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Deficits in visual short-term memory binding in children at risk of non-verbal learning disabilities

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ABSTRACT

It has been hypothesized that learning disabled children meet short-term memory (STM) problems especially when they must bind different types of information, however the hypothesis has not been systematically tested. This study assessed visual STM for shapes and colors and the binding of shapes and colors, comparing a group of children (aged between 8 and 10 years) at risk of non-verbal learning disabilities (NLD) with a control group of children matched for general verbal abilities, age, gender, and socioeconomic level. Results revealed that groups did not differ in retention of either shapes or colors, but children at risk of NLD were poorer than controls in memory for shape-color bindings.

1. Introduction

Visual short-term memory (STM) is responsible for the temporary storage of visual information from the immediate environment, and represents an aspect of the more general concept of visuospatial working memory (WM), which is the cognitive system that comprises both temporary maintenance and active manipulation of visual (i.e., shapes, colors, and textures) and spatial (i.e., locations) information (Baddeley, 2012; Cornoldi & Vecchi, 2003; Cowan, 2008; Wheeler & Treisman, 2002). Such system is strongly associated with visuospatial abilities and crucially supports many fundamental cognitive activities in everyday life, such as object recognition, mental imagery, spatial orientation, and visuospatial learning and reasoning (Cornoldi & Vecchi, 2003). Within the domain of visuospatial memory tasks, visual STM tasks typically require recognition of visual arrays after brief delays, and do not involve spatial information nor the manipulation of stored information as in visual WM tasks (Cowan, 2008). Traditionally, visual STM and WM tasks use simple visual objects consisting of parameterizable features (e.g. shapes and colors), which allow a greater control over stimuli characteristics and hypotheses testing regarding memory functioning (Orhan & Jacobs, 2014).

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Since the seminal work by Luck and Vogel (1997), there has been a debate on the nature of temporary representations in visual memory, that is, its units of storage, and whether visual objects are typically represented as bound units or as a collection of independent features. There is evidence that visual memory operates on both feature- and object-level information, and that memory binding processes are crucial to cope with complex representations (Wheeler & Treisman, 2002). For this reason, visual STM may be tested both by examining the recognition of single features or of combined features. In fact, when it comes to visual memory development, researchers have focused mainly on temporary memory for simple stimuli (such as shapes, colors, visual patterns, etc.), although recent research has also considered the case of multi-feature stimuli, for example, requiring the association between objects and locations (Lorsbach & Reimer, 2005), colors and locations (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006), shapes and colors (Brockmole & Logie, 2013).

Many everyday life and/or learning situations require the temporary processing and maintenance of complex visual information characterized by multiple features and dimensions, such as colors, shapes, sizes, locations, and movements (Orhan & Jacobs, 2014; Wheeler & Treisman, 2002). In order to interact with the immediate environment, it is necessary to identify objects and their respective features, to keep track of static and dynamic objects, and to extract relevant spatial relationships (Cornoldi & Vecchi, 2003). In the developmental and scholastic domains, for example, many games and educational toys designed for children, as well as academic materials (such as graphic representations, illustrations, etc.) require the identification of objects and the matching between particular shapes, colors, and locations.

Developmental research has shown that visual memory binding develops during the childhood and adolescence (Brockmole & Logie, 2013; Cowan et al., 2006); however, it has not deeply investigated whether certain clinical groups have memory binding deficits. The comparison between typically and atypically developing children is crucial to get a better understanding of memory development in children (D'Souza & Karmiloff-Smith, 2011), and the case of binding appears crucial as it could help to understand the difficulties that some groups of children meet in processing and remembering visual information.

