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Spatial and numerical processing in children with non-verbal learning disabilities

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ABSTRACT

Consistently with the idea that numbers and space interact with each other, the present paper aimed to investigate the impact of non-verbal learning disabilities (NVLD) on spatial and numerical processing. In order to do so, 15 NVLD and 15 control children were required to perform different spatial (the line bisection and Simon tasks) and numerical tasks (the number bisection, number-to-position and numerical comparison tasks). In every task, NVLD children presented lower accuracy scores than the control group. While both groups manifested similar pseudo-neglect and Simon effects, they however differed in the numerical comparison task: while control children presented the standard SNARC effect in the uncrossed and crossed postures, no SNARC effect was observed in the NVLD group. Our results therefore suggest that NVLD affects the accuracy and the nature of the mental number line by decreasing its precision and the saliency of its left-to-right orientation.

1. Introduction

Historically, many mathematical advances have been developed through interactions between numbers and space. In cognitive psychology, research has shown that number and space processing interact with each other. The major evidence used to support this fact comes from the observation of some compatibility effects between number and space in behavioural forced-response paradigms. The so-called SNARC effect (Spatial Numerical Association of Response Codes) indicates that (in several Western cultures) small numbers are preferentially associated with a left-sided response whereas larger numbers are preferentially associated with a right-sided response (Dehaene, Bossini, & Giraux, 1993). The SNARC effect was often compared to the spatial Simon effect (the time to respond to a stimulus is faster and more accurate when the position of the stimulus is compatible with the side of the response: Simon, 1969; Simon & Rudell, 1967; Simon & Wolf, 1963) and was interpreted as an index of the spatial organization of the mental number line. According to this account, small numbers are responded to faster with left-sided responses and large numbers are responded to faster with right

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sided-responses because this stimulus–response association is congruent with the left-to-right orientation of the mental number line.

Evidence supporting the existence of an interaction between numbers and space also comes from studies using the line bisection task (Calabria & Rossetti, 2005; Fischer, 2001). In this task, participants tend to perceive a line midpoint to the left of its actual midpoint when this line is composed of small numbers (in Arabic as well as in verbal notation; pseudoneglect effect: Jewell & McCourt, 2000). Inversely, they tend to perceive the line midpoint to the right of its actual midpoint when the line is composed of large numbers. Number processing distortions have also been found in patients presenting hemi-spatial neglect, who typically tend to ignore the contralesional space (usually left) of their lesion (usually situated in the right parietal cortex). So, in a classic line bisection task, in which the midpoint of a physical line has to be indicated, they neglect the left portion of the line and then tend to displace the midpoint of the line towards the right. This hemi-spatial neglect has been shown to extend to the representation of numbers: patients systematically displace the actual midpoint of a numerical interval towards the right (i.e., the large numbers) when asked to bisect it (Hoeckner et al., 2008; Zorzi, Priftis, Meneghello, Marenzi, & Umilta, 2006; Zorzi, Priftis, & Umilta, 2002). However, when small physical lines or small numerical intervals are presented, a "cross-over effect" is observed, which means that, in this case, the bisection performances are deviated towards the left/the smaller numerical values. These spatial and numerical distortions can be improved by wearing prismatic goggles, thereby indicating that numbers and space are intrinsically connected (Rossetti et al., 1998, 2004).

The association between space and number has also been reported in children presenting developmental dyscalculia (Szucs, Devine, Soltesz, Nobes, & Gabriel, 2013) and in children suffering from non-verbal learning disabilities (NVLD) (Mammarella & Cornoldi, 2014; Nichelli & Venneri, 1995; Rourke, 1989). In the literature, NVLD has been associated with neuropsychological, academic and socio-emotional deficits (Rourke, 1989). However, in this paper, we will use the term NVLD to refer to children presenting major difficulties in areas of spatial skills[1] within a context of well-developed psycholinguistic skills (Rourke, 1989). This is in accordance with the name of the most widespread tool that is used to identify NVLD in schools: the Cornoldi's shortened visuo-spatial questionnaire (Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003). This questionnaire is highly correlated to tasks specifically related to the NVLD problem (e.g., block design, corsi block span). However, by using the term visuo-spatial rather than the term NVLD, the authors (Cornoldi et al., 2003) wanted to highlight that the most salient characteristic of NVLD was a spatial processing problem.

In the numerical field, it has already been demonstrated that NVLD perform significantly worse than typically developing children in geometry (Mammarella, Giofrè, Ferrara, & Cornoldi, 2013) and in arithmetic tasks that require some visuo-spatial processes.[1] For example, in written calculation, they produce more borrowing and carrying errors than their control peers (Venneri, Cornoldi & Garuti, 2003), but also more partial calculation errors and column confusions (Mammarella, Lucangeli, & Cornoldi, 2010). In the same line, Vaivre-Douret et al. (2011) tested children with a developmental coordination disorder (often associated with low visuo-spatial skills) and found that 88% of the 43 children tested had school failures in mathematics, more particularly in geometry or while calculating sums in arithmetic. More recently, Crollen and Noël (2015) investigated whether visuo-spatial weaknesses in typically developing children may affect not only pure spatial processing but also basic numerical tasks tapping the number magnitude itself. Indeed, as a large number of studies have shown that the number magnitude representation could be coded on a spatial medium, the authors wanted to test whether visuo-spatial weaknesses could affect this representation. In their study, the performances of children with high and low visuo-spatial abilities were directly compared on different spatial (the line bisection and Simon tasks) and numerical tasks (the number bisection, number-to-position and numerical comparison tasks). While children from the low visuo-spatial group presented the classic pseudo-neglect, Simon and SNARC effects, they systematically showed larger deviation errors as compared to the high visuo-spatial group. The authors therefore concluded that low visuo-spatial abilities did not change the nature of the mental number line but led to a decrease in its accuracy.

In this paper, we wanted to further examine the spatial and numerical weaknesses that are associated to NVLD. Fifteen NVLD children and 15 control children were therefore required to perform the same spatial (the line bisection and the Simon tasks) and numerical tasks (number-to-position, number bisection and numerical comparison task to 5) as in Crollen and Noël (2015). These different tasks allowed us to investigate the impact of NVLD on the representations of space and numbers. First, we examined whether NVLD children presented the same pseudo-neglect, Simon and SNARC effects as their control peers. Second, by comparing the three numerical tasks, we examined whether NVLD impacted all numerical tasks or only impacted the task that requires the processing of external space, i.e., the number-to-position task. Finally, the last question relevant for our purposes was to investigate the impact of NVLD on the coordinate frame in which the SNARC and the Simon effects arise. Several findings already suggested that an effector independent representation of space was involved. It has indeed been demonstrated that the SNARC (Dehaene et al., 1993) and the Simon effects (Röder, Kusmierek, Spence, & Schicke, 2007) occur even when participants respond with the hands crossed over the body midline: small numbers (left-sided stimulus) continue to be associated with the left external space, even when responses on that side are made with the right hand. If NVLD does not affect the reference frame in which the SNARC and the Simon effects occur, children should present both effects in the uncrossed as well as in the crossed hands position. In contrast, if visuo-spatial difficulties prevent

[1] Visuo-spatial processes are one component of our cognitive functioning that refers to our ability to process and interpret visual information about where objects are in space.