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Intuitive Geometry and Visuospatial Working Memory in Children showing
symptoms of Non-verbal Learning Disabilities

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Abstract

Visuospatial working memory (VSWM) and intuitive geometry were examined in two groups aged 11—13, one with children displaying symptoms of nonverbal learning disability (NLD) (N=16), and the other, a control group without learning disabilities (N=16). The two groups were matched for general verbal abilities, age, gender, and socioeconomic level. The children were presented with simple storage and complex-span tasks involving VSWM and with the intuitive geometry task devised by Dehaene, Izard, Pica, and Spelke (2006). Results revealed that the two groups differed in the intuitive geometry task. Differences were particularly evident in Euclidean geometry and in geometrical transformations. Moreover, the performance of NLD children was worse than controls to a larger extent in complex-span than in simple storage tasks, and VSWM differences were able to account for group differences in geometry. Finally, a discriminant function analysis confirmed the crucial role of complex-span tasks involving VSWM in distinguishing between the two groups. Results are discussed with reference to the relationship between VSWM and mathematics difficulties in nonverbal learning disabilities.

Keywords: Nonverbal learning disabilities, Visuospatial working memory, Intuitive geometry.

Introduction

Geometry has long been considered one of the most important forms of mathematical knowledge. In the arcade of the famous school of Athens, where Plato taught, it was written that entry was not permitted to people who did not know geometry. Although geometry is included in all the mathematical curricula in the world, international assessments report that many students present difficulties in learning geometry (Organisation for Economic Co-operation & Development [OECD], 2007). Despite this, a cognitive profile of students with difficulties in learning geometry has never been studied. The present study offers a first contribution in this direction by examining a particular group of learning-disabled children who were hypothesized to present difficulties in geometry.

Learning disabilities occur in approximately 5% of school-age children (Lyon, 1996), and two major subtypes of learning disabilities have been described: children with linguistic disabilities and children with nonverbal learning disabilities (NLD) (Drummond, Ahmad, & Rourke, 2005). A nonverbal learning disability refers to a difficulty in processing visuospatial information or other types of nonverbal information. NLD was also described and labelled either as a dysfunction of the right hemisphere (Gross-Tsur, Shalev, Manor, & Amil, 1995; Nichelli & Venneri, 1995; Weintraub & Mesulam, 1983) or as a visuospatial learning disability (Cornoldi et al., 2003; Mammarella & Cornoldi, 2005a; 2005b). However, the formulation of an inclusive set of characteristics and classifications is still under debate (Roman, 1998; Spreen, 2011). Rourke (1989, 1995) elaborated a model on the NLD syndrome with extensive studies that demonstrated a specific pattern of neuropsychological assets and deficits. Briefly, this pattern includes bilateral tactile-perceptual and coordination deficits, substantially deficient visuospatial abilities, deficits in novel problem solving and concept formation, poor arithmetic skills (Harnadek & Rourke, 1994; Mammarella, Lucangeli, & Cornoldi, 2010), and strong word reading with poor reading comprehension of spatial descriptions (Mammarella et al., 2009). To this list, behavioral descriptions frequently added

deficient social perception and judgment, interaction verbosity of a repetitive nature, and problems in adapting to novel situations (Rourke & Tsatsanis, 2000).

Although different criteria are used for diagnosing children with NLD, there is a general agreement (Solodow, Sandy, Levental et al., 2006; see also Mammarella & Cornoldi, 2011) that the main symptoms of NLD are the presence of a discrepancy between verbal and nonverbal IQ, visuospatial and motor coordination impairments, and school difficulties, in particular in the mathematical area. In a cross-country study comparing the characteristics of British and Italian children who had received a diagnosis of NLD, Cornoldi and collaborators (Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003) validated a rapid-screening measure for teacher identification of children with NLD symptoms, focusing on their visuospatial difficulties. Mathematical difficulties were considered as a typically associated symptom, but not as a defining feature of NLD.

Another critical factor underlying the difficulties encountered by children with NLD seems to be related to visuospatial working memory (VSWM) deficits (Cornoldi, Dalla Vecchia, & Tressoldi, 1995; Cornoldi, Rigoni, Tressoldi, & Vio, 1999; Mammarella & Cornoldi, 2005a, 2005b). According to Logie (1995), VSWM is a specific working memory component, responsible for the maintenance and processing of visual (e.g., color, shape, texture) and spatial (e.g., position of an object in space) information. VSWM has been specifically explored in children with NLD, and evidence showed that they are impaired in both simple storage (i.e., passive) and complex-span (i.e., active) tasks, but that different NLD children may present different specific weaknesses. Simple storage tasks refer to the retention of information that has not been modified after encoding, while complex-span tasks require transformation and manipulation of stored information. Regarding simple storage tasks, for example, Mammarella et al. (2006) observed, in a group of NLD children, a double dissociation between spatial-simultaneous tasks (those requiring them to recall spatial locations presented at the same time) and spatial-sequential tasks (those requiring them to recall spatial locations presented one after the other). Furthermore, a specific analysis of

