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Sequence and Space.  
The Critical Role of a Backward Spatial Span in the Working Memory Deficit of  
Visuospatial Learning Disabled Children

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## Abstract

The clinical use of backward spatial short-term memory tasks, and in particular of the Corsi backward task, has increased and has generated a series of theoretical hypotheses. For example, it has been argued that (in its comparison with the forward version) it has the same implications as the backward digit span and/or it requires the use of amodal central executive components of working memory. This research tested the hypotheses that the backward spatial span does not involve the controlled use of the same type of sequential spatial processing involved in the forward version, that its impairment is modality specific and that children with specific visuospatial learning disabilities (VSLD) have lower performance in backward than in forward Corsi block test, compared to a control group. In Study 1, participants were administered a verbal span test (Digit span test) and a visuospatial span test (Corsi blocks task) both in the forward and backward versions, while in Study 2 only the Corsi test was administered. The comparison between the forward and backward span versions showed that both visuo-spatial learning disabled children (VSLD) and controls presented with the Digit span had a lower performance with the backward version. However, for the Corsi task, this difference was present only for VSLD children. In fact, results revealed a significant impairment in the backward version of the Corsi test in the VSLD group, but not in the forward version, and in the Digit span tasks. Results suggest that the Corsi backward task is not the spatial analogue of the Digit backward task and that it involves specific spatial processes.

## Introduction

Differently from the language area, where a long-standing tradition has described different cognitive processes, the area of visuospatial cognition is still in search of clarifications. However, as it has been repeatedly shown (e.g. Kosslyn, 1994; Ungerleider & Mishkin, 1982), different cognitive functions and different underlying neuropsychological structures can also be defined within the visuospatial domain. A particular problematic aspect concerning the spatial domain involves the treatment of sequential information. In fact, a classical view (Paivio, 1971) assumed that mental imagery and related visuospatial processes tend to lose sequential information, by simultaneously elaborating different information. This view contrasts with models of visuospatial working memory (VSWM) (Logie, 1995) where it is assumed that the maintenance of sequential information is critical in spatial processes. These two different views could be reconciled by distinguishing sequential and simultaneous-spatial processes as suggested by Pazzaglia and Cornoldi (1999). In fact, Pazzaglia and Cornoldi (1999) proposed an articulation of VSWM, distinguishing between visual tasks that require remembering visual information, simultaneous-spatial tasks, in which participants have to remember different locations presented simultaneously (as for example in the Visual Pattern Task, Della Sala, Gray, Baddeley, & Wilson, 1997) and sequential-spatial tasks that involve the ability to remember a sequence of different locations, as in the Corsi blocks task. This paper intends to examine the issue of the dissociability of visuospatial cognition, on the basis of the contrast between the traditional manual use of the forward and the backward versions of the Corsi (1972) task.

The Corsi block-tapping task (Corsi, 1972) is a test increasingly used by clinical neuropsychologists, cognitive and developmental psychologists in clinical settings and experimental investigations of spatial information processing. Originally, it was employed to

investigate cerebral lateralization of verbal and visuospatial functions (Milner, 1971) and for the past 20 years it has been considered as the visuospatial equivalent of the verbal span task.

The original apparatus consists of a series of nine blocks arranged irregularly on a 23 x 28 cm board. On the experimenter's side of the board, the cubes are numbered for easy identification; the blocks are tapped by an examiner at the rate of one block per second, and participants attempt to reproduce the same sequences of increasing length in forward and sometimes also in backward order (Berch, Krikorian, & Huha, 1998; Della Sala, Gray, Baddeley, Allamano & Wilson, 1999). Despite many aspects of the procedure have remained consistent over the years, others, for example board and cube size, the way of administering the task and the scoring procedures, have been significantly changed and little effort has been devoted to examining the contribution of such factors to the variations in subject performance (Berch, et al. 1998; Vecchi & Richardson, 2001).

