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Imaginative representations of two- and three-dimensional matrices in children with nonverbal learning disabilities

Cesare Cornoldi^{*}, Paola Ficili^{*}, David Giofrè^{*}, Irene Cristina Mammarella^{**}, Chiara Mirandola^{*}

^{*} Department of General Psychology, University of Padova, Italy

^{**} Department of Developmental and Social Psychology, University of Padova, Italy

Correspondence concerning this article should be addressed to:

Cesare Cornoldi

Department of General Psychology

University of Padua

via Venezia 8 – 35131 – Padova - Italy

E-mail: cesare.cornoldi@unipd.it

Abstract

Children with non-verbal learning disabilities (NLD) are characterized by high verbal and poor non-verbal intelligence, poor cognitive abilities, school difficulties, and—sometimes—depressive symptoms. NLD children lack visuospatial working memory, but it is not clear whether they encounter difficulties in mental imagery tasks. In the present study, NLD adolescents without depressive symptoms, depressed adolescents without NLD symptoms, and a control group were administered a mental imagery task requiring them to imagine to move along the cells of a 2-D (5×5) or 3-D ($3 \times 3 \times 3$) matrix. Results showed that NLD adolescents had difficulty at performing the imagery task when a 3-D pattern was involved. It is suggested that 3-D mental imagery tasks tap visuospatial processes which are weak in NLD individuals. In addition, their poor cognitive performance cannot be attributed to a depressive state, as the depressed group had a performance similar to that of controls.

Introduction

A nonverbal learning disability has been described in the literature as a discrepancy between high verbal and poor non-verbal intellectual abilities (Myklebust, 1975; Rourke, 1989, 1995).

According to Pelleiter, Ahmad, and Rourke (2001; see also Rourke, 1989, 1995) children with non-verbal learning disabilities (NLD) may experience three main categories of dysfunction:

1. motor: lack of psychomotor coordination, impairments in fine graphomotor skills and complex motor skills (e.g., Harnadek & Rourke, 1994);
2. social: lack of ability to comprehend non-verbal communication often leading to eventual isolation, withdrawal, and difficulties in dealing with novel situations (e.g., Petti, Voelker, Shore, & Hayman-Abello, 2003; Rourke & Fuerst, 1996; Tsatsanis, Fuerst, & Rourke, 1997); and
3. visuospatial organization: impairments in non-verbal problem solving, mathematics, science, concept-formation, and difficulties with mental images and spatial relations (Strang & Rourke, 1983, 1985).

Children with NLD typically experience a variety of academic difficulties in school tasks involving visuospatial abilities (mathematics, science drawing etc.). Furthermore, there is evidence that children with NLD are at increased risk for developing psychopathology, particularly internalizing disorders (e.g., depression; Myklebust, 1975; Rourke, 1989; Strang & Rourke, 1985), during adolescence (Casey, Rourke, & Picard, 1991; Rourke, 1989; Rourke, Young, & Leenaars, 1989).

A core problem in NLD children seems represented by a weakness in visuo-spatial working memory (VSWM), as it has been shown in a series of studies (e.g., Mammarella & Cornoldi, 2005). Given that VSWM is strictly interconnected with the generation and maintenance of mental images (Baddeley, 1986; Brooks, 1967; Cornoldi, 1995; Cornoldi, Dalla Vecchia, & Tressoldi, 1995; Cornoldi & Vecchi, 2003), one could predict that NLD children also run into difficulties in mental imagery tasks, but—surprisingly—there is no clear evidence on this topic. To our knowledge, only

two studies of our research group dealt with this issue. In one study, Cornoldi and Guglielmo (2001) observed that a group of low-spatial, high-verbal intelligence children performed poorly in a series of visual mental imagery tasks (including image generation, inspection, and transformation), but not in the verbal ones. In the second study, Cornoldi, Rigoni, Tressoldi, and Vio (1999) investigated the generation and manipulation of mental images in working memory and found that visuospatial learning disabled children (VSLD) also failed in active tasks which required the generation of mental images. On the contrary, deficits in visual mental imagery tasks have been extensively studied in other groups and, in particular, in blind individuals. For the purposes of the present study, a particularly relevant research was carried out by Cornold

Cortesi, and Preti (1991) who asked their participants to imagine to move along the cells of two- and three-dimensional matrices; they found that congenitally blind individuals were able to generate visuospatial mental images, along with a severe limitation with three-dimensional patterns. Sighted individuals, instead, were able to cope with a large number of cells with a three-dimensional matrix ($3 \times 3 \times 3$ matrix vs. 5×5 matrix, see also Kerr, 1987).