two NLD cases (Cornoldi, Rigoni, Venneri, & Vecchi, 2000) offered evidence in favor of the dissociation between simple storage and complex-span tasks in VSWM. However, a series of studies revealed that children with NLD are usually more impaired on complex-span tasks requiring an active manipulation of stored information than on simple storage tasks (see, for example, Cornoldi et al., 1995; Cornoldi et al., 1999). In sum, these results show that: (a) it is important to consider VSWM, in its different components, for identifying different subtypes of NLD, and (b) VSWM deficits might explain why NLD children fail in a range of activities (e.g., mathematics, drawing, spatial orientation, geometry, etc.) assumed to involve VSWM.

Concerning the failures of NLD children in mathematical tasks, deep attention has been dedicated only to the case of calculation. For example, considering the relationship between VSWM and arithmetic in children with NLD, Venneri, Cornoldi, and Garuti (2003) compared children with NLD to controls in arithmetic calculations. Their results revealed that the group with NLD had more severe difficulties with written calculation, especially when either borrowing or carrying were involved. The authors hypothesized that NLD children do not have a generalized problem with calculation *per se*; instead, their problems derive from dealing with specific processes, including VSWM, which governs calculation. In a further study, Mammarella et al. (2010) found that children with NLD performed significantly worse than did children with typical development in VSWM tasks and in arithmetic tasks associated with visuospatial processes, as, for example, carrying errors, partial calculation errors, and column confusions. Moreover, their results confirmed that an arithmetic difficulty may be associated with NLD but also suggested that a VSWM difficulty may be primary in NLD. In fact, using VSWM tasks as covariates, differences in arithmetic skills disappeared, and a discriminant analysis showed that a VSWM task—and not arithmetic performances—was able to contribute to identification of NLD children.

It is worth noting that in the psychology literature, the role of VSWM in arithmetic is still controversial: some studies have failed to find evidence for a role of VSWM components in mental calculation (Logie, Gilhooly, & Wynn, 1994; Noël, Désert, Aubrun, & Seron, 2001), but others

have demonstrated the involvement of VSWM in arithmetic (Bull, Espy, & Wiebe, 2008; De Stefano & LeFevre, 2004; Holmes & Adams, 2006; Trbovich & LeFevre, 2003). The involvement of visuospatial abilities and VSWM in mathematics could be even greater in geometry than in calculation, and it could be emphasized in the case of NLD children. In fact, geometry requires by definition the treatment of spatial information of two- and three-dimensional patterns. However, to our knowledge, there are no systematic research studies analyzing the relationship between geometry and VSWM in general, and in particular, in children with NLD. Furthermore, evidence is necessary to support the hypothesis that VSWM is critical in learning geometry. In fact, it has been suggested that success in geometrical tasks is not so critically related to spatial abilities as one would intuitively predict, as many other factors may be crucial, including verbalization, abstract reasoning, metacognition and motivation (Aydin & Ubuz, 2010).

An important point to be considered, when examining the relationship between geometry and underlying cognitive processes, is that geometry is a broad area with many facets. In fact, geometrical competence can involve both intuitive concepts, as well as aspects more associated with schooling. The concept of *intuitive geometry* has been recently introduced by Dehaene, Izard, Pica, and Spelke (2006). These authors investigated whether some principles of geometry can be considered as core culture-free concepts (see also Spelke, Lee, & Izard, 2010) by examining the spontaneous geometrical knowledge of an Amazonian native group that was not exposed to a geometrical instruction. Dehaene and colleagues hypothesized that people might possess primitive principles of geometry, similar to the case for numerical knowledge. In fact, in the numerical field, a growing number of studies have shown that infants seem to respond to the numerical properties of their visual world without the benefit of language acquisition (Koechlin, Naccache, Block, & Dehaene, 1999; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; Xu & Spelke, 2000). To look at the particular case of geometry, Dehaene et al. compared Amazonian indigenes and American children/young adults in intuitive knowledge of geometry, and their results revealed that the Amazonian native group succeeded remarkably well with the intuitive concepts of topology

(e.g., connectedness), Euclidean geometry (e.g., line, point, parallelism, and right-angle), and geometrical figures (e.g., square, triangle, and circle). Dehaene and colleagues consequently considered these concepts as primitive core concepts of geometry. Furthermore, they found that the Amazonian native adult group performed poorly in items assessing geometrical transformations, in which subjects have to use concepts like translations, symmetries, and rotations. The authors concluded that these items all imply a mental transformation of one shape to another, and they might require culturally mediated, noninnate concepts of geometry. In a recent study, Giofrè, Mammarella, Ronconi, and Cornoldi (2011) showed that VSWM has a critical role in intuitive geometry and that both VSWM and intuitive geometry contribute to academic achievement in geometry. They also suggested that VSWM is more critical in supporting the acquisition of culturally mediated concepts of geometry than in the acquisition of the primitive core ones.