A number of possible interpretations has been proposed to explain the cognitive components involved in the forward Corsi blocks test. The classical interpretation is that the Corsi blocks task measures *visuospatial working memory* (VSWM), a module for processing visuospatial information, action representation and image generation, postulated to be part of a working memory system (Baddeley, 1986; Logie, 1995; Baddeley & Logie, 1999). According to this view, it was proposed, (Della Sala et al.; 1999; Gilhooly, Wynn, Philips, Logie & Della Sala, 2002) that non-verbal short-term memory comprises visual and spatial-sequential components and that the Corsi test is a useful instrument for measuring the sequential-spatial component. This conclusion was confirmed by Kessels, de Haan, Kappelle and Postma (2002; see also Kessels, et al., 2000) who found that right hemisphere patients and participants with selective impairments in positional memory failed in the Corsi block-tapping task. In another study, Fisher (2001) addressed some methodological shortcomings in the use of the Corsi blocks task as a measure of spatial working memory. Specifically, he used the Corsi task to assess the roles of encoding intervals, memory delay, response alternatives (all 9 vs. only the relevant positions) and ascending vs. descending

order of item presentation. Results showed that item order had no consistent effect and that performance improved with longer encodings and maintenance intervals and with fewer response alternatives. Finally, Kemps (2001) used a variant of the Corsi blocks task to investigate the effect of complexity on visuospatial memory and concluded that long-term memory processes are involved in the temporary retention of visuospatial material only for representations which exist in long-term memory.

Another line of research, (Vecchi & Richardson, 2001; Szmalec, Vandierendonck, & Kemps, in press; Vandierendonck, Kemps, Fastame, & Szmalec, 2004) is based on Baddeley's (1986) tripartite model of working memory and suggests that performance in the Corsi blocks test, and especially in its backward version, is not a pure measure of VSWM. Vecchi & Richardson (2001) administered the Corsi blocks test in a baseline condition and in association with three different interfering tasks assumed to respectively disrupt the activity of the three components of working memory: random generation, spatial tapping and articulatory suppression. Results showed significant differences between baseline and both the tapping and the random generation conditions, hence the authors concluded that both the central executive and the VSWM are involved in the Corsi blocks test. Two studies by Vandierendonck and co-workers (Szmalec et al., in press; Vandierendonck et al., 2004), comparing the forward and the backward versions of the Corsi task, showed that the two versions may involve different processes, but they obtained partly contrasting results. Vandierendonck, Kemps, Fastame and Szmalec (2004) administered a computerized version of the Corsi blocks task either as a single-task or in a dual task design combined with articulatory suppression, matrix tapping, random interval generation or fixed interval generation as concurrent tasks. The random interval generation task impaired memory performance at the intermediate and longer sequence lengths in forward and especially in backward orders. Fixed interval generation, on the contrary, did not show any effect when compared to a single-task control condition. Concurrent performance of the matrix-tapping task impaired memory performance for short as well as for

longer block sequences in both recall orders, whereas articulatory suppression did not clearly impair memory performance. On the basis of these results, the authors concluded that the backward Corsi blocks task calls on both visuospatial and executive processing. Szmalec, et al. (in press) introduced a new task to study the involvement of the central executive namely response selection. They administered a computerized version of the Corsi task in a baseline condition and in dual-task conditions. In this case they found that there was no difference between forward and backward span in the control condition and, pooling together data from two different Experiments (Exps. 3 and 4) they did not find a significant interaction between the Corsi versions and interference, when interference was due to the executive dual-task; however, under the visuospatial secondary task (matrix tapping) performance was less impaired in backward than in forward recall, as shown by the significant interaction between the Corsi version and the dual task request. A subsequent comparison between the forward and the backward versions of the Corsi task by Vandierendonck and Szmalec (in press) examined the specific effects of the matrix-tapping task (which required subjects to tap the four corners of the numeric keypad in counter-clockwise order at a fixed rate of two-three keys per second). The authors found that, in general, the concurrent task affected the forward span more severely than the backward one. Furthermore, by distinguishing the memory for the involved locations (identity score) from the memory of their order (order score), Vandierendonck and Szmalec (in press) found that this difference was only due to the order score, but not to the identity score. They hypothesized that concurrent spatial tapping blocks the spatial rehearsal process, and that this is more critical in forward recall than in backward recall, where the examinee can immediately recall the last positions, without the need for rehearsing them.

