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Numerical and area comparison abilities in Down syndrome

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ABSTRACT

Individuals with Down syndrome (DS) have great difficulty in learning mathematics. In recent years, research has focused on investigating whether precursors of later mathematical competence, such as estimating and comparing numerosities, are preserved in DS. Although studies have suggested a strong relationship between the ability to compare continuous quantities (e.g., area of an object) and that of comparing numerosities, it is still unknown whether this ability is preserved in DS. This study investigated the abilities of individuals with DS to compare area and number and contrasted them with those of two control groups of typically developing individuals. Participants were 16 individuals with DS, 16 typically developing individuals matched by mental age (MA group), and 16 typically developing individuals matched by chronological age (CA group). All participants performed two eye-tracking tasks: an Area Comparison Task (ACT) and a Number Comparison Task (NCT). Stimuli in the two tasks differed in the same ratio to enable comparison of individual performance across both tasks. The results showed that in general, the performance of the three groups was better in the ACT than in the NCT. Critically, performance of individuals with DS in both tasks was consistent with that of individuals with the same MA. The study shows that the abilities to compare area and numerosity are both preserved in DS, and that individuals with this syndrome, like typically developing individuals, show better performance in comparing area than number.

1. Introduction

Down syndrome is a genetic disorder caused by an extra copy of the chromosome 21, and it is the leading cause of intellectual disability (Lubec & Engidawork, 2002). Individuals with Down syndrome (DS) have difficulty with several mathematical abilities (for a review see Brigstocke, Hulme, & Nye, 2008), including greater difficulty in solving simple arithmetic problems (Paterson, Girelli, Butterworth, & Karmiloff-Smith, 2006) and in understanding the principles of counting (Gelman & Cohen, 1988) than typically developing children with the same mental age.

Recent studies have searched for the causes of these difficulties by investigating whether the two core systems of number, the Approximate Number System (ANS) and the Object Tracking System (OTS), are preserved in individuals with DS (Camos, 2009; Sella, Lanfranchi, & Zorzi, 2013). These two systems are thought to be the origin of our

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understanding of number and later mathematical abilities (Carey, 2009; Feigenson, Libertus, & Halberda, 2013). The ANS allows for the rough estimation and comparison of the number of objects in collections, and its precision is determined by the ratio between two quantities to be compared (Halberda, Mazzocco, & Feigenson, 2008). The OTS allows for exact judgments of small numerosities of up to four objects (Feigenson, Carey, & Hauser, 2002). Research has shown that individuals with DS have a preserved ANS but an impaired OTS. Sella et al. (2013), using a task in which children had to indicate whether a numerosity matched one previously shown, found that children with DS with a mean mental age of 4.92 years performed as well at matching numerosities larger than four as their typically developing peers of the same mental age. These results are consistent with a previous report showing that children with DS performed as well as children of the same mental or chronological age at comparing larger numerosities (8 vs. 16 and 8 vs. 12) (Camos, 2009). Infants with DS, however, have difficulty with comparing small numerosities (2 vs. 3) (Paterson et al., 2006). Finally, two other numerical abilities supported by the ANS are relatively preserved in individuals with DS: numerical estimation and approximate addition. Lanfranchi, Berteletti, Torrisi, Vianello, and Zorzi (2015) reported that numerical estimation of children with DS is comparable to that of typically developing children with similar mental age. Belacchi et al. (2014) found that individuals with DS performed as well in an approximate addition task as a group matched by fluid intelligence.

A strong relationship has been suggested between the abilities to discriminate number and quantities like area (Brannon, Lutz, & Cordes, 2006). In fact, current theories of magnitude processing have proposed that all kinds of magnitudes (e.g., number, time, and space) are computed by one general system (Lourenco & Longo, 2011; Walsh, 2003). Evidence to support this proposal comes from studies with typically developing infants, which have reported that six-month-olds have the same ability to discriminate numerosity and area up to a ratio of 1:2 (Brannon et al., 2006; Xu & Spelke, 2000). In Xu and Spelke (2000), infants were habituated to a numerosity (8 or 16 dots); however, stimuli varied in continuous features (e.g., total area, dot size). In Brannon et al. (2006), infants were habituated to one size of an Elmo face. Critically, although the complexity of the stimuli were different (e.g., in Xu and Spelke, stimuli changed not only in numerosity, but also in other continuous features), infants dishabituated to two-fold changes, that is, to a new numerosity that was either double or half, or to an Elmo face that was twice the size of the original. In childhood as well as in adulthood, better performance has been reported for area comparison than for number comparison tasks (Odic, Libertus, Feigenson, & Halberda, 2012). To the best of our knowledge, there has been no investigation of the ability of individuals with DS to compare quantities other than number. It thus remains unknown whether individuals with DS show a typical development of quantity discrimination.

Atypical development can provide crucial insights into the ability to discriminate different kinds of magnitudes (Allman, Pelphrey, & Meck, 2012). Various studies have shown how genetic disorders and their particular cognitive profiles lead to greater deficits for some magnitudes than for others. Rousselle, Dembour, and Noël (2013) reported that the ability of individuals with William syndrome (WS), a genetic disorder caused by a deletion on chromosome 7q11.23, to compare number, length, and duration was aligned with that of children of the same non-verbal mental age; their performance in comparing numerosity and length, but not duration, was significantly less than that of children of similar verbal ability. This pattern of performance was predicted based on the cognitive profile of WS, where language skills are relatively preserved but visuospatial abilities are impaired. The study (Rousselle et al., 2013) found that individuals matched by verbal mental age were older (7.5 years) than those matched by non-verbal age (6.08 years); that is, verbal abilities were more preserved than visuospatial ones.

Previous research has demonstrated that DS is characterized by relatively preserved visuospatial abilities but impaired language skills (Moldabsky, Lev, & Lerman-Sagie, 2001; but see Yang, Conners, & Merrill, 2014). One would expect that this relative visuospatial ability would predict relative ability in comparing both area and numerosity. As a consequence, if the ability of individuals with DS to compare both area and large numerosities are preserved, we should find a pattern similar to that reported in typically developing children, that is, better performance at comparing area than number (Odic et al., 2012). Current theories of number development have stressed the importance of continuous quantity discrimination in early number processing (Cantrell & Smith, 2013; Leibovich & Henik, 2013), and testing this prediction could provide important information about the ability of individuals with DS to improve their numerical processing.

The present study investigated whether the ability to compare area is preserved in DS, and contrasted it with the ability to compare numerosity. The comparison of area was chosen because of its close relationship to number discrimination (Cordes & Brannon, 2008). Two eye-tracking tasks were performed: an Area Comparison Task (ACT) and a Number Comparison Task (NCT). An eye-tracking paradigm was used that kept the tasks as simple as possible for individuals with DS.

Recent studies have shown the benefits of using eye-tracking measures to evaluate cognitive processes in individuals with developmental disabilities (Brady, Arderson, Hahn, Obermeier, & Kapa, 2014), and such fine-grained measures as the duration of visual attention might be a more sensitive measure of differences in performance than correct/incorrect responses. This study used two eye-tracking tasks, in which participants saw images displaying two objects differing in size (ACT) or two collections differing in numerosity (NCT). Participants were asked to look at the image with the larger object or the larger numerosity. The abilities of individuals with DS were compared with two different typically developing control groups: one of similar mental age and another of similar chronological age.