Impairment of simultaneous-spatial working memory in nonverbal (visuospatial) learning disability: A treatment case study

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We report the case of B.A., an 11-year-old child with a nonverbal (visuospatial) learning disability (NLD). Detailed psychometric and neuropsychological assessment on visuospatial working memory (VSWM) revealed specific simultaneous-spatial working memory impairment. A treatment targeting simultaneous-spatial working memory was given to B.A. for seven sessions (over one month); this resulted in improvement of simultaneous-spatial working memory, with the benefit that the training was maintained after six months.

Discussion of clinical and theoretical implications is given, taking account of the distinctions that can be made between the different components of visuospatial working memory and different subtypes of NLD, thus allowing the tailoring of specific training to target the impaired VSWM component.

Keywords: Nonverbal (visuospatial) learning disability; Visuospatial working memory; Treatment; Single case.

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INTRODUCTION

The nonverbal (visuospatial) learning disability

Nonverbal (visuospatial) learning disability (NLD) children are characterised by intact verbal, but impaired visuospatial abilities (Nichelli & Venneri, 1995; Rourke, 1989; Voeller, 1986). Over the past 20 years a growing number of studies have also been devoted to understanding and describing the typical impairments of children with NLD. This is a rare type of learning disability, described for the first time by Johnson and Myklebust (1967) and then by Rourke under the label of nonverbal learning disabilities syndrome (Rourke, 1989, 1995). However, at present, NLD is not included in either the International Classification of Diseases (ICD-10) or the Diagnostic and Statistical Manual of Mental Disorders (DSM-IVR).

Children exhibiting NLD typically show problems in visuospatial-organisational, psychomotor, tactile-perceptual, nonverbal problem-solving skills, and visuospatial working memory deficits (Cornoldi, Dalla Vecchia, & Tressoldi, 1995) associated with right hemisphere dysfunction (Tranel, Hall, Olson, & Tranel, 1987), but perform normally in linguistic tasks such as rote verbal learning, verbal classification and regular phoneme-grapheme matching. Children with NLD also quite commonly encounter difficulties in a number of aspects of academic learning, especially drawing, science (Pelleiter, Ahmad, & Rourke, 2001), arithmetic (Mammarella, Lucangeli, & Cornoldi, 2009; Rourke, 1993; Venneri, Cornoldi, & Garuti, 2003) and informal learning (during spontaneous playing activities and other social situations). Forrest (2004; see also Badian, 1983; Johnson & Myklebust, 1967) suggested that the mathematics abilities of children with NLD are not uniform, and that problems in the social sphere seem to be due to a low competence in comprehending nonverbal communicative signs in social and emotional contexts.

Even though children with NLD have been examined in a wide variety of studies (see Rourke, 1995, for a review), and diagnostic criteria have frequently been proposed (e.g., Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003; Pelletier et al., 2001), the diagnosis is still under discussion (Solodow et al., 2006) and further cognitive neuropsychological research is needed to find their specific patterns of functioning. However, a critical factor underlying NLD children’s difficulties appears to be related to deficits in visuospatial working memory (see for example, Cornoldi, et al., 1995; Cornoldi, Rigoni, Tressoldi & Vio, 1999; Cornoldi & Vecchi, 2003).

Visuospatial working memory

In the Baddeley model (1986; 2000), visuospatial working memory (VSWM) is described as a working memory slave system devoted to maintaining and
manipulating visual and spatial information. In recent years, increasing evidence has shown that the system should be split still further. For example, numerous studies have shown a double dissociation between tasks for visual and spatial working memory, suggesting empirical evidence for the existence of separate subcomponents within VSWM (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Klauer & Zhao, 2004; Logie, 1995). Animal and human neuroimaging studies, for example, have shown that visual and spatial memory components are related to activation in different regions of the brain, i.e., the dorsal (what system) and ventral (where system) prefrontal cortex, respectively (Courtney, Ungerleider, Keil, & Haxby, 1996; Ungerleider & Haxby 1994; Wilson, O'Scalaidhe, & Goldman-Rakic, 1993).