In particular, clinical groups with difficulties in visual STM and WM tasks or, more generally, in visual tasks could have visual memory binding deficits. Regarding this aspect, individuals with Williams syndrome and non-verbal learning disabilities (NLD) represent two important cases as they have a cognitive profile characterized by impairments in visuospatial abilities and relatively preserved linguistic abilities (Bellugi, Lichtenberger, Jones, Lai, & St. George, 2000; Cornoldi, Vecchia, & Tressoldi, 1995; Drummond, Ahmad, & Rourke, 2005; Farran & Jarrold, 2003; Jarrold, Baddeley, & Hewes, 1999; Mammarella & Cornoldi, 2005a; Mammarella & Pazzaglia, 2010; Vicari, Bellucci, & Carlesimo, 2003; Wang & Bellugi, 1994) and have been examined in a preliminary way with respect to their memory binding processes (Garcia, Mammarella, Tripodi, & Cornoldi, 2014; Jarrold, Phillips, & Baddeley, 2007), suggesting not only visual but also spatial WM binding difficulties. The study by Jarrold et al. (2007) showed that individuals with Williams syndrome and individuals with moderate learning disability have deficits in object-location memory binding, whereas memory for either objects or locations is spared. In the present study, we examine the case of children at risk of NLD, who share with children with Williams syndrome several problems in VSWM (Carretti, Lanfranchi, De Mori, Mammarella, & Vianello, 2015) and whose ability to bind visual and spatial information had been recently explored by Garcia et al. (2014).

However, diagnostic criteria for NLD are not yet included in the main classification systems, and for this reason NLD has been characterized with slight variations by the literature. A common focus of impairments in NLD is the presence of good verbal abilities and poor visuospatial skills (Mammarella & Cornoldi, 2014, for a review and a meta-analysis). Several authors argue that a fundamental aspect of NLD is a discrepancy between verbal and non-verbal intelligence, that is, children with NLD are characterized by average or above average performances in verbal intelligence, with significant poorer performances in measures of visuospatial intelligence (Mammarella & Cornoldi, 2014; Semrud-Clikeman, Walkowiak, Wilkinson, & Christopher, 2010). In fact, the discrepancy between verbal and visuospatial IQ represents the main criterion used by worldwide clinicians for the diagnosis of NLD (Solodow et al., 2006).

The literature has described several neuropsychological deficits associated with NLD, such as deficits in tactile and visual perception, visuospatial reasoning and memory, and psychomotor coordination (Rourke, 1989). In addition, NLD also involves difficulties with graphomotor aspects of writing (Gross-Tsur, Shalev, Manor, & Amir, 1995), language comprehension (Humphries, Cardy, Worling, & Peets, 2004; Mammarella et al., 2009; Mammarella, Meneghetti, Pazzaglia, & Cornoldi, 2015; Semrud-Clikeman & Glass, 2008), and social interaction (Semrud-Clikeman, Walkowiak, Wilkinson, & Minne, 2010). Concerning learning difficulties, it has been shown that children with NLD present problems in calculation (Forrest, 2004; Mammarella, Bomba, et al., 2013) and geometry (Mammarella, Giofrè, Ferrara, & Cornoldi, 2013). The difficulties that children with NLD meet in mathematics seems related to visuospatial aspects of calculation, such as carrying errors and column confusions (Mammarella, Lucangeli, & Cornoldi, 2010; Mammarella, Bomba, et al., 2013; Venneri, Cornoldi, & Garuti, 2003). It is worth noting that the diagnosis of NLD has been distinguished from that of dyscalculia (or mathematical learning disability), which is characterized by severe and generalized mathematical difficulties, and does not involve problems in processing visuospatial information or lower visuospatial than verbal intelligence.

There is a wealth of evidence that individuals with NLD perform particularly poorly in tests of visuospatial STM and WM (Cornoldi et al., 1995; Mammarella & Cornoldi, 2005a; Mammarella & Pazzaglia, 2010), and some authors have proposed that their difficulty mainly concerns the spatial component and only marginally involves the visual one (Mammarella et al., 2010). However, until now, visual STM was studied in children with NLD mainly with reference to memory for single features