The present study was devoted to exploring the geometrical competencies and the role of VSWM in children displaying some symptom of NLD who were hypothesized to encounter difficulties in geometry. It should be noted that our NLD group had not received a clinical diagnosis but was identified through a school screening. In particular, our NLD group displayed the most typical symptoms of NLD, both reported by their teachers through the Short Visuospatial (SVS) Questionnaire (Cornoldi et al., 2003) and recognized through two subtests (i.e., one spatial and one verbal) of the Primary Mental Ability (PMA) battery (Thurstone & Thurstone, 1963). Our screening did not use mathematical difficulties as a criterion for identifying children with NLD, thus avoiding the risk of a circularity of looking for mathematical difficulties in children identified on the basis of a mathematical difficulty.

The main aims of the current study were as follows: First, we wanted to examine whether the mathematical difficulties of NLD children could be extended to the case of intuitive geometry; second, we looked for further support for the presence of VSWM deficits of NLD children, mainly in complex-span tasks; and third, we examined whether the hypothesized VSWM deficits are

critical in explaining group differences in intuitive geometry, thus offering indirect evidence for the assumption that skill in geometry is supported by VSWM.

To reach these aims, in the present study, different measures of VSWM and intuitive geometry were administered to the group of NLD children and to a control group matched for verbal general abilities, age, gender, and socioeconomic level. For VSWM, three simple storage tasks (visual, spatial-sequential, spatial-simultaneous) and three complex-span tasks were used. The simple storage tasks were selected on the basis of the Cornoldi and Vecchi model (2003), distinguishing between visual, spatial-sequential, and spatial-simultaneous. The complex-span tasks were selected from the literature and chosen to ensure a variety of task types, mapping different processes. To examine geometry, we administered the intuitive geometry task (Dehaene et al., 2006). As already mentioned, this test involves trials assessing different concepts of geometry. This articulation offered the possibility of individuating the aspects where the specific visuospatial deficit of NLD could have a greater impact and, in contrast, the aspects where abstract reasoning, supported by language, could compensate for the visuospatial deficit.

Method

Participants

The initial screening involved a sample of 278 children (143 males, 135 females) aged 11 to 13 years ($M = 149.69$ months; $SD = 10.61$), with 99 children from sixth grade, 100 from seventh grade, and 79 from eighth grade.

The identification of NLD children and the control group (CG) was carried out on the basis of difficulties detected by their teachers through the SVS Questionnaire (Cornoldi et al., 2003). General verbal and visuospatial abilities were evaluated using the Verbal Meaning and Spatial Relations subtests of the Primary Mental Ability Test (PMA; Thurstone & Thurstone, 1963),

respectively. For all children, parental consent was obtained prior to testing. Children referred to as having a very low socioeconomic level were not included in the groups.

The inclusion criteria of NLD children were the following: (a) visuospatial scores on the SVS Questionnaire lower than 20th percentile; (b) scores lower than two standard deviations in the Spatial Relations subtest of the PMA; and (c) average scores in the Verbal Meaning subtest of the PMA. In contrast, the inclusion criteria of the CG group were the following: (a) scores equal to or higher than 50th percentile in the visuospatial score of the SVS Questionnaire and (b) average performance in both PMA subtests (Spatial Relations and Verbal Meaning).

Our sample was composed of 16 NLD children (9 male and 7 female), sixth, seventh, and eighth graders, aged between 11 and 13, and 16 control group (CG) children (9 male and 7 female) matched for age, schooling, gender, PMA Verbal Meaning subtest scores, and socioeconomic level as assessed by their teachers (Table 1).

Insert Table 1 about here

As shown in Table 1, the two groups did not differ significantly in terms of age or scores on the PMA Verbal Meaning subtest. As expected, the differences between groups were significant on the visuospatial scores of the SVS Questionnaire and on the PMA Spatial Relations subtest. Each child's socioeconomic level was estimated by teachers using a 4-point scale (1 = high socioeconomic level; 2 = medium-high; 3 = medium-low; 4 = very low), and the two groups did not differ in this estimation (U Mann-Whitney $p = .37$).

Materials and Procedure

Participants were tested in an individual session lasting approximately 1 hour in a quiet room outside the classroom. In order to avoid biasing of performance in any test through effects of practice or fatigue, test presentation order was counterbalanced according to a randomized Latin

square. Children were presented with six VSWM tasks and the intuitive geometry task (Dehaene et al., 2006).