However, the visual and spatial components of VSWM are not easy to distinguish and are open to further differentiations. Pickering and colleagues (Pickering, Gathercole, Hall, & Lloyd, 2001) proposed that the distinction found in VSWM processes is a static/dynamic one. The basis for this view is the observation that, while differing in their relative visual and spatial content, information also differs in how far the format of its presentation is dynamic (as moving paths between blocks) or static (as static patterns). Recently, Lecerf and de Ribaupierre (2005) suggested three – rather than two – modes of encoding visuospatial information. According to the authors, it is possible distinguish between extrinsic vs. intrinsic encoding. The former is responsible for anchoring with respect to an external frame of reference; the latter is based on the relationships each item has to a pattern. Moreover, two kinds of intrinsic encoding are described. Pattern encoding specifies not only the location of the entire pattern but also relationships between elements of the pattern. Instead, path encoding involves spatio-temporal links between the different positions. Hence, pattern encoding is involved when the task allows simultaneous encoding, whereas path encoding is involved when the task requires sequential encoding. Similarly, Pazzaglia and Cornoldi (1999; see also Mammarella, Pazzaglia, & Cornoldi, 2008a) proposed a distinction between simultaneous-spatial encoding – referring to spatial locations simultaneously presented in a working memory task, which is related to static processes (Pickering et al., 2001) and pattern encoding (Lecerf & de Ribaupierre, 2005), and sequential-spatial encoding, in which participants are presented with spatial locations produced sequentially and have to recall previous positions, which is related to dynamic processes (Pickering et al., 2001) and path encoding (Lecerf & de Ribaupierre, 2005). Finally, Pazzaglia and Cornoldi (1999) proposed the existence of a visual encoding, in which the unitary perception of shapes and/or textures is critical for tasks that require visual information to be recalled.
Nonverbal (visuospatial) learning disabilities and visuospatial working memory

Increasing evidence is being accumulated that confirms the importance of VSWM in understanding the cognitive impairments of children with NLD (Cornoldi et al., 1995, 1999; Mammarella & Cornoldi, 2005a, 2005b). VSWM deficits might explain why children with NLD fail in a series of activities (mathematics, drawing, spatial orientation, etc.) that are assumed to involve VSWM. Study of VSWM in these children may therefore allow a better understanding of the nature of their difficulties and also provide an opportunity to examine the functioning of VSWM. In particular, analysis of VSWM may be useful for individuating different profiles of children with NLD and offer further support to the concept of differentiation between different VSWM components. For example, Cornoldi, Rigoni, Venneri, and Vecchi (2000) analysed two NLD cases that showed a double dissociation between passive (e.g., simple-span) and active (e.g., complex-span) tasks. More recently, Mammarella et al. (2006) tested three children with NLD, aged 8 to 12 years, who showed a double dissociation between sequential-spatial and simultaneous-spatial tasks. In particular, L.P. performed at 1.5 SD below the mean score on a series of simultaneous-spatial tasks, whereas performance on sequential-spatial tasks was relatively good. A similar pattern of results was observed in F.S., who obtained poor scores on three tasks assessing simultaneous-spatial memory but whose scores on sequential-spatial and visual tasks were good. In contrast, B.L.’s performance showed impairments on sequential-spatial tasks but not on simultaneous-spatial tasks. The results of both Cornoldi et al. (2000) and Mammarella et al. (2006) highlight the possibility of distinguishing between different subtypes of NLD on the basis of performance in VSWM tasks. Finally, recent results (Mammarella, et al., 2009) demonstrate that children with NLD may present differentiated weaknesses, with impairment that is more severe in the spatial domain than the visual domain.

Treatment of nonverbal (visuospatial) learning disabilities

A very large number of individuals with NLD are not being adequately assessed or treated (Rourke, van der Vlugt, & Rourke, 2002). Moreover, there are few treatment studies on children with NLD; instead, focus has dwelt on their emotional and social difficulties (Telzrow and Bonar, 2002; Telzrow & Koch, 2003; Rourke, 1995; Voeller, 1986). However, in this context, Forrest (2004) proposed dividing NLD into two categories: visuospatial, for children with visual and spatial deficits affecting academic performance, and social processing, for those whose social skills deficits are primary and cause impairment in everyday functioning. For the first category, the
visual and spatial deficits (in association with academic intervention) should be the main target of treatment. Instead, for the second category, social skills are primary and should be the focus of intervention. However, in the literature, there is a lack of research that tests treatment based on the visual and/or spatial abilities of NLD children.

Aims of the present study

Our main aim was to test the efficacy of a visuospatial memory treatment for a child with NLD. In particular, we investigated whether such a child, suffering simultaneous-spatial working memory impairment, could improve simultaneous-spatial working memory after specific training of this VSWM subcomponent. On the basis of the assumption that different VSWM subcomponents might be partially independent (Cornoldi & Vecchi, 2003), we predicted that specific simultaneous-spatial working memory training should have a specific effect in encoding and maintaining simultaneous-spatial stimuli.

To our knowledge, the only relevant studies in the literature concern either general working memory treatment involving both verbal and visuospatial tasks (Cavallini, Pagnin, & Vecchi, 2003; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005), or else treatment involving only verbal material (Carretti, Borella, & De Beni, 2007; McNamara & Scott, 2001). Specific VSWM treatments have not been studied to date. Our treatment involved not only VSWM tasks, but also a hypothesised subcomponent of VSWM, i.e., simultaneous-spatial working memory.

