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Naming speed and effortful and automatic inhibition in children with arithmetic learning disabilities

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ABSTRACT

We report a two-year longitudinal study aimed at investigating the rate of access to numerical and non-numerical information in long-term memory and the functioning of automatic and effortful cognitive inhibition processes in children with arithmetical learning disabilities (ALDs). Twelve children with ALDs, of age 9.3 years, and twelve gender–age-matched controls were involved in the study. Rate of access was measured through digit- and letter-naming tasks, automatic cognitive inhibition was measured using a negative priming paradigm, and effortful cognitive inhibition was measured rating intrusion errors in a working memory task. Children with ALDs suffered from a deficit in the speed of activating both numerical and non-numerical information from long-term memory and in effortful inhibition mechanisms. No evidence for dysfunction of the automatic inhibition processes was found.

During the last decade, there has been increasing interest in research on learning disabilities in mathematics. According to Geary (2003), a mathematical learning disability in children with average general intelligence "can result from deficits in the ability to represent or process information used in one or all of the many areas of mathematics domains (e.g., arithmetic and geometry), or in one or a set of individual domains (e.g., theorems vs. graphing) within each of these areas."

In the present study, we sought to examine some of the cognitive factors that could be considered as underlying Arithmetic Learning Difficulties (ALD) with a view to explaining the high grade of co-morbidity between mathematical and other developmental disorders such as dyslexia or attention deficit hyperactivity disorder (Gros-Tsur, Manor, & Shalev, 1996; Shalev, Manor, & Gross-Tsur, 1997).

The literature to date has explored the role of different cognitive routes in mathematical cognition that can underpin ALD involving visuospatial (Geary, 1993, 2003; Rourke, 1993) or phonological processes (Fuchs et al., 2005; Hecht, Torgesen, Wagner, & Rashotte, 2001), as well as one or more aspects of working memory (Bull & Johnston, 1997; Bull, Johnston, & Roy, 1999; D'Amico & Guarnera, 2005; Geary, Hamson, & Hoard, 2000; Geary, Hoard, & Hamson, 1999; McLean & Hitch, 1999; Passolunghi, Mammarella, & Altoè, 2008; Passolunghi & Pazzaglia, 2004, 2005; Passolunghi, Vercelloni, & Schadee, 2007; Swanson & Sachse-Lee, 2001).

At present, it seems that two aspects of cognitive functioning of children with ALD are in need of further investigation: the first concerns the rate of access to numerical and non-numerical information in long-term memory; the second involves the functioning of automatic and effortful cognitive inhibition processes (Nigg, 2000).

1. Rate of access to information in long-term memory

In order to identify the numerical symbols, to recite the counting sequence (Logie & Baddeley, 1987), to perform on-line math computations (Hecht et al., 2001), or to retrieve numerical facts, children need to access verbal numerical information in long-term memory quickly (Ashcraft, 1982; Campbell, 1998; Geary, 1993; Geary, Brown, & Samaranayake, 1991; Geary & Hoard, 2001; Jordan, Hanich, & Kaplan, 2003; Kaufmann, Lochy, Drexler, & Semenza, 2004; McCloskey, Caramazza, & Basili, 1985).

The speed taken to retrieve information from long-term memory is generally measured through naming tasks that have been extensively used in the study of disabilities in learning to read (Denckla, 1972; Denckla & Rudel, 1974; Wagner, Torgesen, & Rashotte, 1999). Evidence for impaired long-term memory representation in reading-disabled children comes from slow naming rates for linguistic and numerical material (for a review, see Wolf & Bowers, 1999). Rate of access to information in long term memory, thus, could reasonably be one of the common underlying factors on dyslexia and dyscalculia.

However, studies of naming rate in children with ALD are comparatively few and results are often conflicting. Some studies have shown a specific association between the performances of children in

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numerical naming and arithmetical tasks. Dark and Benbow (1991) demonstrated that individuals who are mathematically talented were particularly fast in identifying numerical items.

Similarly, Fuchs et al. (2005) showed that ability in rapid digit naming tasks is associated with the development of mathematics ability in first grade children. More specifically, Landerl, Bevan, and Butterworth (2004) demonstrated that children with dyscalculia were significantly slower than controls in naming one and two digit numbers, even when naming speed for colour names was controlled. According to Landerl et al. (2004), controlling for colour naming rules out an interpretation of group differences explained by a general speed of processing, articulation rate and access to semantic memory. They propose that there might be a specific deficit in accessing and retrieving the linguistic labels of numbers that is part of a core deficit in number processing in children with ALD. Consistent with Landerl et al. (2004), Van der Sluis, de Jong, and van der Leij (2004) showed that ALD children were slower than non-disabled children in naming digits and quantity but not in naming letters and object (i.e., geometrical figures).

The hypothesis of a selective deficit in the rate of access to numerical information might also help to explain the particular weakness of children with ALD in short-term memory tasks that use numerical material (D'Amico & Guarnera, 2005; Passolunghi & Siegel, 2001; Swanson & Sachse-Lee, 2001) that is combined with a frequently normal performance in span tasks involving linguistic material (Bull & Johnston, 1997; D'Amico & Guarnera, 2005; McLean & Hitch, 1999; Passolunghi & Siegel, 2004).

