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Enumeration skills in Down syndrome

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ABSTRACT

Individuals with Down syndrome (DS) exhibit various math difficulties which can be ascribed both to global intelligence level and/or to their atypical cognitive profile. In this light, it is crucial to investigate whether DS display deficits in basic numerical skills. In the present study, individuals with DS and two groups of typically developing (TD) children matched for mental and chronological age completed two delayed match-to-sample tasks in order to evaluate the functioning of visual enumeration skills. Children with DS showed a specific deficit in the discrimination of small numerosities (within the subitizing range) with respect to both mental and chronological age matched TD children. In contrast, the discrimination of larger numerosities, though lower than that of chronological age matched controls, was comparable to that of mental age matched controls. Finally, counting was less fluent but the understanding of cardinality seemed to be preserved in DS. These results suggest a deficit of the object tracking system underlying the parallel individuation of small numerosities and a typical – but developmentally delayed – acuity of the approximate number system for discrimination of larger numerosities.

1. Introduction

Down syndrome (DS) is due to abnormalities on chromosome 21 and it is the most common cause of intellectual disability (Kittler, Krinsky-McHale, & Devenny, 2008). The cognitive profile of this syndrome is characterized by a relative weakness in verbal abilities, while visuo-spatial skills seem to be relatively preserved (Dykens, Hodapp, & Finucane, 2000).

It is well known that children and adults with Down syndrome (DS) exhibit several mathematical difficulties as compared to typically developing (TD) individuals (Brigstocke, Hulme, & Nye, 2008). Children with DS obtain lower scores in a wide range of tests assessing basic math knowledge, arithmetic abilities and counting skills (Buckley & Sacks, 1987; Carr, 1988; Gelman & Cohen, 1988; Porter, 1999). These mathematical deficits can be attributed to the general intelligence level or to the atypical cognitive profile of DS. In this light, it is crucial to determine whether math underachievement in DS can be related to the low level of cognitive functioning or to specific deficits in basic numerical skills. Such an investigation may provide new insights regarding the source of difference in math achievement between DS and TD individuals.

Two basic pre-verbal mechanisms have been highlighted as fundamental for numerical processing in human and non-human species: the Object Tracking System (OTS; Mandler & Shebo, 1982; Trick & Pylyshyn, 1994; Xu, Spelke, & Goddard, 2005) and the Approximate Number System (ANS; Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Piazza, 2010; Stoianov & Zorzi, 2012). The OTS is a domain-general system that encodes spatio-temporal characteristics of objects with a

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capacity limited to three-four items. Despite the fact that the OTS is primarily a non-numerical mechanism, it supports visual enumeration of small sets of objects. Indeed, observers can quickly, accurately and effortlessly perceive the numerosity of small sets, a phenomenon known as *subitizing* (from the Latin *subitus*, immediate; Kaufman, Lord, Reese, & Volkmann, 1949). Children with developmental dyscalculia have a reduced subitizing range and tend to adopt serial counting to determine the numerosity of small sets (Landerl, Bevan, & Butterworth, 2004; Moeller, Neuburger, Kaufmann, Landerl, & Nuerk, 2009; Schleifer & Landerl, 2011), a finding that suggests a crucial role of the OTS mechanism for numerical development (Carey, 2001; Le Corre & Carey, 2007).

When the numerosity exceeds the subitizing range (i.e., more than 4 elements) and serial counting is precluded, visual enumeration become imprecise, with a variability of response that obeys Weber's law (Dehaene, Izard, Spelke, & Pica, 2008; Stoianov & Zorzi, 2012). This pattern, which is regarded as the signature of the ANS, implies that the ability to discriminate two numerosities decreases as a function of their numerical ratio and it can be indexed by the Weber fraction, also known as *number acuity*. This ability is already active during the first year of life (e.g., six months-old infants can discriminate 8 vs 16 dots; Xu & Spelke, 2000) and it is progressively refined during childhood (Halberda & Feigenson, 2008; Halberda, Ly, Wilmer, Naiman, & Germine, 2012; Piazza et al., 2010). Crucially, number acuity has been found to correlate with mathematical achievement (Halberda, Mazzocco, & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2011; Lourenco, Bonny, Fernandez, & Rao, 2012; Mazzocco, Feigenson, & Halberda, 2011a) and it is severely reduced in children with developmental dyscalculia (Mazzocco, Feigenson, & Halberda, 2011b; Piazza et al., 2010).