In simultaneous-spatial tasks, the child is simultaneously presented with objects in various different spatial locations and has to recall the exact location of each one. Hence, order of the objects is not crucial in performing the task, whereas the locations of the objects and also the between-objects relationships become crucial. In the present treatment, three sessions required recognition of locations and identity of the stimuli simultaneously presented, three sessions required them to be remembered, and a last session was introduced to train the simultaneous-spatial memory with reference to everyday situations. This training started with simple tasks, to allow the child to experience success and thus gain motivation. The training was given individually and was presented as a game. The trainer suggested one or more possible strategies for recalling visuospatial information depending on the type of task and/or materials involved and, at the end of each session, strategy efficacy was discussed.

CASE REPORT

B.A. had received a clinical diagnosis of nonverbal (visuospatial) learning disability at a centre for developmental disabilities in Verona, Italy (Don
Calabria Centre) on the basis of the presence of the typical symptoms of children with NLD. At the time of the assessments preceding the training, B.A. was 11 years old and attended sixth-grade. B.A.’s parents and teachers had both become increasingly concerned about the child’s difficulties in dealing with visuospatial material and in academic learning. They reported B.A. as impaired in recalling the position of objects, in orientation in the area around the school, and in remembering the location of familiar landmarks. The teachers were also worried about the difficulties in arithmetic displayed by B.A. at school. The intellectual efficiency of B.A. was assessed in February, 2006 using the only Wechsler scale for children available at that time in Italy (WISC-R, Wechsler, 1974). The child obtained a Verbal IQ of 94, a Performance IQ of 75 and a Total IQ of 84. The results obtained by B.A. on the WISC subtests gave further support to the clinical diagnosis of nonverbal (visuospatial) learning disability, since (in agreement with Pelletier et al., 2001), B.A. obtained his best results on the Similarity and Vocabulary subtests (13 and 10 scaled points, respectively), and worst results on the Picture Completion (5), Block Design (6) and Coding (6) subtests. B.A. performed the Rey’s Complex Figure Test (Rey, 1941), which taps visuo-constructive abilities; the child having to copy a complex drawing. Incidental recall of the design was also tested after a 3-minute delay. B.A.’s performance on both copy and delayed recall was below the 10th percentile.

B.A. did not show either internalised psychopathology or other social disorders. Furthermore, although developmental coordination disorders are often present in NLD (Alloway, 2007; Rourke, 1995; Zoia, Barnett, Wilson, & Hill, 2006), B.A. showed typical motor development. B.A. was not impaired in reading speed ($z = -0.08$), accuracy ($z = 0.16$) or text comprehension ($z = 0.54$).

At the time of the first assessment (February 2006), the child presented difficulties in writing numbers, numerical facts, and mental calculation. From March to July 2006, B.A. received treatment targeting arithmetic abilities, specifically providing strategies useful for recalling numerical facts and for doing mental calculation. Thus, at the time of the assessment preceding the visuospatial memory treatment (July 2006) B.A. was rather slow in doing calculations ($z = -0.89$), and written calculation ($z = -0.20$) made various visuospatial errors (i.e., column confusions and errors in carrying or borrowing), but performances were only modestly below the mean normative data.

In conclusion, the pattern of data derived from the subtests of the WISC-R, the impairment in copying and recalling the Rey’s Complex Figure, the previous difficulties in arithmetic (improved after a training), the good abilities in reading and comprehension and the other symptoms are in line with a diagnosis of NLD, specifically as regards the visuospatial category as described by Forrest (2004).
Pre-treatment visuospatial working memory assessment

For the assessment of the basic components of VSWM, B.A. was presented with the passive VSWM tests from the BVS battery (*Batteria Visuo Spaziale* - Visuospatial Battery; Mammarella, Toso, Pazzaglia, & Cornoldi, 2008b), which involves nine computerised VSWM tests (see Figure 1): three to assess

<table>
<thead>
<tr>
<th>VISUAL MEMORY</th>
<th>SPATIAL MEMORY</th>
</tr>
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<tbody>
<tr>
<td><strong>SEQUENTIAL</strong></td>
<td><strong>SIMULTANEOUS</strong></td>
</tr>
<tr>
<td>Nonsense Shapes Task</td>
<td>Sequential Light-Bulbs Recognition Task</td>
</tr>
<tr>
<td><img src="image1" alt="Nonsense Shapes Task" /></td>
<td><img src="image2" alt="Sequential Light-Bulbs Recognition Task" /></td>
</tr>
<tr>
<td>Little Fish Recognition Task</td>
<td>Sequential Lines Test</td>
</tr>
<tr>
<td><img src="image4" alt="Little Fish Recognition Task" /></td>
<td><img src="image5" alt="Sequential Lines Test" /></td>
</tr>
<tr>
<td>Toy Balloons Recognition Task</td>
<td>Dot Matrix Sequential Test</td>
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<tr>
<td><img src="image7" alt="Toy Balloons Recognition Task" /></td>
<td><img src="image8" alt="Dot Matrix Sequential Test" /></td>
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</table>

*Figure 1.* The nine measures of VSWM according to the distinctions among visual, sequential- and simultaneous-spatial subcomponents.
the visual component, three the sequential-spatial component, and three the simultaneous-spatial component. The nine tests have the same structure, the participant having to decide if a series of figures/locations are the same or different (for one stimulus) from that previously presented. The BVS battery was designed to provide information about the efficiency of visual working memory where the recognition of different shapes or textures is required, sequential-spatial working memory where the recognition involves locations sequentially presented, and simultaneous-spatial working memory where the recognition involves the same material as for the sequential-spatial task but presented simultaneously rather than sequentially.