Both blind and individuals with NLD, despite their differences in many abilities, are characterized by visuospatial deficits and tend to engage in verbal activities which do not require visuospatial knowledge. In order to test whether individuals with NLD have similar difficulties at performing imaginative tasks involving two- and three-dimensional matrices, as blind do, we used and adapted the methodology appeared in Cornoldi and Guglielmo (2001) to select adolescents with visuospatial difficulties; further, we used the same materials first adopted by Kerr (1987).

The task administered is the Mental Pathway task (Kerr, 1987), which was initially developed to explore the ability to generate mental images from verbal instructions and to maintain and process them on the basis of information presented subsequently; participants are required to imagine to move within 2-D (5×5) and 3-D ($3 \times 3 \times 3$) matrices, following a pathway whose directions are orally provided by the experimenter, and then they are asked to point to the final

position reached. The task was administered to a NLD group, to a control group, and also to a third group formed by adolescents with depressive traits (depressed group). In fact, given that adolescents with NLD tend to experience depressive traits (see Rourke, 1989), which could affect the outcome of some cognitive tasks, we decided to administer a test for depression to the participants with NLD in order to exclude this possibility, but we also included a group of adolescents with depressive traits and good visuospatial and verbal abilities, in order to evaluate whether depression could indeed affect the cognitive performance. Finally, the performance of a control group of adolescents matched for age and with good visuospatial and verbal abilities was compared to that of the other two groups.

Furthermore, we included a variation within the task, adapted from Fiore, Borella, Mammarella, and Cornoldi (2010). In their study, Fiore and colleagues (2010) had a group of adults and elder participants perform a task similar to that proposed by Kerr (1987) but with an active manipulation of the stimuli presented.

In details, participants were asked to imagine to move within 2-D and 3-D matrices, mentally following a pathway with two different requests: recalling either the final position (FP) or both the final position and the whole pathway (WP). In the FP condition (after participants had been given instructions for the direction of each pathway they were required to mentally follow) they were asked to recall only the last position of the imagined pathway. In contrast, in the WP condition participants had to remember both the final position and the whole pathway; thus, they had to keep highly activated all positions of the pathway. Fiore et al. (2010) found that younger adults performed better than the older group in both WP and FP, and that older adults were more impaired in WP than in FP.

We were thus interested in evaluating whether adolescents with NLD would be affected by this further manipulation. On the one hand, it could be hypothesized that adolescents with NLD would not fail in such a task, given that impairments at the level of executive functions have not

been reported. On the other hand, there is evidence that children with NLD may be affected by irrelevant information (Mammarella & Cornoldi, 2005) and may thus fail in tasks such as the one described, especially in the WP condition (Fiore et al., 2010). Mammarella and Cornoldi (2005) argue that children who fail to remember the correct position cannot take advantage of the possibility of excluding irrelevant locations previously processed.

Method

Participants

From an initial sample of 405 children aged between 13 and 17, attending middle and high schools, we selected a group of 16 NLD children (6 boys and 10 girls) with a mean age of 14.5 years ($SD = .61$) and two comparison groups, a group of 11 children with depressive traits (3 boys and 8 girls) with a mean age of 15.09 years ($SD = .69$) and a control group of 18 children (6 boys and 12 girls) with a mean age of 14.44 years ($SD = .51$). Written consent from parents was obtained for all participants before beginning. The children of the NLD group were described by their teachers as poor learners and obtained a low score ($M = 0.36$, $SD = 0.68$) on the “Spatial Reasoning” test included in the Primary Mental Abilities (PMA; Thurstone & Thurstone, 1963). The task consists of the presentation of a target stimulus and of six different alternative test stimuli; the child had to identify which of the six test stimuli correspond to the rotated version of the target stimulus.