Visuospatial Working Memory Tasks

Participants were presented with six tasks (four computerized, two paper-and-pencil). Five of them were part of an Italian standardized VSWM test battery (Mammarella, Toso, Pazzaglia, & Cornoldi, 2008), while the dot matrix test was derived from Miyake, Friedman, Rettinger, Shah, and Hegarty (2001). Three tests were simple storage tasks (i.e., passive), while three were complex-span tasks (i.e., active). Moreover, the simple storage tasks were distinguished as visual, spatial-sequential, and spatial-simultaneous (Cornoldi & Vecchi, 2003; Mammarella, Pazzaglia, & Cornoldi, 2008; Pazzaglia & Cornoldi, 1999).

The six tests used a self-terminating procedure: They were administered starting with the simplest series and rose in complexity, and participants continued as long as they were able to solve at least two items out of three at a given level. For scoring, we used the absolute scoring method, as it is predominantly used in child working memory (WM) research (Hornung, Brunner, Reuter, & Martin, 2011). Items at the second level had a value of 2, at the third level a value of 3, and so on; final scores were the sum of the values for the three final correct responses (for example, if a participant successfully solved two items at the fourth level and one at the fifth, then the score was $4 + 4 + 5 = 13$). Before administering each task, participants were given two practice trials with feedback.

Simple Storage Tasks

In simple storage tasks, participants had to decide whether a series of figures/locations were the same as or different from the one previously presented: following a first stimulus presentation, either the same stimulus or one with a change of just one element was presented. This was followed by a response screen containing two letters, U (*uguale* = same) and D (*diverso* = different):

Participants had to respond by pressing one of two keys on the keyboard.

The *nonsense shapes task*, involving passive visual working memory, was based on the presentation of nonsense figures varying from two to eight, according to the complexity level. At the beginning of each trial, a blank screen appeared for 1000 ms, followed by another blank screen for 500 ms, and then the nonsense figures (3000 ms), followed by another blank screen for 500 ms. After presentation of a fixation point for 1500 ms, either the same series of figures or a series differing in one figure was presented for the recognition task.

The *sequential dot matrix task* involved passive spatial-sequential working memory. In this task, a gray screen was presented for 1000 ms followed by a 5 x 5 matrix shown to participants for 250 ms. Immediately afterward, red dots appeared in various cells of the matrix one at a time for 1000 ms, followed by a 250-millisecond interval. The number of red dots varied from two to eight, according to the complexity level. After a delay of 500 ms after the last red dot appeared, a fixation point of 1000 ms, and another delay of 500 ms, the same sequence or one with one red dot in a different order was presented at the same rate. Participants had to decide whether the sequence of dots was the same as that just presented, or if there was a change in order.

The *simultaneous dot matrix task* involved passive spatial-simultaneous working memory. The same display as that used in the sequential dot matrix task was used (5 x 5 matrices), but this time the red dots appeared simultaneously. In the test, participants had to decide if the new pattern of red dots was the same as that just presented, or whether one red dot appeared in a different location. After a blank screen of 1000 ms, a 5 x 5 matrix appeared on the screen for 500 ms, and then a variable number (two to eight, depending on the complexity level) of red dots appeared for 2500 ms, followed by another delay of 500 ms. After a fixation point of 1000 ms, the same arrangement of dots, or one with a red dot in a different location, was presented.

Complex-Span Tasks

The *jigsaw puzzle task* (adapted from Vecchi & Richardson, 2000) tests the ability to manipulate a visual shape. It consists of a series of drawings derived by Snodgrass and Vanderwart (1980). Each drawing is fragmented into 2 to 10 numbered pieces forming a puzzle. Drawings

represent common, inanimate objects with a high value of familiarity and of image agreement. Each whole drawing is presented for 2000 ms, together with its verbal label, and is then removed. The material of each puzzle and the response sheet (a blank matrix with a number of cells corresponding to the number of pieces) are then displayed in front of the participant with the pieces set out in a nonordered way. Puzzles have to be solved not by moving the pieces but by writing down or pointing to the corresponding number of each piece on a response sheet. The level of complexity is given by the number of pieces composing each puzzle (e.g., from 2 to 10).

The *dot matrix task* (derived from Miyake et al., 2001) tests the ability to simultaneously process visuospatial information and to maintain information in the visuospatial store. The test required participants to verify a matrix equation while simultaneously remembering a dot location in a 5 x 5 matrix. Each trial contained a set of matrix equations to be verified, each followed by a 5 x 5 matrix containing one dot. In the matrix equation display, a simple addition or subtraction equation was presented. Participants were given 4500 ms to verify whether the sum (or subtraction) of two successively presented segments was correctly described by a third presented pattern. Immediately afterward, a 5 x 5 matrix containing a dot in one cell was automatically displayed on the screen for 1500 ms. After a sequence of two to five equations and matrices, participants had to recall (in any order) which cells of the 5 x 5 matrix had contained dots (by clicking in the empty cells with the mouse).