The Nonsense Shapes Task, the Little Fish Recognition Task and the Toy Balloons Recognition Task are mainly visual and require decision on whether or not the nonsense figures (derived from Vanderplas & Garvin, 1959), fish-shaped figures or balloon textures are identical to previously presented stimuli. Visual items are presented for 3000 ms, followed by a blank screen for 500 ms. After presentation of a fixation point for 1500 ms, either the same series of figures or a series varied in one figure is presented, followed by a response screen displaying the letters U (uguale = same) and D (diverso = different): the child responds by pressing one of two different keys on the keyboard. Cronbach’s alphas for the tests are .89, .88, and .86, respectively.

In the Sequential Light-Bulbs Recognition Task, in the Sequential Lines Test and in the Dot Matrix Sequential Test, participants are asked to judge if the order of presentation of the information is the same in the recall phase as in the presentation phase. Each location is presented for 1000 ms, followed by a 250 ms interval. After a delay of 500 ms from the time the last location was lit up, a fixation point of 1000 ms and another delay of 500 ms, the same sequence or a sequence with one location in a different order is presented at the same rate. Cronbach’s alphas for the tests are .89, .87, and .91, respectively.

Finally, in the three spatial-simultaneous tasks, the Simultaneous Light-Bulbs Recognition Task, the Simultaneous Lines Test and the Dot Matrix Simultaneous Test, participants have to decide whether or not a series of positions presented simultaneously are different from those presented in a previous phase. The simultaneous locations are presented for 2500 ms, followed by a delay of 500 ms. After a fixation point of 1000 ms the presentation is repeated but a location may be changed. Cronbach’s alphas for the tests are .88, .85, and .89, respectively.

The tests progress from second (two stimuli) to eighth level (eight stimuli), with three repetitions at each. For each test, half of the repetitions required a “same” response and half a “different” response. A self-terminating procedure is employed: participants perform the tasks until they have managed to solve at least two out of three repetitions at a specific level. In scoring, the repetitions at second level have a value of 2, those at third level a value
of 3, and so on; the final score is the sum of the three last correct responses. For example, if the child successfully solves two repetitions at fourth level, and one at fifth, then the score is $4 + 4 + 5 = 13$. Before administration of each task, two practice trials with feedback are presented. Examples of the tasks are given in Figure 1.

Table 1 reports the raw and $z$ scores of B.A. before training (pre-treatment), immediately after training (post-treatment), and after six months (follow-up). Defective performance was calculated in accordance with the procedure suggested by Crawford and Howell (1998; see also Crawford & Garthwaite, 2002; Crawford, Howell, & Garthwaite, 1998), based on use of the formula of Sokal and Rohlf (1995), that treats the statistics of the normative or control sample as statistics rather than as population parameters and uses the $t$-distribution (with $N - 1$ degrees of freedom), rather than the standard normal distribution, to evaluate the abnormality of the individual’s scores.

The normative sample was derived from the BVS battery (Mammarella et al., 2008b) and involved 73 children (36 males and 37 females) of the same age as B.A. The presentation order of tests was balanced between the three categories and was as follows: Dot Matrix Sequential Test, Simultaneous Light-Bulbs Recognition Task, Nonsense Shapes Task, Sequential Lines Test, Dot Matrix Simultaneous Test, Toy Balloons Recognition Task, Sequential Light-Bulbs Recognition Task, Simultaneous Lines Test and Little Fish Recognition Task. Thus, in general, one sequential-spatial, one simultaneous-spatial and one visual task were presented alternately. Exactly the same presentation order was used in the post-treatment and follow-up assessment.

During pre-treatment evaluations, B.A. specifically failed on spatial-simultaneous tasks. In particular, the scores obtained were significantly below the mean on the Simultaneous Light-Bulbs Recognition Task, $t(72) = -3.209$, $p < .001$, and on the Simultaneous Lines Test, $t(72) = -1.893$, $p < .05$. As reported in Table 1, other scores obtained by B.A. during pre-treatment assessment were not significantly below the mean.