Adolescents were considered for inclusion in the Depressed group if their score obtained at the Children’s Depression Inventory (CDI; Kovacs, 1988) was the same or higher than the mean score that characterizes children with a major depressive disorder ($M = 21.36$, $SD = 3.24$). Children in the NLD and Depressed group did not have a general cognitive deficit, and they were similar in the “Verbal Meaning” test included in the PMA battery (i.e., a subtest based on the identification of synonyms), which did not relate to their specific problem (scores were, respectively, $M = 14.72$, $SD = 3.03$ for the NLD group and $M = 14.78$, $SD = 4.19$ for the Depressed group). The Control Group

had a mean score of $M = 15.04$ ($SD = 2.05$) on the PMA “Verbal Meaning” (comparable with NLD and Depressed groups). On the abovementioned “PMA-Spatial Reasoning,” the Control Group obtained a mean score of 13.69 ($SD = 1.62$; comparable to that of the Depressed group but significantly greater than NLD group) and on the CDI the Control Group had a mean score of 11.91 ($SD = 2.95$; comparable with NLD group but

significantly poorer than that of the Depressed group). Table 1 reports the overall scores obtained by the three groups of children, with respect to PMA (Spatial Reasoning and Verbal Meaning) and to CDI.

Materials and Procedure

Mental Pathway Task (adapted from Kerr, 1993)

This task used 3-D versus 2-D matrices composed of 3 cm cubic wooden blocks (examples are given in Figure 1). A total of 24 trials were presented, 12 based on a 3-D matrix, 12 on a 2-D matrix. Participants were asked to look at the matrix in order to memorize its mental representation; the matrix was then covered up and participants had to mentally follow a pathway whose directions were verbally given by the experimenter; in particular, they were told to imagine to move sequentially through adjacent blocks. For both types of matrices, to make the task more realistic, the metaphor of a visit to a complex building was used: participants were told that the pathway would be similar to one that they could be asked to follow inside a building, with each block corresponding to a room. In the 3-D matrix ($3 \times 3 \times 3$) type, participants were presented with a total of 12 pathways (6 in FP and 6 in WP condition), each involving seven statements of directions read aloud by the experimenter at a rate of 2 seconds per statement. The starting point of each pathway was the top-left block. The statements of directions were left/right, forward/backward, and up/down (only for 3-D matrix). Any block, including those of the back side which, from an imaginal frontal

point of view, are hidden, could be included in the pathway; no block occurred more than once in a pathway.

Two task conditions were proposed: in the FP condition, the participants had to recall only the last position of the imagined pathway at the end of the presentation of each pathway; in the WP condition, they had to remember the final position and then the whole pathway. Participants were told upon beginning whether they would have to recall only FP, or both FP and WP. In the 2-D matrix (5×5) type, the task was the same as for the 3-D matrix, except for the fact that it involved cells in only two varying dimensions. Participants were presented with a total of 12 pathways (6 in FP and 6 in WP condition). As before, participants had to mentally follow a pathway on the matrix and then, depending on task condition, either point to FP or point to FP and then point to the whole pathway (WP). Again, participants were told in advance whether they would have to recall only FP or both FP and then WP. Each pathway involved seven statements of directions read aloud by the experimenter at the rate of 2 seconds per statement. The starting point was the bottom-left block. The order of conditions was balanced. For both 3-D and 2-D matrices, the order of FP and WP conditions was counterbalanced across participants. Further, in both matrices participants were familiarized with the matrix through two practice trials, during which they were allowed to follow the pathway directly on the matrix; feedback cues were provided for the practice trials. Performance was evaluated in terms of the number of correctly reported last positions in FP task and in terms of the number of correctly reported pathways in WP condition.