However, an alternative interpretation of the data obtained by Vandierendonck and Szmalec (in press) could be that spatial tapping specifically involves sequential-spatial processes distinguishable both from simultaneous-spatial and visual processes (Pazzaglia & Cornoldi, 1999). A similar type of sequential-spatial process could be involved to a larger extent in the forward spatial span than in

the backward one, thus producing a specific selective interference effect. The importance of considering the specific implications of the sequential component in spatial memory has been stressed to a greater extent in other studies. Farrand and Jones, for example, (1996, see also Jones, Farrand, Stuart & Morris, 1995) tested the hypothesis that performance in memory tasks for serial order can be understood in terms of a unitary model in which representations of articulations, sounds and nonverbal visuospatial stimuli are functionally equivalent. The authors explained the difference between the forward and backward version in verbal and spatial span by suggesting that the verbal task called upon the recall of both item and order information, but the spatial memory task required only order information. It was this difference that determined the effect of direction, not the difference in class of representation used for the verbal and spatial tasks. In fact, in the Digit span test, digits are not re-presented to the subject at retrieval, and participants have to reproduce the items and report their order; in contrast, in the Corsi test, participants are asked to base their report on the order in which a series of wooden blocks was indicated by the experimenter. In a series of experiments Farrand and Jones (1996) tried to match verbal and visuospatial span either by presenting items also during recall so that only their order had to be reported or by not presenting the items, so that recall of both items and orders was required. They suggested that the differences in the direction of report found between the verbal and spatial tasks depend on retrieval requirements and not on the modality of the stimuli. However, Smyth & Scholey (1996) found similarities between serial order and position effects in the verbal and spatial domains, but they concluded that there is no need to suggest only one memory system that maintains order, although order is similarly treated across different domains.

A number of neuropsychological studies have been carried out using the Corsi task; for example, De Renzi & Nichelli (1975) described two patients with right posterior lesions and a selective deficit of the spatial span; other patients were studied by Hanley, Young and Pearson (1991) and Luzzatti, Vecchi, Agazzi, Cesa-Bianchi and Vergani (1998). Neuropsychological research has also

shown that prefrontal areas, mainly located in the right-hemisphere, may be involved in visuospatial working memory tasks (Zarahn, Aguirre, & D'Esposito, 2000; see also Vallar & Papagno, 1995 for a review). Leung, Gore, and Goldman-Rakic (2002) specifically considered the neurological activation associated with the memory for sequentially presented locations finding an involvement of the middle frontal gyrus. As frontal areas are also assumed to be involved in executive tasks these data suggest that a central executive component could be involved in VSWM tasks.

In general, despite the fact that the Corsi task is frequently used also in its backward version, the implications of this version are not clear. In fact, the backward version was introduced in order to have a case mirroring the backward digit span task. It was assumed that both the backward digit span and the backward Corsi span measure the same type of immediate memory but in different modalities. Some studies have, in fact, shown that the two tasks have some analogies. For example, Carlesimo et al., (1998) found that Alzheimer patients were similarly impaired in both backward verbal and backward spatial tasks. However, data reported above (e.g. Vandierendonck & Szmalec, in press) suggest that backward spatial working memory tasks could not be treated as the spatial mirrors of the backward digit span. Similarly, Wilde and Strauss (2003, see also Isaacs & Vargha-Khadem, 1989), using the Wechsler Memory Scale, (Wechsler, 1974) found that a backward spatial span does not imply the typical pattern of performance of the digit span (forward recall better than backward recall), since some people had an even better performance with the backward spatial span than with the forward spatial span.

A similar performance in the two Corsi versions could suggest that the two involve the same type of processes with a similar degree of difficulty. However, part of the collected evidence (e.g. Szmalec et al., in press) suggests that the spatial features in a backward span are different with respect to the forward version. Obviously, this difference could concern a different involvement of the central executive component in the two versions. However, in this case, one would predict that, being equal the quantity of presented material, the version involving to a greater extent the central

executive would produce a lower performance, due to the greater cognitive load, as shown for the backward digit span, but this does not seem to be the case. Smyth and Scholey (1992) suggested that whereas executive resources are required to reverse the order of presentation of the verbal items, additional executive resources are not required to reverse the order of presentation of the spatial Corsi blocks items. Similarly, Li & Lewandowsky (1995) observed that the superiority of the reversed spatial recall can be explained by the greater efficiency of the spatial representation of the reversed order.