The *visual pattern test, active version* (VPTA; derived from Della Sala, Gray, Baddeley, & Wilson, 1997) tests the ability to maintain simultaneously presented spatial information and to make a simple transformation of it. Participants were presented with matrices created by filling half cells of a matrix for 3000 ms. The matrices increased in size from smallest (four squares at first level, with two filled cells) to largest (20 squares at final level with 10 filled cells). After the presentation phase, when participants memorized the filled squares, the initial stimulus was removed, and participants were presented with a blank test matrix on which they had to reproduce the pattern, filling in the cells corresponding to the positions in a row *below* the row filled in the

presentation matrix (whose bottom row was always empty). For example, if in the presentation matrix the second square in the first row was filled, the participant had to fill in the second square in the second row. The level of complexity was defined as the number of filled cells in the matrix (2 to 10).

Intuitive Geometry Task

In the *intuitive geometry task* (Dehaene et al., 2006), items were randomly presented by a computer. At the beginning of the procedure, a masking screen appeared for 2000 ms, followed by the stimuli (randomly presented). Each stimulus remained on the screen until subjects gave a response. Items consisted of an array of six images, five of which instantiated the desired concept, while the remaining one violated it. For each stimulus, participants were asked to point to the odd-one-out.

Participants were presented with 43 items split into seven concepts: topology (e.g., closed vs. open figures), Euclidean geometry (e.g., concepts of straight lines, parallel lines, etc.), geometrical figures (e.g., squares, triangles, and so on), symmetrical figures (e.g., figures showing horizontal vs. vertical symmetrical axes), chiral figures (in which the odd-one-out was represented by a mirrored figure), metric properties (e.g., the concept of equidistance), and geometrical transformation (e.g., translations and rotations of figures).

Different scores were computed: first, the total mean percentage of correct responses, and, second, the mean percentages of correct responses derived from the seven concepts of geometry.

Results

Differences in Intuitive Geometry and VSWM

The mean scores obtained by the NLD and control group are presented in Table 2. Moreover, the mean percentages of correct responses of the two groups in the seven concepts of geometry are reported in Figure 1.

A one-way analysis of variance (ANOVA) comparing the two groups showed significant differences on the total score of geometry, $F(1, 30) = 10.08, p = .003$, Cohen's $d = 1.12$). Moreover, NLD children performed significantly more poorly than did the CG in Euclidean geometry, $F(1, 30) = 6.93, p = .013$, Cohen's $d = .93$, and in geometrical transformation, $F(1, 30) = 7.77, p = .009$, Cohen's $d = .99$. No differences between groups were found in topology, $F(1, 30) = 3.08, p = .09$, Cohen's $d = .62$, geometrical figures, $F(1, 30) < 1$, Cohen's $d = .26$, symmetrical figures, $F(1, 30) < 1$, Cohen's $d = .21$, chiral figures, $F(1, 30) = 2.83, p = .10$, Cohen's $d = .59$, and metric properties, $F(1, 30) = 2.26, p = .14$, Cohen's $d = .53$.

For VSWM tasks, two multivariate analyses of variance (MANOVAs) were performed: The first compared simple storage tasks (nonsense shapes, sequential dot matrix, and simultaneous dot matrix tasks) by group and the second complex-span tasks (jigsaw puzzle, dot matrix, and VPTA) by group. We chose to calculate two separate MANOVAs, since the two categories of tasks are clearly distinguishable (see for example, Miyake, & Shah, 1999; Cornoldi, & Vecchi, 2003; Cowan, 2005). We did not find a significant difference between groups in simple storage tasks, $F(3, 28) = .69, p = .41, \eta^2 = .02$, while the comparison on complex-span tasks revealed a main effect of group, $F(3, 28) = 5.70, p = .004, \eta^2 = .38$. Univariate tests of significance showed that NLD children and the CG scored significantly differently in all three of the tests: the jigsaw puzzle task, $F(1, 30) = 6.11, p = .019$, Cohen's $d = .87$, the dot matrix task, $F(1, 30) = 10.09, p = .003$, Cohen's $d = 1.12$, and the VPTA, $F(1, 30) = 11.14, p = .002$, Cohen's $d = 1.18$.

