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Mental additions and verbal-domain interference in children with developmental dyscalculia

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ABSTRACT

This study examined the involvement of verbal and visuo-spatial domains in solving addition problems with carrying in a sample of children diagnosed with developmental dyscalculia (DD) divided into two groups: (i) those with DD alone and (ii) those with DD and dyslexia. Age and stage matched typically developing (TD) children were also studied. The addition problems were presented horizontally or vertically and associated with verbal or visuo-spatial information.

Study results showed that DD children's performance on mental calculation tasks was more impaired when they tackled horizontally presented addition problems compared to vertically presented ones that are associated to verbal domain involvement. The performance pattern in the two DD groups was found to be similar. The theoretical, clinical and educational implications of these findings are discussed.

1. Introduction

Developmental dyscalculia (DD), sometimes called mathematical learning disability, is characterized by severe impairments in the acquisition of mathematical skills. Traditional classification systems such as the DSM-IV-TR (American Psychiatric Association, 2000) and the ICD-10 (World Health Organization, 1992) indicate that a diagnosis of DD should be attributed to children who substantially underachieve on standardized mathematical testing with respect to the level expected for their age, education, and intelligence and whose academic achievement or everyday life is negatively affected. There may, in particular, be a considerable discrepancy between the children's general intellectual ability and their academic achievement (for alternative viewpoints, see Francis et al., 2005; Siegel, 1989; Stanovich, 2005). It is noteworthy that different terms and criteria are currently used in reference to DD (see Butterworth, 2005, for a review), but reports on the severe form should be distinguished from surveys on mild mathematical learning problems in children scoring above the 10th percentile on standardized mathematics achievement tests (Mazzocco & Devlin, 2008; Murphy & Mazzocco, 2007). Despite the lack of consensus on terms and criteria, most researchers nevertheless agree that children with DD fail to remember arithmetical facts or to use appropriate strategies or calculation procedures when working on math problems (Dowker, 2005; Geary, 1993; Landerl, Bevan, & Butterworth, 2004; Shalev & Gross-Tsur, 2001), and they have difficulty when they are faced with increasing task demands (Murphy & Mazzocco, 2009). According to some authors (Shalev & Gross-Tsur, 2001), dyscalculia in school-aged children is relatively common, occurring as a comorbidity in about 40% of

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individuals with dyslexia (Gathercole, Alloway, Willis, & Adams, 2006; Geary, 1993; Lewis, Hitch, & Walker, 1994). Some studies (Andersson & Lyxell, 2007; Fuchs & Fuchs, 2002) indicate that children with DD and dyslexia exhibit more severe and generalized functional difficulties with respect to children with DD alone.

Conflicting evidence has been produced with regard to the debate over the role of verbal or visuo-spatial processes in causing learning disability in DD. Several authors (e.g. Swanson & Sachse-Lee, 2001) have stressed the importance of the former, while others (e.g. Passolunghi & Cornoldi, 2008) have highlighted the latter. The discussion has focused mainly on the issue of working memory (WM), believed to be one of the cognitive mechanisms that is impaired in children with DD. According to the Baddeley and Hitch model (1974) and Baddeley (1986), WM is a multi-component structure made up of two subsystems each specializing in handling different kinds of information. The phonological loop is accountable for the temporary storage of information connected to the verbal domain, while the visuo-spatial sketchpad is thought to be responsible for temporary storage and manipulation of visual and spatial information. Both the phonological loop and the visuo-spatial sketchpad are in direct contact with the central executive involved in coordinating activities in the cognitive system. In the latest version of the model, Baddeley (2000) added an episodic buffer, which is responsible for binding information across domains and memory subsystems into integrated chunks.