In fact, subjective experience seems to show that recalling sequences of verbal items in a reverse order is rather difficult and requires a certain degree of control, whereas the demands made by the reversed retrieval seem to be quite different for spatial materials. We suggest that the main difference between the two Corsi versions concerns the greater degree of involvement of discrete sequential-spatial processes in the forward version than in the backward one. This hypothesis is supported by the consideration that in the forward version information is typically maintained as a series of discrete sequential positions, but it is improbable that the same type of information can be used for carrying out the backward task. In fact, in the visuospatial domain it is possible to avoid the typical procedure adopted in the verbal domain, where -in order to do a backward task- people maintain the information in the original order and then, piece by piece, retrieve it in reversed order. In the backward version of the Corsi task a subject can make use not only of the order of presentation (spatial-sequential processes), but also of an overall representation (especially when the sequence is not particularly long) of the entire pathway described by the series of positions (or at least of parts of the pathway), and then follow the pathway in the required direction. In this way the role of the initial automatic binding of features, like the order and identities, is reduced, whereas the overall representation of the pathway described by the locations becomes more critical. The overall representation of the pathway would imply sequential-spatial processes to a lesser extent than in the forward spatial task and would imply to a larger extent processes which could be

referred either to the spatial-simultaneous (Pazzaglia & Cornoldi, 1999) or to the visual (Logie, 1995) component of visuospatial working memory. The hypothesis of a lesser involvement of sequential-spatial processes in the backward version is also supported by the observation that a sequential-spatial task disrupts forward Corsi more than backward Corsi (Vandierendonck & Szmalec, in press). On the basis of this assumption, individuals competent in sequential memory, either verbal or visuospatial, but with specific visuospatial difficulties, mainly concerning non sequential components of visuospatial working memory, should show a greater difficulty in the backward version with respect to the forward version, i.e. a pattern of performance opposite to the one found with the concurrent spatial tapping task.

In fact, it is possible that the representation of the entire pathway, useful for carrying out the backward spatial span task, is difficult for individuals with a specific VSWM deficit but with particularly good verbal and sequential skills. In this case, positions should be maintained only serially, and the direction of recall could make a difference. The present research investigates these issues in children with visuospatial learning disabilities (VSLD), a particular type of learning disability, described for the first time by Rourke under the label of nonverbal learning disabilities (1989; 1999). Children exhibiting non-verbal learning disabilities typically show problems in visuospatial-organizational, psychomotor, tactile-perceptual and nonverbal problem solving skills, associated with right hemisphere dysfunction (Nichelli & Venneri, 1995; Tranel, Hall, Olson, & Tranel, 1987), but perform normally in linguistic tasks such as rote verbal learning, verbal classification and regular phoneme-grapheme matching. Despite the fact that children with a non-verbal syndrome (visuo-spatial learning disability) have been clinically examined in a series of studies (Rourke, 1999, for a review), cognitive neuropsychological research is still needed in order to find their specific patterns of functioning. A critical factor underlying VSLD children's difficulties seems to be related to deficits in visuospatial working memory (Cornoldi, Dalla Vecchia, Tressoldi, 1995; Cornoldi, Rigoni, Tressoldi & Vio, 1999; Cornoldi & Vecchi, 2003).

These deficits could explain why VSLD children fail in a series of activities (mathematics, drawing, spatial orientation, etc), which are assumed to involve VSWM. Therefore, the study of VSWM in these children may offer both the opportunity to better understand the nature of their difficulties and of examining the functioning of VSWM in individuals with specific difficulties in this working memory component.

In this research, we carried out two studies comparing the performance of control groups with groups of VSLD children in the Corsi blocks test. Based on the literature and on the theoretical analysis of the tasks, we made three main predictions. Our first prediction was that the backward spatial span does not have the same relationship with the forward span as the digit span versions have, and in particular that children with typical cognitive development (forming the control group) would show a lower backward than forward digit span, but not a similar difference with the spatial span versions. Our second prediction was that VSLD children would have, in general, a greater deficit, with respect to Controls in the Corsi task, than in the Digit span test. Third, we expected that children with VSLD would perform less well in the backward version of the Corsi blocks test than in the forward span.