Insert Table 2 and Figure 1 about here

In order to analyze the relationship between VSWM and intuitive geometry, we decided to examine the effect of VSWM on the total score of intuitive geometry using analyses of covariance (ANCOVAs). Specifically, we compared the total score of intuitive geometry of the two groups with ANCOVAs, considering the complex-span tasks as covariates.¹ Using both the dot matrix task

and the VPTA as covariates, the difference between groups was no longer significant, respectively, $F(1, 28) = 2.99, p = .09, R^2 = .40$, and $F(1, 28) = 1.92, p = .18, R^2 = .33$; whereas the difference was still significant using the jigsaw puzzle as covariate: $F(1, 28) = 4.75, p = .038$.

Discriminant Function Analysis

In order to find tasks with the highest discriminative power in distinguishing between NLD and CG children, a discriminant analysis was performed to identify the variables most capable of making this distinction and to predict the probability of different participants belonging to each group. Before conducting the discriminant function analysis, issues related to sample size and multivariate normality were addressed (Tabachnick & Fidell, 1996). The criterion that the sample size of the smallest group should exceed the number of predictors was met. Group size was equal, ensuring multivariate normality. The discriminant function analysis was carried out with the stepwise method, using the six VSWM tasks and the total score of intuitive geometry. The tasks included in the analysis were the VPTA and the dot matrix task, for which Wilks' λ (Lambda) = .63, indicating that these were the variables best separating the two groups. The discriminant function analysis had a reliable association with children with NLD and the CG: $\chi^2(2) = 13.32, p < .001$. The VPTA and the dot matrix task were able to correctly classify into groups 68.8% of NLD children (i.e., 11/16) and 87.5% of the CG children (i.e., 14/16).

Discussion

The relationship between VSWM and intuitive geometry was analyzed as a contribution to the study's main goal of examining difficulties in developing geometrical competence. This was approached by administering VSWM and intuitive geometry tasks to NLD children matched with controls for age, gender, verbal abilities, and socioeconomic level. As noted above, our NLD children showed most of the typical symptoms, but they had not been diagnosed as having a

nonverbal learning disability; thus, our results cannot be directly generalized to children with a clinical diagnosis of NLD.

The first main result of the study was that the NLD children's difficulties in mathematics are extended also to the case of intuitive geometry. The result may seem rather obvious, as geometry has an evident visuospatial component and NLD are characterized by a visuospatial weakness, but previously this fact had never been documented. Furthermore, the geometrical failure of NLD children was differentiated; in fact, they performed significantly more poorly than did controls specifically in two subtests: Euclidean geometry and geometrical transformation.

The subtest on Euclidean geometry seems to represent a core concept of geometry. According to Spelke et al. (2010), natural geometry is founded on at least two evolutionarily ancient and cross-culturally universal cognitive systems that capture abstract information about the shape of the surrounding world: two *core systems* of geometry. The first represents the shapes of large-scale navigable surface layouts, while the second represents small-scale movable forms and objects. Empirical evidence regarding the origins of this latter system—which also involves concepts of Euclidean geometry (e.g., line, point, parallelism, and right-angle)—comes from developmental studies demonstrating that infants are sensitive to variations of angle (Schwartz & Day, 1979; Slater, Mattock, Brown, & Bremner, 1991) and length (Newcombe, Huttenlocher, & Learmonth, 1999). This system therefore shows qualitative continuity not only over human development (Izard & Spelke, 2009) but also across cultures (Dehaene et al., 2006). It has to be noted that the Euclidean geometry subtest was relatively easy for all children, and that also NLD children, despite performing significantly poorer than controls, obtained a high percentage of correct responses. For this reason, some caution is needed in interpreting this finding, and further research should examine whether this problem is more evident with younger NLD children.

Geometrical transformation is the second subtest in which we observed significant differences between NLD children and controls. Different from the previous subtest, the performances of both groups were not particularly high; although they were both above the chance

level (which is represented by the value of 16.6% as reported by Dehaene et al., 2006). The geometrical transformation subtest is considered by Dehaene and colleagues as involving a culturally mediated concept of geometry, since children have to individuate the odd-one-out among six images representing modifications based on translations, symmetries, rotations, and so on. In a recent study comparing adults and 4- to 10-year-olds, Izard and Spelke (2009) showed that, at all ages, children were able to detect angle and length relationships but failed to detect directional relationships (i.e., requiring discrimination of rotated images) before adolescence. According to Spelke and colleagues (2010), the core systems of geometry are able to capture Euclidean distance and angle, but not geometrical transformation and, therefore, fail to distinguish, for example, a shape from its mirror image. In our study, the group differences were particularly small in the subtests involving geometrical figures, symmetrical figures, and metric properties, probably because NLD children could rely on their preserved linguistic skills. In particular, geometrical figures could be named and the odd-one-out could be rejected on the basis of the different verbal label. Similarly, the metric properties could also be found through a verbalization process.

In sum, our results suggest that NLD children experience particular difficulty with two specific aspects of intuitive geometry: The first represents a core principle of geometry, while the second is a culturally mediated concept necessary in order to perform geometrical transformations such as mental rotations.