However, contrary to this hypothesis, several studies have demonstrated an association between arithmetic performance and the rate of access to both numerical and non-numerical information (Bull & Johnston, 1997; Hecht et al., 2001; Temple & Sherwood, 2002). In particular, Temple and Sherwood (2002) described a small group of children with ALD who were slower than controls in both colour and object naming. They interpreted this pattern as an indication of impairment in the rate of access to semantic information in long-term memory although cautioning that their study was based on a very small sample size. Another study reported by Bull and Johnston (1997) found differences between groups with high and low arithmetic ability in both digit naming tasks and in letter naming tasks. Yet this study used a composite measure of letter and digit naming, so that the specific contribution of each could not be estimated. Similarly, the longitudinal studies of Hecht et al. (2001) and Swanson and Beebe-Frankenberger (2004) demonstrated that both measures of letter and digit naming were important predictors of computation skills for second and third grade children. However, in these studies, latent variables were extracted, so the specific influence of letter and digit naming could not be examined.

Given the discrepancy between results, one aim of our study was to examine whether children with ALD are significantly slower than age-matched controls in the rate of access to numerical and non-numerical information from long-term-memory.

2. Effortful and automatic cognitive inhibition

Findings from a growing number of studies suggest that failure on various arithmetic tasks is also related to the effortful inhibition of endogenous information, i.e. the ability to suppress or inhibit irrelevant information that is liable to overload working memory or attention processes (Dempster, 1991; Nigg, 2000).

Problems in discharging irrelevant information have been described in the case of children with reading comprehension difficulties (Chiappe, Hasher, & Siegel, 2000; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Gernsbacher, 1993), suggesting that a dysfunction in effortful cognitive inhibition might also be at the basis of co-morbid reading and arithmetic difficulties.

An inhibition deficit could likely impair learning of different arithmetical skills. For example, Barrouillet, Fayol, and Lathulière (1997) propose that difficulties in the ability to suppress or inhibit irrelevant or non-pertinent information may give rise to disruption in the retrieval process of simple arithmetical facts in children with ALD (see also Conway & Engle, 1994; Geary et al., 1991, 2000; Koontz & Berch, 1996). Similarly, Passolunghi, Cornoldi, and De Liberto (1999; see also Passolunghi & Cornoldi, 2000) showed that the arithmetical problem solving of children with ALD is significantly influenced by their poor memory recall for critical information and enhanced memory recall for irrelevant information of arithmetic problem texts. "Memory overload" resulting from the failure to inhibit irrelevant information could impair, for example, accurate representations of arithmetical word problem. Further studies (D'Amico & Guarnera, 2005; Gathercole, Pickering, Knight, & Stegmann, 2004; Passolunghi, Marzocchi, & Fiorillo, 2005; Passolunghi & Pazzaglia, 2004; Swanson & Sachse-Lee, 2001) reported impaired working memory spans in children with ALD that, as claimed by Passolunghi and Siegel (2001, 2004), result from an inability to inhibit irrelevant information that overloads the working memory system. This result, that was replicated by Passolunghi & Siegel (2004) is, however, far from being clearly demonstrated and was not confirmed in a more recent study by Censabella and Noël (2008), that failed to find significant differences between children with math disabilities and controls in the suppression of irrelevant information from working memory.

Against the number of studies focusing on the controlled and effortful cognitive inhibition of endogenous information in children with ALD, there is no evidence supporting the functional role of the uncontrolled and automatic inhibition of endogenous information. This process is extensively covered in the literature using the Negative Priming (NP) paradigm (see May, Kane, & Hasher, 1995, for a review). It consists of the presentation of a prime followed by a probe trial. In the prime trial, a pair of stimuli is presented to individuals with one item in the pair requiring a response (the target), while the other item (the distractor) must be ignored. In the probe trial the distractor items become the target items and the reaction time to the target is typically slowed. This naming delay indicates the necessary effort to "re-activate" the previously inhibited information. The NP effect is considered to be an indicator of normal automatic inhibitory functions, and is generally found in adults and in children from the age of 5 to 6 years (Simone & McCormick, 1999; Tipper & McLaren, 1990), and becomes more robust from middle childhood to adulthood.

A dysfunctional automatic cognitive inhibition process might impair a range of arithmetical skills in children with ALD, including the abilities to represent the linguistic labels of numbers in the counting sequence and the retrieval of arithmetical facts. However, considering the results obtained by Johnson, Im-Bolter, and Pascual-Leone (2003) related to mainstream and gifted children, and by Nigg, Butler, Huang-Pollock, and Henderson (2002) on ADHD patients, we are more inclined to expect a normal NP effect in children with ALD which indicates normal functioning of automatic inhibition processes. Johnson et al. (2003) found that both gifted and mainstream children showed NP effects on a spatial location task, even though the gifted children were quicker to apply their attentional resources to the tasks (i.e. had faster response times). Such results, therefore, indicated that only speed of processing discriminated between the gifted and mainstream children. Similarly, Nigg et al. (2002) showed normal NP effects in adults with ADHD. These results combined seem to indicate that automatic cognitive inhibition might not be involved in the explanation of individual differences in scholastic learning or ADHD disorders.

We performed two studies with the aim to investigate the rate of access to long-term information and the processes of automatic and effortful inhibition in children with ALD. For Study 1 we first selected, from a sample of 108 children, a group of children with specific ALD and a group of age and gender matched controls. We presented them with tasks that required the rapid naming of digits and letters.

Based on the literature, our prediction was that children with ALD were generally slower than controls in naming. Moreover, we aimed to determine whether children with ALD suffer from a selective difficulty