### Study 1

#### Method

##### Participants:

A group of 18 children who had received a diagnosis of visuospatial learning disability (VSLD). In order to have a diagnosis of VSLD, children had to meet the three criteria proposed by Cornoldi, et al. (1997): 1) learning disability involving the processing and learning of nonverbal material; 2) presence of discrepancy between verbal and spatial intelligence (at least .66 standard deviations or 10 IQ points, when IQ information is available); 3) failure in cognitive neuropsychological tests

involving visuospatial abilities. Both the VSLD Group and a matched Control Group (CG) included 18 children, 12 males and 6 females. Groups were similar for socio-cultural level and matched for grade, age and school. We received informed consent from the participants' parents and teachers. Appendix 1a presents demographic and selection data for VSLD children. The VSLD children were identified as poor learners on the basis of school reports and difficulties described by their teachers through the Shortened Visuospatial Questionnaire (SVS) (Cornoldi, Venneri, Marconato, Molin & Montinari, 2003). The SVS Questionnaire offers a visuospatial score (VS Score) based on 10 items (range 10-40). These items were validated for their sensitivity in detecting some of the deficits that represent critical features for VSLD; the Questionnaire also includes two items which are used to obtain an indicative verbal learning score (Verb. Score) (range 2-8) and one item which is used to obtain a teacher's estimate of the child's general abilities (range 1-4). As Cornoldi et al., (2003) found, the visuospatial and verbal learning scores are highly correlated and children who show difficulties in nonverbal learning and receive a diagnosis of VSLD may also have some difficulties in verbal learning, despite their good basic verbal abilities. Children also underwent a clinical evaluation including tasks which are used with VSLD children (Cornoldi et al., 1997) and were tested for their verbal and spatial abilities on the basis of the Vocabulary and Block-Design subtests of the WISC-R scale (Wechsler, 1974) (see Appendix 1a).

#### Materials and procedure:

All participants were individually tested, with a verbal (Digit span test) and a visuospatial working memory task (Corsi blocks test). Tasks were administered in the following order: forward digit span, backward digit span, forward Corsi blocks and backward Corsi blocks test. We used the Wechsler's version (1974) for the Digit Span test with two trials for each length level and the request that children recalled at least one sequence correctly. For the Corsi blocks test the experimenter tapped sequences of increasing length in the forward condition and in the backward

condition, at the rate of one block per second. We used two trials at each difficulty level; like in the Digit span test the spatial span was taken to be the longest sequence in which at least one out of the two presented sequences was correctly reproduced by the children.

## Results and Discussion

Table 1 reports the means and standard deviations (SD) of the forward and backward versions of the Digit span and Corsi blocks tests in VSLD children and CG groups. A 2 (group: VSLD vs. CG) x 2 (type of version: forward vs. backward) mixed ANOVA on Digit span scores revealed a significant main effect of version,  $F(1, 34)=74.85, p<.0001, \eta_p^2 = .69$ ; indicating that both the VSLD children and the CG's performance was significantly poorer when recalling the digit sequences in the backward version than in the forward version. The difference in the digit span between groups did not reach significance  $F(1, 34)=4.32, p=.09, \eta_p^2 = .12$  (CG:  $M = 4.94$  vs. VSLD:  $M = 4.28$ ) and, in particular, the interaction was very far from significance  $F(1, 34)=.89, p=.77, \eta_p^2 = .003$ .

A 2 (VSLD vs. CG) x 2 (type of version: forward vs. backward) mixed ANOVA on the Corsi test scores showed significant effects of group,  $F(1, 34)=27.68, p<.001, \eta_p^2 = .45$  and of version  $F(1, 34)=5.94, p=.02, \eta_p^2 = .15$ , indicating that the VSLD children made more errors than the CG in the tasks and that the backward version was more difficult than the forward one. Also the interaction was significant,  $F(1, 34)=16.51, p<.001, \eta_p^2 = .33$ . A post hoc comparison using Sheffè's test showed that the two groups were significantly different in both versions ( $p<.05$ ). Furthermore, forward and backward conditions were different in the VSLD group ( $p<.01$ ) but not in the CG.

