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Approximate additions and working memory in individuals with Down syndrome

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ABSTRACT

There is some evidence that individuals with Down syndrome (DS) may have a poorer mathematical performance and a poorer working memory (WM) than typically developing (TD) children of the same mental age. In both typical and atypical individuals, different aspects of arithmetic and their relationships with WM have been largely studied, but the specific contribution of WM to the representation and elaboration of non-symbolic quantities has received little attention. The present study examined whether individuals with DS are as capable as TD children matched for fluid intelligence of estimating numerosity both of single sets and of added sets resulting when two sequentially presented sets are added together, also considering how these tasks related to verbal and visuospatial WM. Results showed that the DS group's performance was significantly worse than the TD group's in numerosity estimation involving one set, but not when estimating the numerosity resulting from the addition. Success in the addition task was related to success in the working memory tasks, but only for the group with DS; this applied especially to the visuospatial component, which (unlike the verbal component) was not impaired in the group with DS. It is concluded that the two numerosity tasks involve different processes. It is concluded that the arithmetical and working memory difficulties of individuals with DS are not general, and they can draw on their WM resources when estimating the numerosity of additions.

1. Introduction

When teaching and supporting cognitively impaired individuals, it is crucial to examine to what extent they can learn not only formal mathematics, an area where they typically have severe difficulties (Buckley, 1985; Pieterse & Treloar, 1981), but also intuitive mathematics, which may help them to adapt to the demands of the environment.

Intellectually disabled individuals frequently have to make decisions based on estimating the numerosity of sets, and particularly the numerosity resulting from the sum of successively presented sets. For instance, they may have taken

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some chocolates from a dish a few times and need to estimate how many they have taken altogether without being able to see what they had taken previously. The present study examines to what extent individuals with an intellectual disability due to Down syndrome (DS) are capable of estimating numerosity of single and added sets, and the role of underlying cognitive mechanisms, and working memory in particular, in supporting this estimation.

There is robust evidence to show that the estimation of the numerosity of a single set relies on an innate predisposition shared by humans and animals, founded on an early, non-symbolic system of numerical representation (Carey, 2001; Feigenson, Dehaene, & Spelke, 2004). Several studies (e.g. Dehaene, 1997; Gallistel, 1990; Meck & Church, 1983) have also proposed that this approximate, abstract and pre-verbal representation of numerosity is processed by a specific cognitive component, which has been called the approximate number system (ANS). The precision of this representation is expressed in terms of ''number acuity'' (Izard & Dehaene, 2008; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004).

Some authors consider the ANS as the basis of exact arithmetic (Barth et al., 2006; Barth, La Mont, Lipton, & Spelke, 2005; Gilmore, McCarthy, & Spelke, 2007). When children learn number words in counting routines, the ANS should establish connections with the related symbols that begin to acquire meaning (Dehaene, 1992; Dehaene & Cohen, 1995, 1997; Gallistel & Gelman, 1992). The capacity to represent and mentally manipulate approximate numerosity could be the key to learning arithmetic, that gradually develops with the support of language and instruction (e.g. Butterworth, 1999; Gelman & Gallistel, 1978; Lemer, Dehaene, Spelke, & Cohen, 2003) and thus predict success in mathematical learning (see Passolunghi & Lanfranchi, 2012).

However exact and approximate representations of numerosity can be distinguished, as proposed by Butterworth (1999) who hypothesized that a specific impairment of the ''number module'', which enables the representation of exact numerosity, is at the root of dyscalculia. Consistent with this view, Iuculano, Tang, Hall, and Butterworth (2008) found that children with dyscalculia are impaired in tasks of exact numerosity, but not in approximate number tasks (see also Rousselle & Noël, 2007), but this observation was contrasted by Piazza et al. (2010) who found that also approximate estimation may be poor in developmental dyscalculia.

In sum, there is evidence that developmental dyscalculia may be related with a difficulty to estimate numerosities and this evidence could be used for exploring the factors underlying the arithmetic difficulties experienced by other disabled group, like individuals with Down syndrome (DS). In fact there is evidence of individuals with DS behaving poorly in mathematics (e.g. Abdelahmeed, 2007; Gelman & Cohen, 1988), also revealing a different pattern of behavior from TD children of comparable mental age varying according to the type of task. Marotta, Viezzoli, and Vicari (2006) found, for example, that individuals with DS were differently comparable with TD children of different ages, depending on the mathematical tasks they were presented. In a recent study Sella, Lanfranchi, and Zorzi (2013), by administering two delayed match-to-sample tasks, also found that individuals with DS were more weak in some numeric tasks than in other ones. In particular, individuals with DS were poorer than children matched for mental age in discriminating small numerosities (within the subitizing range) but not in discriminating large numerosities, offering thus support to a previous evidence collected by Camos (2009).

The fact that individuals with DS are poorer than TD children in some tasks than in other tasks could also be the effect of a specific developmental trajectory in the cognitive competences of individuals with DS, coinciding with a different involvement of verbal or visuospatial processes in mathematical tasks at different ages (Paterson, Girelli, Butterworth, & Karmiloff-Smith, 2006; Vicari, Marotta, & Carlesimo, 2004). In fact, among the various components that are related to mathematics but not domain-specific, verbal and visuospatial WM seem to be particularly important. The relationship between WM and arithmetic has been largely documented in both TD and atypically developing individuals, although the specific contribution of WM to the representation and elaboration of non-symbolic quantities has attracted relatively little interest (see Geary, Hoard, Nugent, & Byrd-Craven, 2007 vs. Butterworth & Reigosa, 2007). Many studies have used the working memory model proposed by Baddeley (1986, 2007) as a framework in which to study mathematical abilities. In fact, the two modality-specific systems of WM – the phonological loop and the visual-spatial sketchpad – specialized in processing language-based and visuospatial information, respectively, seem both involved in arithmetic. In particular, in the case of numerosity estimation resulting from the addition of sets maintained in memory, both the verbal component (verbalization and counting processes) and the visuospatial component (to recall the sets) of WM may be involved, similarly to what happens in the case of the mental addition of symbolic quantities. In fact, in the case of approximately adding symbolic numbers, both WM components have been shown to have a role – using a dual task paradigm – by Caviola, Mammarella, Cornoldi, and Lucangeli (2012) in TD children, and by Mammarella, Caviola, Cornoldi, and Lucangeli (2013) in children with developmental dyscalculia. In fact, approximate calculation in children seems to involve WM to a larger extent than exact calculation, unlike the situation seen in adults (Kalaman & LeFevre, 2007).

Despite the obvious differences between adding numbers or adding analogical sets, both the two addition tasks could at least partly share a similar WM involvement. Studies on the relationship between WM and addition of analogical sets in individuals with DS could thus take advantage of the knowledge gained in the large body of research on the WM weaknesses of individuals with DS, that are severe but selective, affecting verbal WM to a larger extent than visuospatial WM, and with further differentiations within each of these components (Bargagna, Perelli, Dressler, & Pinsuti, 2004; Carretti, Lanfranchi, & Mammarella, 2013; Jarrold, Baddely, & Hewes, 2000; Kanno & Ikeda, 2002; Lanfranchi, Cornoldi, & Vianello, 2004; Seung & Chapman, 2004; Vicari et al., 2004).