The association of learning disabilities with WM impairments has been demonstrated in a number of studies (Krajewksi & Schneider, 2009; Passolunghi & Siegel, 2001; Schuchardt, Maehler, & Hasselhorn, 2008), but the nature of that relationship in children with DD is unclear (see Raghubar, Barnes, & Hetch, 2010 for a review), and there is conflicting evidence on the role of the verbal and the visuo-spatial domains. Hitch and McAuley (1991), and Swanson and Sachse-Lee (2001) found DD children deficient in verbal WM, but that finding has not been confirmed in other studies (Bull, Johnston, & Roy, 1999; Geary, Hoard, & Hamson, 1999; Landerl et al., 2004; McLean & Hitch, 1999). The role of the visuo-spatial domain is less obvious and has only been identified in some subgroups of children with DD (McLean & Hitch, 1999; Passolunghi & Cornoldi, 2008; Passolunghi & Mammarella, 2010, 2012; van der Sluis, van der Leij, & de Jong, 2005), although there does not appear to be any visuo-spatial WM impairment in some. Bull et al. (1999) have reported, in fact, that test results measuring visuo-spatial WM in DD children were comparable to control scores.

Possible explanations for the variable picture delineating the role of verbal and visuo-spatial domains in DD could be linked to developmental changes or the use of different selection criteria or testing strategies (see, for example, Dowker, 2005; Henry & Maclean, 2003). According to Raghubar et al. (2010), studies on the relationship between underlying cognitive processes and mathematics can be classified as one of two types: (i) experimental dual task studies in which participants carry out activities that draw on verbal and visuo-spatial domains while they perform math tasks and (ii) individual difference and developmental studies examining working memory in children with math difficulties. Each method has its advantages and limitations, and the latter might be avoided by using both methods at the same time. In particular, the use of a dual task paradigm only with typically developing individuals do not guarantee that the same mechanisms observed in these children are also involved in children with DD, as – due to their difficulties – the latter group could use different processes. These limitations could be avoided by testing children with DD in a dual task condition. Hence, in the present study a dual task paradigm in a sample of children with DD matched with typically developing (TD) children was used.

Diagnosed in a specialized learning disabilities center, the children with DD were divided into two subgroups depending on whether or not they had an associated reading problem (i.e. DD alone or DD + dyslexia). The combination of the study of disabled children with the study of the consequences of a dual task condition should offer new insight on the processes involved in mental calculation and should add important implications for the comprehension of DD. Although extensive studies have been conducted on the factors and cognitive deficits that might contribute to DD, the mechanisms involved are still controversial. It is still open to debate whether difficulty in learning mathematics is due to just one basic number-specific core competence being impaired (for example to the inability to represent exact numerosities) or to the combined effect of several impairments in a more general cognitive system (Butterworth, 2005), as suggested by evidence showing either verbal or visuo-spatial deficits in children with DD. In addition, it is not clear whether a verbal processing deficit is present due a comorbidity with other forms of learning disability, such as dyslexia, or it is also present in children who have a DD alone.

In sum, the field of DD has been insufficiently explored and many issues still remain unclear. Our study intended to offer new information on the main characteristics of DD, by using the advantages offered by the dual task paradigm, with particular reference of two main issues, i.e. whether DD is associated with a difficulty in using either verbal or visuo-spatial processes and whether a difficulty in using verbal processes is a typical characteristic of dyscalculia or is present only when dyscalculia is associated with other learning difficulties, associated with language use, as in the case of dyslexia. In our research, the children were asked to perform a primary task (solving addition problems with carrying) combined with a secondary one requiring verbal or visuo-spatial processing (i.e., remembering a series of letters or a pattern of squares in a matrix) (Imbo & LeFevre, 2010; Trbovich & LeFevre, 2003). The dual task method has been widely used in typically achieving adults to study single-digit and multi-digit arithmetical skills and at times in children (Caviola, Mammarella, Cornoldi, & Lucangeli, 2012; Imbo & Vandierendonck, 2007) with the intent of shedding light on the nature of the processes involved in calculation; it has never been used in children with DD. Trbovich and LeFevre (2003) analyzed an adult sample's performance on multi-digit addition problems presented horizontally and vertically combined with a verbal or visuo-spatial WM secondary task or in a control condition (participants were presented with the same material but not asked to perform the secondary task). Their results showed that participants were quicker and more accurate in solving vertically presented addition (VA) problems. A verbal secondary task impaired their performance on horizontally presented addition (HA)