Table 1 about here

In conclusion, the results of Study 1 indicate that children with VSLD have significantly lower scores in a visuospatial task (the Corsi blocks test) and, in particular, in the backward version of the test. On the contrary a slight difference between VSLD children and the CG in the verbal working memory task (the Digit span test) did not reach significance. Results confirmed that the VSLD group has normal verbal memory but poorer spatial memory (Rourke, 1989; Cornoldi et al., 2003). Furthermore, results with the spatial span did not mirror the results with the digit span. In fact performance in the backward digit span was lower than in the forward version both for the CG and VSLD group, whilst performance on the backward Corsi was impaired only in visuospatially disabled subjects. The specific difficulty of the VSLD children, in comparison with the controls, in reversing the spatial order was not associated with a specific difficulty in reversing the verbal order, since both groups had a similar decrease in performance moving from the forward to the backward digit verbal span.

However, results from Study 1 would acquire greater impact if they could be generalized to different groups of VSLD children and to different conditions given the limited age range of children in Study 1 and the impossibility of examining whether the effect was stable across ages and in the presence of developmental variations in spatial abilities. Therefore Study 2 compared children of different ages, and introduced a more general measure of spatial and verbal abilities (in this case spatial and verbal IQ estimates were collected). In addition we controlled the potential effects of order since in the first study the two versions of the Corsi had been presented in a fixed order and had not been counterbalanced and hence results could have been caused also by an order effect. For example, order effect, due to practice, could have been present only in the CG because the VSLD group have low visuospatial abilities and can't take advantage of the forward blocks presentation.

## Study 2

Study 2 examined whether poor performance in the backward Corsi test in VSLD children could be generalized to different groups of children and was stable across ages. The design contrasted VSLD children and controls (CG), second-graders and fifth-graders, in the performance of the forward and backward versions of the Corsi task counterbalanced for order of presentation. This was done to control for the possibility of results being due to the order of presentation.

## Method

### Participants:

Participants were selected according to the general criteria used in Study 1. Verbal and visuospatial general abilities were evaluated using respectively the “Verbal Meaning” and the “Spatial Relations” subtests of the Primary Mental Ability Test (PMA) (Thurstone & Thurstone, 1963) (see Appendix 1b for information about the subjects). The VSLD group included 11 children attending second grade and 10 children attending fifth grade. The CG comprised 13 second-graders and 12 fifth-graders. For each grade, the two groups were similar for socio-cultural level, age and schooling. We received informed consent from participants’ teachers and parents to administer the cognitive tests.

### Materials and Procedure:

We tested children individually and administered the same material used in Study 1 for the Corsi blocks test. In this Study, trials were counterbalanced to avoid order effects: half the participants started with the forward and half with the backward version of the Corsi test.

## Results and Discussion

A preliminary analysis examined whether the order of task administration affected performance. The order seemed to introduce some noise to the data; however it did not significantly change the performance nor significantly affect any of the design variables and therefore the children's scores were pooled together, without any further consideration of the order.

The main results are presented in Table 2. A 2 (VSLD vs. CG) x 2 (second vs. fifth grade) x 2 (versions: forward vs backward Corsi test) mixed ANOVA revealed significant effects of version,  $F(1, 42)=9.22, p<.01, \eta_p^2 = .18$ , (forward visuospatial span  $M=4.78$ , vs. backward visuospatial span  $M=4.37$ ) and of groups  $F(1, 42)=6.12, p<.05, \eta_p^2 = .13$ . Also the effect of grade was significant  $F(1, 42)=34.78, p<.0001, \eta_p^2 = .45$ , (second graders:  $M= 3.89$  vs. fifth graders:  $M= 5.27$ ). The two way interaction, groups by versions, approached significance  $F(1, 42)=3.69, p=.06, \eta_p^2 = .10$ . Post hoc comparisons using the Sheffè test showed that the groups's performance was significantly different in the backward version ( $p < .01$ ) whereas the difference in the forward version was not significant (critical value = .59 for  $p = .05$ ), and that the performances in the forward and backward versions differed for the VSLD group ( $p<.01$ ) but not for CG.