The acquisition of a symbolic number system allows children to go beyond the pre-verbal number processing mechanisms. In particular, learning of the list of number words and the acquisition of a counting routine allows for accurate serial enumeration of potential infinite sets. Counting entails three basic principles (Gallistel & Gelman, 1992; Gelman & Gallistel, 1978): (i) a one-to-one correspondence between each object and the corresponding word in the counting list; (ii) a stable (and correct) order of the counting list; and (iii) identification of the last word in the counting list as the numerosity (cardinality) of the set. Proficient mastering of counting skills has an important influence on early math achievement (Jordan, Kaplan, Locuniak, & Ramineni, 2007; Passolunghi, Vercelloni, & Schadee, 2006).

The investigation of basic numerical skills in individuals with DS is relatively sparse, despite the fact that these abilities might be at the hearth of their math underachievement in comparison with typically developing children. The functioning of OTS and ANS was previously investigated by Paterson, Girelli, Butterworth, and Karmiloff-Smith (2006) in individuals with DS as compared to a group of individuals with William syndrome and to control groups matched for mental age and chronological age. Using a preferential looking paradigm, they found that children with DS (M_{age} = 30 months) did not discriminate between two and three objects, thereby suggesting a deficit in OTS. In contrast, performance of young adults with DS (M_{age} = 24 years-old) in a numerosity comparison task (using sets both within and beyond the subitizing range) was similar to that of control individuals. More recently, Camos (2009) reported that six year-old children with DS were able to discriminate between 16 and 8 dots but failed to discriminate between 12 and 8, thereby showing the classic ratio-dependent signature of ANS. Their performance was comparable to that of typically developing pupils (both MA and CA matched controls), but the limitation to two numerical ratios might have hidden potential differences in number acuity between children with DS and control groups. In summary, the ANS appears to be preserved in individuals with DS, whereas the OTS seems to be less efficient, at least in young children with DS.

A debated issue regarding counting skills in individuals with DS is whether they have a superficial or a deep understanding of counting (for a review, Abdelahmeed, 2007). On one hand, some studies suggest that individuals with DS use counting as a mere routine lacking the understanding of cardinality principle. Indeed, Gelman and Cohen (1988) maintained that children with DS learn to count by rote and often lack the knowledge of the cardinality principle. Porter (1999) also reported that children with DS can count by rote but are less efficient to detect counting errors performed by other individuals. On the other hand, different studies support the idea that individuals with DS properly understand the meaning of counting as well as the cardinality principle. For example, Caycho, Gunn, and Siegal (1991) found a similar understanding of counting principles in children with DS and control children matched for receptive vocabulary. Similarly, Bashash, Outhred, and Bochner (2003) found that children with DS were able to apply the three fundamental principles of counting in several counting contexts. Finally, Nye, Fluck, and Buckley (2001) reported a pattern of results in which children with DS demonstrated a conceptual understanding of cardinality, although they made more errors in the counting procedure. It clearly appears that the picture of the counting ability in DS is still controversial and it requires further investigation.

In the present study, we employed two numerosity match-to-sample tasks in order to evaluate the functioning of visual enumeration in children with DS in comparison to typically developing groups matched for both mental and chronological age. In both tasks, children observed a briefly presented sample numerosity and, after a delay period, a target numerosity. They had to decide whether the target numerosity was equal or different from the sample numerosity. In the dots-to-dots match-to-sample task, we assessed the ability to compare numerosities within and beyond subitizing range/OTS capacity. Our aim was to verify whether children with DS have a reduced subitizing range and to highlight possible differences in number acuity when numerosity discrimination entails larger numerosities. In the digit-to-dots match-to-sample task, the sample was an Arabic number and the target was a set of dots. Note that counting of the items in the target can yield the exact cardinality of the set to be matched with the cardinality entailed by the Arabic digit. Therefore, this task assessed the efficiency of the counting routine as well as the understanding of the cardinality principle