Regarding the second aim of our research (i.e., finding further support for a VSWM impairment in children with NLD), results revealed that NLD children performed significantly more poorly than did the CG on complex-span tasks, but not on simple storage tasks. This result is in agreement with previous research (see, for example, Cornoldi et al., 1995, 1999; Mammarella & Cornoldi, 2005a). The crucial role of VSWM in children with NLD has been extensively demonstrated in the last 30 years, but the present results support the hypothesis that NLD children encounter difficulties in VSWM tasks, especially when information must not only be maintained but also actively processed.

Finally, our third main aim was to analyze whether, to some extent, a VSWM deficit might explain the failure of NLD children in intuitive geometry. This relationship was supported by the observation that NLD children actually presented both types of problems. Moreover, our covariance analyses showed that, when the contribution of two complex-span tasks was eliminated, the difference in the intuitive geometry score between groups also disappeared. Specifically, both the dot matrix task and the VPTA as covariates removed the differences between NLD children and controls in the intuitive geometry task. Mammarella et al. (2008), in an attempt to classify visuospatial complex-span tasks, hypothesized that both the dot matrix task and the VPTA involve spatial working memory processes that are sequentially and simultaneously presented, respectively. Differently, the jigsaw puzzle task seems to involve, to a greater extent, visual working memory processing; in fact, participants have to make complex transformations of visual information. Our results thus confirmed that a spatial working memory difficulty may be primary in children with NLD, offering further support for the assumption that VSWM is critical for some aspects of mathematical cognition, such as intuitive geometry. Both Dehaene et al. (2006) and Giofrè et al. (2011) suggested that intuitive geometry can be distinguished by core and culturally mediated concepts. Furthermore, Giofrè et al. showed that the role of VSWM is critical in supporting culturally mediated concepts of geometry. However, in the current study, a differential pattern of difficulties between these two types of concepts of geometry did not emerge. The novel finding of the present study is then represented by the crucial role of spatial complex-span tasks in intuitive geometry. In fact, as already mentioned, using both the dot matrix task and the VPTA as covariates, the differences between NLD children and the controls in the intuitive geometry task disappeared.

Taking up this point, our study concluded by exploring whether specific tasks contributed to the identification of NLD children. The discriminant function analysis demonstrated that the dot matrix task and the VPTA were the instruments most useful in this sense: Using these VSWM tasks, 68.8% of the NLD children were correctly classified, confirming that, in general, assessment of VSWM is important for analysis of these children. Thus, results from the discriminant function

analysis strengthened the hypothesis that VSWM difficulty is primary in explaining the performances of children showing symptoms of NLD, and that failures in intuitive geometry are mediated by their impairment in spatial working memory tasks. However, it is worth noting that 31.2% of children with NLD were incorrectly classified, thus suggesting that some other variables could be crucial in the identification of children with NLD, such as, motor coordination, visuo-constructive, and visuospatial abilities (Drummond et al., 2005; Gross-Tsur et al., 1995; Roman, 1998; Rourke, 1995). Hence, further research is needed to confirm and extend the present results, to study many other factors, such as motivation and metacognition, that presumably affect the acquisition of geometrical knowledge (see, e.g., Aydin & Ubuz, 2010) and to overcome the limitations of the present research.

For example, a limitation of our study concerns the specific range of VSWM and geometry tasks that were assessed. In particular, the area of geometry is very large, and different aspects could be examined, also with reference to different ages and instructional requirements. Further research should also consider the role of other working memory components and spatial ability tasks. Moreover, the small sample size tested in the current study suggests some caution in interpreting our findings. Despite these limitations, we think that the present study has the merit of opening a window on issues that were until now neglected—specifically, the issue of children having a learning difficulty related to the area of geometry and on their underlying cognitive mechanisms.

In conclusion, our research demonstrates that, in general, children showing symptoms of NLD performed more poorly than did the CG on intuitive geometry and complex-span tasks involving VSWM and that two of the three complex-span tasks used in the current research are appropriate for identifying children with NLD. Furthermore, the fact that these two VSWM tasks accounted for group differences in the intuitive geometry task lends support to the hypothesis that VSWM is involved in geometry and that VSWM deficits in NLD children mediate their difficulties in intuitive geometry.

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Footnotes

¹The interactions between VSWM tests and groups were never significant, demonstrating that the slopes of the covariates are homogeneous in the two groups. Specifically, for the total score of geometry: dot matrix task by group, $F(1,28) < 1$; VPTA by group, $F(1,28) < 1$; jigsaw puzzle task by group, $F(1,28) = 1.88$ $p = .18$.

Figure Caption

Figure 1: Mean percentages of correct responses on the seven concept of geometry in children showing symptoms of NLD and CG. Error bars represent standard errors.