**Visuospatial memory treatment**

The overall aim of the visuospatial memory treatment was to improve B.A.’s ability to memorise simultaneous-spatial material. Treatment was conducted in seven sessions, given over one month with a fixed interval between sessions. Specifically, the training was given on Monday and Thursday each week. Each session took about 40 minutes, plus 10 final minutes for discussing strategies used and giving a metacognitive debriefing to the child. In fact, the trainer also suggested one or more possible strategies for recalling visuospatial information depending on the type of task and/or materials involved and,
**TABLE 1**

B.A.’s performance on the BVS battery. Defective performance assessing the abnormality of the difference between the child mean scores and test scores (average based on Crawford and Howell, 1998)

<table>
<thead>
<tr>
<th></th>
<th>Pre-treatment</th>
<th>Post-treatment</th>
<th>Follow-up</th>
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<tbody>
<tr>
<td><strong>Visual tasks</strong></td>
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<tr>
<td><strong>Nonsense shapes</strong></td>
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<td></td>
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</tr>
<tr>
<td>z score (raw score)</td>
<td>−0.93 (6)</td>
<td>0.63 (16)</td>
<td>1.56 (22)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.919</td>
<td>0.623</td>
<td>1.548</td>
</tr>
<tr>
<td>Estimated % of population falling</td>
<td>18.05%</td>
<td>73.24%</td>
<td>93.70%</td>
</tr>
<tr>
<td>(CI 95%)</td>
<td>(11.55–25.83%)</td>
<td>(64.59–80.97%)</td>
<td>(88.76–97.12%)</td>
</tr>
<tr>
<td><strong>Little fish</strong></td>
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<tr>
<td>z score (raw score)</td>
<td>−0.95 (7)</td>
<td>0.40 (16)</td>
<td>−0.95 (7)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.940</td>
<td>0.398</td>
<td>−0.940</td>
</tr>
<tr>
<td>Estimated % of population falling</td>
<td>17.53%</td>
<td>65.43%</td>
<td>17.53%</td>
</tr>
<tr>
<td>(CI 95%)</td>
<td>(11.12–25.23%)</td>
<td>(56.41–73.84%)</td>
<td>(11.12–25.23%)</td>
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<tr>
<td><strong>Toy balloons</strong></td>
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<td></td>
</tr>
<tr>
<td>z score (raw score)</td>
<td>−0.63 (7)</td>
<td>−0.06 (10)</td>
<td>1.07 (16)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.621</td>
<td>−0.060</td>
<td>1.062</td>
</tr>
<tr>
<td>Estimated % of population falling</td>
<td>26.83%</td>
<td>47.62%</td>
<td>85.42%</td>
</tr>
<tr>
<td>(CI 95%)</td>
<td>(19.09–35.48%)</td>
<td>(38.60–56.73%)</td>
<td>(78.20–91.24%)</td>
</tr>
<tr>
<td><strong>Sequential-spatial tasks</strong></td>
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<tr>
<td><strong>Sequential light-bulbs</strong></td>
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</tr>
<tr>
<td>z score (raw score)</td>
<td>−0.93 (13)</td>
<td>−0.93 (13)</td>
<td>0.99 (22)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.928</td>
<td>−0.928</td>
<td>0.978</td>
</tr>
<tr>
<td>Estimated % of population falling</td>
<td>17.84%</td>
<td>17.84%</td>
<td>83.44%</td>
</tr>
<tr>
<td>(CI 95%)</td>
<td>(11.37–25.58%)</td>
<td>(11.37–25.58%)</td>
<td>(75.89–89.67%)</td>
</tr>
<tr>
<td><strong>Sequential lines</strong></td>
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</tr>
<tr>
<td>z score (raw score)</td>
<td>−0.71 (10)</td>
<td>0.38 (16)</td>
<td>0.38 (16)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.702</td>
<td>0.378</td>
<td>0.378</td>
</tr>
<tr>
<td>Estimated % of population falling</td>
<td>24.26%</td>
<td>64.67%</td>
<td>64.67%</td>
</tr>
<tr>
<td>(CI 95%)</td>
<td>(16.82–32.71%)</td>
<td>(55.63–73.13%)</td>
<td>(55.63–73.13%)</td>
</tr>
<tr>
<td><strong>Dot matrix sequential</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z score (raw score)</td>
<td>−0.12 (16)</td>
<td>0.07 (17)</td>
<td>−0.87 (12)</td>
</tr>
<tr>
<td>t-values for discrepancies</td>
<td>−0.118</td>
<td>0.069</td>
<td>−0.866</td>
</tr>
</tbody>
</table>

(Table continued)
at the end of each session, strategy efficacy was discussed. For example, chunking, verbalisation of visual and spatial stimuli, to avoid overload of VSWM and mental imagery strategies (i.e., forming relationships among stimuli using imagery), were suggested, depending on the type of task presented.

Specifically, the treatment took the form of activities designed to improve ability to recognise locations and identity of stimuli simultaneously presented. It then shifted to activities aimed at improving ability to recall simultaneously presented locations, and then finally proposed everyday activities involving simultaneous-spatial memory.