Table 1 about here

Figure 1 about here

Results

As it can be seen in Table 2, the most important result of the present study concerns the difficulty the NLD group had with the three-dimensional matrices. A $3 \times 2 \times 2$ mixed ANOVA (Group [NLD, DG, CG] \times matrix type [5×5 , $3 \times 3 \times 3$] \times task condition [FP, WP]) showed a trend toward significance for the variable Group ($F(2, 42) = 3.08$, $MSE = 2.82$, $p = .056$, $\eta_p^2 = .13$), such that the NLD group had in general a worse performance than the other two groups. We also found a main effect of task condition ($F(1, 42) = 7.18$, $MSE = 1.46$, $p = .010$, $\eta_p^2 = .15$), qualified by a significant interaction between matrix type \times task condition ($F(1, 42) = 4.43$, $MSE = 1.15$, $p = .041$, $\eta_p^2 = .10$), such that in the 3-D condition, participants have a better performance when they have to remember only the last position. The other effects were not significant.

Table 2 about here

In general, the raw scores of the Control Group were comparable to the raw scores of the Depressed group (see Table 2), showing that an eventual condition of depression is not critical for a low performance in the task. Of more interest was the comparison between the scores of the control group and the scores of the NLD group. Comparisons with the Student t-test showed that the difficulty of the NLD with the three-dimensional matrix was particularly evident when the working memory load was greater (i.e., with the whole pathway condition). In fact, we found: a significant effect of WP $3 \times 3 \times 3$, $t(32) = 2.47$, $p = .019$; a trend of FP $3 \times 3 \times 3$ ($p = .12$); and null effects of FP 5×5 ($p = .38$) and WP 5×5 ($p = .48$). As distributions were not perfectly normal, we replicated the comparisons with the Mann-Whitney test finding the same pattern. In fact, we found: a significant effect of WP $3 \times 3 \times 3$ ($U = 88.50$, $p < .05$); a trend toward significance of FP $3 \times 3 \times 3$ ($U = 96.00$, $p = .092$); and null effects of FP 5×5 and WP 5×5 ($U = 123.50$, $p = .469$, and $U = 127.00$, $p = .542$ respectively).

Discussion

There is a growing body of evidence on non-verbal learning disabilities. However, despite the fact that many children are diagnosed with NLD, there is still a paucity of studies on this topic, compared to other learning disabilities which involve the verbal component. In particular, the ability to represent mental images has been poorly investigated in children with NLD, letting only to hypothesize the role of this ability in visuospatial imagery tasks and eventual difficulties these children may run into. The present study was aimed at further investigating this issue, requiring participants to imagine to be moving within two- and three-dimensional matrices. We hypothesized that adolescents with NLD would have a similar performance to that of blind individuals, which indeed have problems in the visual and spatial domains (Cornoldi et al., 1991), thus showing greater difficulties at the three-dimensional tasks. In three-dimensional tasks, differently from two-dimensional ones, adolescents with NLD may not take advantage of their verbal abilities in performing the task. Results confirmed this hypothesis. However, we cannot rule out the possibility that younger children may encounter problems even at the level of two-dimensional tasks. The fact that adolescents, in our study, did not fail the two-dimensional matrices could be due to the fact that they may have gained strategies and abilities useful for the fulfillment of two-dimensional tasks. One could argue that the nature itself of the task we adopted for selecting these participants, namely a task of spatial abilities, could have “a role in the outcome of the study.” However, the spatial task included in the PMA battery is thought to tap a pure visuospatial ability, regardless of the content of the information provided; further, the item included in the task adopted here are all two-dimensional items.

Another hypothesis could be that the underlying difficulties were due to the effects of depressive traits, often reported in individuals with NLD. However, the adolescents included in the NLD group were selected upon their score on the CDI and were excluded if depressive traits were available. They were thus only characterized by non-verbal difficulties. The comparison with the

performances of the NDL group and the group with depressive symptoms (without any difficulty in the non-verbal domain) gave us the possibility of examining a potential influence of depression. Results showed that the group of adolescents with depressive traits performed more poorly than the control group in three out of the four conditions, but the difference was far from significant. Furthermore, in one condition depressed children were even better than controls, suggesting that emotional and motivational factors are not presumably crucial in the performance on the task.

