fall on the line. This estimation task is particularly revealing about the mapping of numerical magnitude because it transparently reflects the ratio characteristics of the number system. In their seminal study, Siegler and Opfer found that the estimates of numerate adults are linearly related to numerical magnitude, whereas children show a developmental progression from a logarithmic to a linear pattern. That is, the pattern of estimates in younger children is characterized by overestimation of small numbers and underestimation of larger numbers, thereby showing a logarithmic mapping that is thought to reflect the preverbal system of approximate magnitude representation (the Approximate Number System; Feigenson, Dehaene, & Spelke, 2004; Piazza, 2010; Stoianov & Zorzi, 2012). With increasing age and education (in particular, familiarity with the tested numerical range), children shift from this compressed pattern to a formal and linear pattern that entails the accurate placement of numbers (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Booth & Siegler, 2006; Siegler & Booth, 2004; Siegler & Opfer, 2003).

Note that the nature of the compressed pattern of estimates is debated (e.g., Barth & Paladino, 2011; Karolis, Iuculano, & Butterworth, 2011) and for this reason we refer to the classic distinction between logarithmic and linear positioning without assuming that the selected model is a faithful index of the underlying representation (also see Berteletti, Lucangeli, & Zorzi, 2012). Nevertheless, it is widely accepted that the shift between these two patterns is an indication of an increased understanding of the numerical values and the principles that underline the numerical system.

Numerical estimation is important for a variety of educational outcomes. In particular, it is related to general measures of mathematical proficiency and to measures of specific numerical processes (Booth & Siegler, 2008; Laski & Siegler, 2007), as well as to memory for numbers (Thompson & Siegler, 2010). Moreover, early estimation skills predict later success in mathematics (Chard et al., 2005; Jordan, Kaplan, Nabors Olah, & Locuniak, 2006). Notably, children with mathematical learning disabilities often generate logarithmic patterns of estimates in the number-to-position task when same-age typically developing (TD) children have already shifted to a linear mapping (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Sella, Lucangeli, Zorzi, & Berteletti, 2013). Moreover, lower precision of estimation persists in children with mathematical learning disabilities even when they have achieved a linear mapping, and the discrepancy from TD peers seems to be related to differences in IQ and in working memory (Geary et al., 2008). In this sense the general level of cognitive functioning seems to influence the emergence of an adequate mapping of numerical magnitude.

In the present study we focused on numerical estimation in DS, which, to the best of our knowledge, has never been investigated in previous studies. In particular we assessed numerical estimation in individuals with DS against those of two groups of TD children, one matched for chronological age (TD-CA) and one matched for mental age (TD-MA). The key question is whether the pattern of estimates displayed by individuals with DS – and hence the type of mapping (logarithmic vs linear) deployed in the task – is tied to experience (indexed by chronological age and schooling), overall cognitive level (indexed by mental age) or shows specific deficit even with respect to mental age.

2. Materials and methods

2.1. Participants

Twenty-one pre-teen and teenagers with DS (9 males; M_{age} = 14 years, 2 months) took part in the study. Two control groups of TD individuals were recruited. One group (N = 21, 9 males; M_{age} = 5 years, 6 months) was matched for mental age (TD-MA) to the DS group and it served to provide an indication of typical performance at a given development level. The second group (N = 21, 9 males; M_{age} = 14 years, 2 months) was matched for chronological age (TD-CA) to the DS group and it served to take into account length of experience. None of the participants had associated physical deficits that could compromise the execution of the tasks. All children were Caucasian. Parental consent was obtained prior to testing. All participants were included in a broader study on numerical cognition in DS and a different portion of these data has been reported in Sella, Lanfranchi, et al., 2013. The study was conducted in accordance with the standard ethical guidelines as defined by the Declaration of Helsinki.

Matching for mental age was based on measures of verbal mental age (Peabody Picture Vocabulary Scale-Revised, PPVT-R; Dunn & Dunn, 1997). A TD child was included in the TD-MA control group when his/her raw scores on the PPVT-R fell within (in either direction) 4 standard score points of the corresponding DS child score. A TD child was included in the chronological age group when his/her chronological age was within (in either direction) 4 months of the corresponding DS children age. Moreover, in order to have also a measure of fluid intelligence, the Raven's Coloured Matrices (Raven, Raven, & Court, 1998)