The training started with simple tasks to allow children to experience success and thus gain motivation. The training was presented as a game in which the character Mickey had to undertake various activities. The same sequence of events characterised each session: explanation of objectives, stimuli presentation, demonstration of the task, questions, feedback, and finally discussion

TABLE 1

<table>
<thead>
<tr>
<th></th>
<th>Pre-treatment</th>
<th>Post-treatment</th>
<th>Follow-up</th>
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<tbody>
<tr>
<td>Simultaneous-spatial tasks</td>
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<tr>
<td>Simultaneous-light-bulbs</td>
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</tr>
<tr>
<td>$z$ score (raw score)</td>
<td>$-3.23$ (7)</td>
<td>0.87 (24)</td>
<td>0.38 (22)</td>
</tr>
<tr>
<td>$t$-values for discrepancies</td>
<td>$-3.209^*$</td>
<td>0.859</td>
<td>0.381</td>
</tr>
<tr>
<td>Estimated % of population falling below patient’s discrepancies (CI 95%)</td>
<td>0.10% (0.01–0.40%)</td>
<td>80.35% (72.36–87.12%)</td>
<td>64.77% (55.73–73.23%)</td>
</tr>
<tr>
<td>Simultaneous-lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z$ score (raw score)</td>
<td>$-1.91$ (7)</td>
<td>0.49 (19)</td>
<td>$-0.31$ (15)</td>
</tr>
<tr>
<td>$t$-values for discrepancies</td>
<td>$-1.893^*$</td>
<td>0.486</td>
<td>$-0.307$</td>
</tr>
<tr>
<td>Estimated % of population falling below patient’s discrepancies (CI 95%)</td>
<td>3.12% (1.10–6.46%)</td>
<td>68.57% (59.66–76.74%)</td>
<td>37.98% (29.35–47.07%)</td>
</tr>
<tr>
<td>Dot matrix simultaneous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z$ score (raw score)</td>
<td>$-1.16$ (13)</td>
<td>$-0.56$ (16)</td>
<td>$-0.56$ (16)</td>
</tr>
<tr>
<td>$t$-values for discrepancies</td>
<td>$-1.156$</td>
<td>$-0.560$</td>
<td>$-0.560$</td>
</tr>
<tr>
<td>Estimated % of population falling below patient’s discrepancies (CI 95%)</td>
<td>12.57% (7.22–19.38%)</td>
<td>28.85% (20.91–37.63%)</td>
<td>28.85% (20.91–37.63%)</td>
</tr>
</tbody>
</table>

Impaired performances of B.A. are reported in bold.
about the strategies employed to perform the tasks. For each task, the trainer suggested a number of strategies, depending on the task requirements, and at the end of the activity child and trainer discussed their usefulness in a particular task. The difficulty was stepped up both within each session (changing the number of stimuli to be remembered) and over the whole training programme (distinguishing between the cognitive task requests). Each session involved a maximum of 10 activities, but the child was stopped after 40 minutes, correctly completing as many activities as possible in each session. The training was divided into three phases: memory recognition, memory recall and everyday memory. In the memory recognition sessions, the child had to recognise locations of items; in the memory recall sessions, the task was to retrieve from memory locations previously presented and, finally, in the everyday memory sessions, the child was presented with maps and had to recall where landmarks were located. The child had a booklet in which the activities could be followed, and in which to indicate responses.

Memory recognition. Session 1: The child had to recognise locations of objects (of increasing complexity) in familiar environments (i.e., school, home) selecting from three or four alternatives. The trainer showed the locations of various objects in front of the child (e.g., where the toys are in Mickey’s bedroom), verbalising the position of each object (e.g., the train is on the floor in front of the chair). The child had to choose the correct location of the object shown by the trainer, pointing to pictures in the booklet provided. For each trial, a short story about Mickey was presented in order to gain the child’s interest.

Session 2: The child had to answer simple questions about the relationship between locations of some unfamiliar patterns, e.g., the locations of various kinds of fish in an aquarium. The trainer verbalised the name and location of each of the objects, and the child had to answer simple questions (e.g., Is the swordfish located in the bottom-left side of the aquarium?). The level of complexity was stepped up in each trial, by increasing the number of items.

Session 3: The child was presented with a simple, familiar environment in which locations and their relationships had to be recognised, selecting from three or four alternatives. Session 2 differed from Session 3 in that this latter required recognition of the positions of simple landmarks rather than objects (e.g., the location of different rooms in Mickey’s house, or of attractions at Mickey’s favourite amusement park).

In these three sessions the child had to recognise correct answers in the booklet.

Memory recall. Sessions 4, 5 and 6: These sessions had the same aims as those above, the only difference being that the child had to recall (rather than
recognise) the locations of the objects pointed out by the trainer in the booklet.