Finally, for what concerns the condition in which only the last position of the pathway was to be remembered, requiring, thus, an updating of the information, adolescents with NLD did not specifically fail in this task, instead performed more poorly in the condition which required them to memorize the entire pathway. This last task involved a higher engagement of VSWM, but did not require inhibitory mechanisms. It has been previously hypothesized that younger children with NLD may have inhibitory difficulties (Mammarella & Cornoldi, 2005), making it reasonable to conclude that in these children the inhibitory difficulty could be determined by the influence of more general visuospatial abilities. In the present study, adolescents with NLD had difficulty at the three-dimensional level which did not involve specific control processes over the updating of information. Future research should examine whether even adolescents would fail in more complex tasks which require the inhibitory mechanisms and the online updating of information.

In conclusion, our data show that children with NLD have a particular difficulty when they must process a high quantity of information in a three dimensional pattern. This result has two main implications. First it suggests that individuals with spatial difficulties may overcome spatial requests that involve two dimensions, but they need help and training when three dimensional representations are required. Second, it suggests that the representation of the three dimensional space is highly specific and requires the allocation of spatial resources which cannot be supported by resources related with other modalities.

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Figure 1

An example of the 5x5 and 3x3x3 matrices.

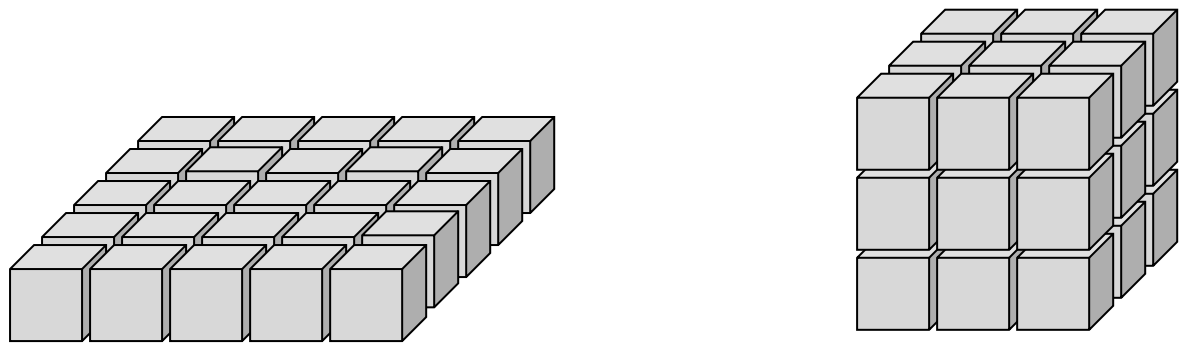


Table 1.

Means and Standard Deviations of the Raw Scores Obtained at the PMA and CDI Batteries by the Group of Children with Non-Verbal Learning Disability (NLD), the Group of Children with Depressive Traits (Depressed Group) and the Control Group

	NLD		Depressed group		Control group	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
PMA Spatial Reasoning	.36	.68	14.3	2.6	13.7	1.9
PMA Verbal Meaning	14.7	3.03	14.8	4.2	15.04	2.05
CDI	11.2	2.9	21.4	3.2	11.9	2.9

Table 2

Means and Standard Deviations Obtained by the Three Groups in the Four Conditions: Final Position 5×5 (FP), Final Position (FP) $3 \times 3 \times 3$, Whole Pathway (WP) 5×5 , and Whole Pathway (WP) $3 \times 3 \times 3$

	<i>NLD</i>		<i>Depressed</i>		<i>Control</i>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
FP 5×5	1.56	1.21	1.45	1.2	2	1.61
FP $3 \times 3 \times 3$	1.75	1.77	2.18	1.47	2.67	1.5
WP 5×5	1.25	1	1.82	.87	1.5	1.04
WP $3 \times 3 \times 3$.69	.95	1.45	1.86	1.94	1.83