Figure 1

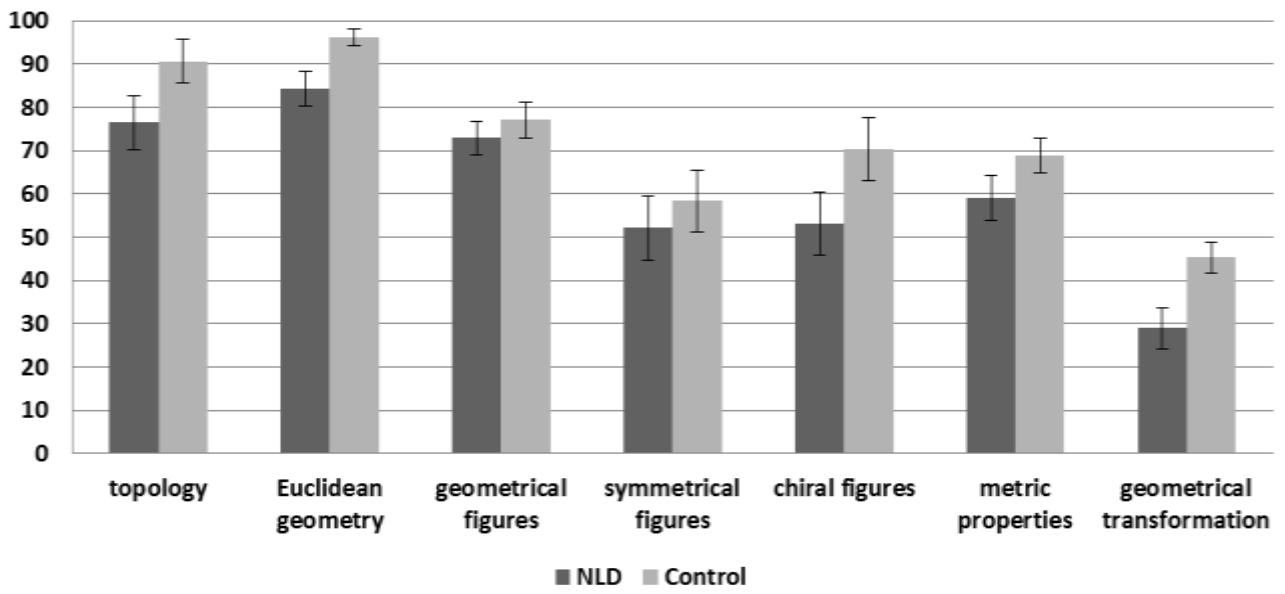


Table 1. Characteristics of children showing symptoms of NLD and controls (CG): mean, standard deviations (SD), confidence intervals (CI 95%), and statistical analyses.

	NLD (N=16)			CG (N=16)			Statistical Analyses		
	Mean (SD)	CI 95%		Mean (SD)	CI 95%		$F(1,30)$	p	η^2
		I.L.	S.L.		I.L.	S.L.			
Age (months)	146.25 (9.52)	141.18	152.32	146.06 (9.21)	141.15	150.97	.003	.955	.0001
<i>Svs Questionnaire</i>									
Visuospatial score	22.81 (2.88)	21.28	24.35	33.38 (3.34)	31.59	35.16	91.64	.001	.75
<i>PMA</i>									
Verbal meaning	13.81 (4.92)	11.19	16.43	13.88 (2.78)	12.39	15.36	.002	.965	.0001
Spatial relations	2.75 (2.79)	1.26	4.24	15.06 (3.99)	12.94	17.19	102.22	.001	.77

Table 2. Reliability, maximum possible score, mean scores at the VSWM tasks and, mean total score for the intuitive geometry task (standard deviations in brackets) for children showing symptoms of NLD and controls (CG).

<i>VSWM tasks</i>	Reliability	Max Possible	NLD	CG	<i>Cohen's d</i>
			<i>M (SD)</i>	<i>M (SD)</i>	
Simple storage tasks					
Nonsense shapes	.83	24	11.5 (6.67)	13.31 (5.61)	.29
Sequential dot matrix	.91	24	14.43 (6.58)	18.63 (3.09)	.82
Simultaneous dot matrix	.90	24	17.19 (4.78)	19.06 (5.09)	.38
Complex span tasks					
Jigsaw puzzle	.84	30	11.25 (6.02)	16.25 (5.41)	.87
Dot matrix	.79	12	5.44 (3.61)	8.63 (1.75)	1.12,
VPTA	.89	30	8.06 (7.07)	15.13 (4.65)	1.18
Intuitive geometry task (mean percentages)					
Total score	.65	100%	61.63 (12.07)	72.67 (6.92)	1.12