Everyday memory. Session 7: The last session trained simultaneous-spatial memory processes with reference to everyday situations. Maps of cities with landmarks (e.g., train station, church, school, etc.) were presented, and the child had to recall the location of the landmarks shown by the trainer. (Figure 2 gives an example of a map and of verbal instructions given by the trainer.)

Table 2 summarises the main points of the training sessions.

Post-treatment and follow-up assessment

At the end of the seven sessions of treatment, during an interview, B.A. was described by teachers and parents as having improved in everyday situations involving visuospatial requests. To address the specific goal of the study, i.e., examination of improvements in simultaneous-spatial working memory, B.A. was re-tested with the BVS battery (Mammarella et al., 2008b), both immediately after the training and also six months later, to examine whether there was maintenance of the training benefits over time (i.e., follow-up assessment).

Table 1 gives a summary of the raw and \( z \) scores obtained by the child in the three assessment sessions. It is immediately clear that B.A. improved markedly (by more than 2 \( z \) scores) in the tasks where performance had been particularly poor; this improvement was well maintained at the follow-up. These improvements cannot be attributed to a retest effect, since retest improvements in these tasks are typically below 0.2 SD (Reynolds & Bigler, 1994), nor to maturation (in the case of the follow-up), since the age variations in the tests are also very small (Mammarella et al., 2008b). To confirm that the child had improved in the simultaneous-spatial working memory tests, in which performance had been poor during pre-treatment assessment, we used the formula of Sokal and Rohlf (1995; see Crawford & Howell, 1998). As reported in Table 1, B.A. no longer showed significant failing in VSWM tasks; in both the Simultaneous Light-Bulbs Recognition Task, \( t(72) = 0.859, p > .19 \) and in Simultaneous Lines Task, \( t(72) = 0.486, p > .314 \), B.A.’s scores were not significantly below the mean, in contrast with the pre-treatment assessment.

Moreover, in order to analyse the effect of the treatment, the frequencies of trials solved and unsolved by B.A. for each test during pre-treatment, post-treatment and follow-up assessments were compared using Cochrane statistic. For each VSWM test, a value of 0 (1) was assigned for each trial incorrectly (correctly) solved. Comparison between pre- and post-treatment measures on simultaneous-spatial tests revealed that B.A.’s performance significantly
This map shows the area round Mickey’s school. The school is located in Via Palude (bottom-left of the figure). Opposite the school, between Via Rossi and Via della Repubblica, is the bus-station. Mickey’s mother always buys her fish in the fish market in Via della Repubblica. In Via Sarpi there is the newspaper kiosk (top-right). On the other side of Via Roma is the library (top-left), and between the library and Mickey’s school there is a wonderful ice-cream shop.

After reading the story, the same environment but without the landmarks, was shown to B.A., who then had to relocate the landmarks correctly, by answering some questions. For example:

What is opposite the school?
What is between the library and the school?
What is in Via Sarpi?

**Figure 2.** An example of a map shown in the seventh session of the treatment. The child has to recall the location of the landmarks in the booklet provided.

improved in the Simultaneous Light-Bulbs Recognition Task, $\chi^2(1) = 21.00$, $p < .001$, and the Simultaneous Lines Task, $\chi^2(1) = 14.22$, $p < .001$. A significant improvement was also seen in two visual working memory tests, i.e., the Toy Balloons Recognition Task, $\chi^2(1) = 8.75$, $p < .003$, and the
Nonsense Shapes Task, $\chi^2(1) = 7.95, p < .008$. Comparison between pre-treatment and follow-up results revealed that B.A.’s performance improved on Simultaneous Light-Bulbs Recognition Task, $\chi^2(1) = 14.32, p < .001$, and the Simultaneous Lines Task, $\chi^2(1) = 11.75, p < .001$. In addition, performance improved for the Nonsense Shapes Task, $\chi^2(1) = 8.90, p < .002$ and the Toy Balloons Recognition Task, $\chi^2(1) = 3.85, p < .05$, while for the Little Fish Recognition Task performance at follow-up returned to pre-treatment assessment values.

Finally, to get a clearer understanding of the changes between post-treatment and follow-up, the McNemar statistic was used to compare the number of trials solved and unsolved by the child on each test. There were no changes between post-treatment and follow-up on simultaneous-spatial or sequential-spatial tasks, showing that the effect of the simultaneous-spatial treatment was still in place after six months. However, a decrease in performance was observed for the Little Fish Recognition Task (McNemar, $p < .016$). The same results can be observed in Table 2, where, using the formula of Sokal and Rohlf (1995; see Crawford & Howell, 1998), no drops in performances were reported during follow-up assessment, demonstrating that B.A. had maintained the effects of simultaneous-spatial training after six months.