Table 2 about here

Results from Study 2 confirmed the main result of Study 1, i.e. that the VSLD are poorer in the backward version of the Corsi task than in the forward version, whereas this effect was not present in the CG. This pattern of performance was not related to a particular age of the VSLD child since it was observed both in second and fifth-graders. Furthermore results were not due to presentation order, since in Study 2 the order of trials was counterbalanced. In this Study the group difference in the forward version did not reach significance, thus offering further evidence suggesting that a

VSWM difficulty in VSLD children may be selective and mainly concern the backward spatial span.

### General Discussion

A considerable body of evidence has demonstrated a dissociation between verbal and visuospatial working memory in neuropsychological patients (e.g. Baddeley, Della Sala, Spinnler, 1991). In standardised neuropsychological tests, the Corsi blocks task is frequently used to assess visuospatial working memory. However, evidence suggests that the Corsi blocks test is more complex than was initially proposed (Vecchi & Richardson, 2001). As mentioned above, studies from the literature outline a large variety of interpretations as regards the cognitive processes implied in the Corsi test.

For example, Vandierendonck et al., (2004) showed that central executive involvement increases when participants have to reproduce the spatial positions in the backward compared to the forward order of presentation (similarly to what happens in the verbal span). However, Smyth and Scholey (1992) reported opposite conclusions, that is, executive resources are not required in the backward version of Corsi blocks task. Our results are in support of the latter position since the backward version of the spatial span may produce the same level of performance as the forward version. If the central executive is more involved in both the backward digit and backward Corsi spans than in the forward spans, one should predict: first that in general the backward Corsi produces a poorer absolute performance than the forward Corsi (and in the current study this is not the case for controls) and, second, that people failing specifically in the backward Corsi should equally fail in the backward digit (and this was not found in the VSLD children).

A general yet equally important result of the present research is that the forward and backward versions of the Corsi task produce, for individuals without a specific visuospatial difficulty, the

same level of performance, a result which is not mirrored by results obtained with the Digit Span test. In fact, it has been showed that the absolute values of span scores decrease with an increase of the required controlled processing (see for example, Daneman & Carpenter, 1980). The result obtained by the controls in the spatial span contrasts with the assumption that, the quantity of material being equal, the higher control required by the involvement of the central executive in the case of the backward span should reduce the overall performance in the task and suggests that in the present case central attentional processes were not involved to a greater extent in the backward version than in the forward version. However, the involvement of central executive processes in both versions of the Corsi task deserves further attention; in particular, we need a common explanation of why the backward version of the Corsi task is sometimes more difficult (and more sensitive to interference produced by a dual task involving the central executive) than the forward version. In particular, age, length of the sequence, and modality of presentation of the Corsi sequence (manual *vs.* computerised) could affect the specific pattern of performance in the backward version.

Considering the equal performance control children obtained in the two Corsi versions, one could assume that the two versions, *i.e.* the forward and the backward one, measure the same component of VSWM. However, also this hypothesis must be rejected on the basis of the different performance of the VSLD children in the two versions. The data obtained with the VSLD group offered two main important elements. First, we found that children with visuospatial learning disabilities compared to controls did not present a significant difference on the Digit span tests, but showed a lower performance in the Corsi tasks. This result adds further evidence to the hypothesis that a basic deficit underlying the difficulties these children meet in a variety of tasks and situations could concern visuospatial working memory (Cornoldi *et al.*, 1995, 1999; Cornoldi & Vecchi, 2000; 2003). Second, VSLD children were particularly poor in the backward version of the Corsi task when compared to the CG and their own performance in the forward version. Results cannot be

attributed to presentation order, since in Study 2 the presentation order of the forward and backward versions of the Corsi task was counterbalanced between subjects. Therefore, results show that, at least for the VSLD group, the two versions of the Corsi task do not measure the same component of VSWM, since they produced different performances, nor does the backward version involve to a greater extent a more central component of working memory, since VSLD children were not poorer than controls in the backward digit span. Therefore, the main result i.e. that VSLD children are poorer in the backward than in the forward version of the Corsi task needs explaining, possibly with reference to the particular characteristics of the visuospatial disability which can be found in learning disabled children. Although VSLD children do not have general difficulties in executive processes, it cannot be excluded that they may show specific problems regarding the use of controlled processes in the visuospatial domain (see for example, Cornoldi et al., 1995).