**DISCUSSION**

The specific patterns of B.A.’s failures in VSWM and of the treatment benefits confirm that children with a diagnosis of NLD exhibit many
similarities but also fairly substantial individual differences. For this reason treatments must be tailored, bearing in mind not only the similarities displayed by children with NLD, but also the unique characteristics of each child.

Forrest (2004) suggested that children with NLD should be distinguished according to the nature of the underlying impairments, and proposed one visual-spatial disability category for children with severe visuospatial deficits, and a different diagnostic category – including for example, social processing disorders – for children whose social skill deficits are primary and result in impairment in everyday functions. In our view, for children belonging to the first category, such as B.A., who did not present internalised psychopathology, analysis of VSWM could be crucial, and the specific visuospatial deficits should be the main focus of the treatment.

The analysis of B.A.’s VSWM demonstrated a specific deficit in simultaneous-spatial working memory tasks that required recognition not only of the location of items but also relationships of items in the pattern. For one month, B.A. was given training in handling simultaneous-spatial information. This involved three sessions on recognition of patterns, three sessions on recall of objects presented simultaneously in the test space, and one session for generalising strategies to everyday life. The results demonstrated that the training on simultaneous-spatial memory was successful and the improvements were maintained after six months – in other words, the training had been suitably designed and effective. Specifically, the study shows that simultaneous-spatial working memory treatment can increase the amount of simultaneously presented information the child can hold in VSWM. Moreover, our results confirm the positive effect of treatment, in particular teaching new strategies, on simultaneous-spatial task performance. B.A. failed on only two out of the three simultaneous-spatial working memory tasks (i.e., Sequential Light-Bulbs Recognition Task and Sequential Lines Test), and the improvement after training was marked only for these two tests, whereas the differences between both post-treatment vs. pre-treatment and follow-up vs. pre-treatment were not significant for the Dot Matrix Simultaneous Test. However, for this latter test, B.A.’s performance rose from a value comparable with that of 12.57% of the population to one of 28.85% of the population. The different pattern of performance observed here might be due to the possibility the task offers ofanchoring memory for locations to a verbally recoding board (e.g., remembering that a location was at the second cell from the left, etc.). Thus, B.A. might have benefited from good verbal skills. A meta-analysis of memory training in ageing (Verhaeghen, Marcoen, & Grossen, 1992) showed that the benefits of training are closely linked to metacognitive aspects, such as thinking about one’s own memory. Children might also benefit from application of new understanding
of these aspects. Moely et al. (1992) found that children who were trained and encouraged to use strategies were more likely to use these strategies in the specified learning situation, and were more likely to generalise the strategies they learnt to other situations.

A point to note is that, after the treatment, both simultaneous-spatial and visual working memory performances increased, specifically in the Toy Balloons Recognition and Nonsense Shapes Tasks. In the literature, some of the tasks we considered as tapping simultaneous-spatial working memory are interpreted as visual working memory tasks (Della Sala et al., 1999). B.A.’s improvements in both visual and simultaneous-spatial working memory may therefore be a demonstration of the close relationship between these two VSWM sub-components. However, at follow-up, the effect of the treatment remained stable for simultaneous-spatial working memory tasks but not for visual working memory tasks. Statistical analyses demonstrated that B.A.’s performances at follow-up were lower than those at post-treatment assessment for the Little Fish Recognition Task, whereas no variations were observed for the Nonsense Shapes or Toy Balloons Recognition Tasks. It might be that the simultaneous spatial treatment produced unstable generalisations to visual memory, or alternatively that the results found for visual memory are the effect of inconsistent performance by B.A. over time (days), not the effect of treatment per se. In summary, although simultaneous-spatial and visual working memory have at times been confused in previous studies (Logie & Pearson, 1997; Della Sala et al., 1999), we believe that these subcomponents of VSWM, despite being contiguous, involve different processes (Cornoldi & Vecchi, 2003).

Our study has some limitations. First, we studied only one single case treatment. The results look promising but only extension with further data can demonstrate that the treatment is valid and useful for other children with specific simultaneous-spatial working memory impairments, and confirm the specificity of simultaneous-spatial working memory. Further studies should find and consider other children with NLD, overcoming the difficulty of recruiting children with NLD showing a specific impairment in a VSWM subcomponent. Finally, further research should also focus on the possibility of generalising the results on academic achievement. B.A. did improve the main areas of difficulty at school. However, other children with NLD are frequently found to be impaired in mathematics. An interesting study might test whether VSWM treatments produce a benefit on academic achievement.

In conclusion, our study has both clinical and theoretical implications. A treatment method for remediation of simultaneous-spatial working memory deficits in a child with NLD is described; the effect of the training was positive and, moreover, the benefits of the training were maintained for up to six months, demonstrating that the metacognitive training was relatively
long-enduring. At the same time, the study confirms the view of a specific simultaneous-spatial working memory, applicable not only in assessment, as demonstrated by Mammarella et al. (2006), but also in intervention.

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