We think that our results raise the general issue of the treatment of sequential information in spatial memory, suggesting that specific critical components of VSWM do not rely on sequence processing (Pazzaglia & Cornoldi, 1999). It is possible that, in the forward version participants rely on sequential processes, maybe involving non-specific sequential or also verbal processes, whereas in the backward condition subjects must rely on specific visuospatial strategies. In this respect, the forward version of the Corsi task should specifically involve the treatment of sequential information in spatial memory. A concurrent spatial task, requiring one to sequentially tap different positions, involves the treatment of a sequence and may thus affect the forward version more than the backward version (Szmalec, et al, in press; Vandierendonck & Szmalec, in press; Zimmer, Speiser, & Seidler, 2003). Differently, the backward version seems to rely to a lesser extent on sequential processes and to a greater extent on non-sequential visuospatial processes, which may be critically impaired in children with specific visuospatial difficulties (Cornoldi & Guglielmo 2001). Also Cornoldi, et al., (1999) showed that children with VSLD scored lower in all visuospatial tasks,

including memory for locations, thus confirming that they have particular difficulties when non-sequential spatial processes are involved.

Children with visuospatial difficulties should be more impaired in the backward version of the test than in the forward version because although competent in the treatment of sequential information, their non-sequential visuospatial abilities are impaired. Thus in the forward Corsi test VSLD children could compensate with sequential processes strategies, but in the backward condition the charge on the visuospatial non-sequential domain was higher and their sequential abilities were not sufficient to adequately perform the task.

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*Table 1.* Mean, standard deviations (SD) and confidence intervals (CI 95%) of the forward and backward Digit span and Corsi blocks test in the two groups of children (CG= Controls and VSLD = Visuospatial Learning Disability Group).

GROUPS	TESTS	Mean	SD	CI 95%	
				Inferior Limit	Superior Limit
VSLD	Forward Digit Span	5.11	.76	4.69	5.25
	Backward Digit Span	3.44	.70	3.05	3.84
CG	Forward Digit Span	5.72	.96	5.31	6.14
	Backward Digit Span	4.17	.92	4.17	4.56
VSLD	Forward Corsi	4.82	.71	4.52	5.23
	Backward Corsi	3.94	.73	3.62	4.36
CG	Forward Corsi	5.35	.75	4.92	5.61
	Backward Corsi	5.56	.62	4.84	5.23

*Table 2.* Mean, standard deviations (SD) and confidence intervals (CI 95%) of the forward and backward Corsi blocks test in the two groups of children (CG = Controls and VSLD = Visuospatial Learning Disability Group) distinguished by grade.

Grade	Groups	Corsi Test	Mean	SD	CI 95%	
					Inferior Limit	Superior Limit
2 <sup>nd</sup> Graders	VSLD	Forward	4.00	.77	3.46	4.54
		Backward	3.27	.90	2.69	3.85
	CG	Forward	4.23	.93	3.73	4.73
		Backward	4.08	.86	3.54	4.61
5 <sup>th</sup> Graders	VSLD	Forward	5.30	.82	4.73	5.87
		Backward	4.60	1.07	3.99	5.21
	CG	Forward	5.67	.86	5.15	6.18
		Backward	5.50	1.00	4.94	6.06

### Appendices

Demographic and selection data for the VSLD children of Study 1 (1a) and Study 2 (1b). Age is described in months. The children's scores for Study 1 are accompanied by one-three asterisks (\*) or pluses (+) when deviating respectively one, one and a half or two standard deviations from the mean score either negatively or positively. For the SVS Questionnaire (Cornoldi, et al., 2003), the visuospatial (VS Score) and verbal (Verb. Score) items are presented in raw and percentile values and the General Abilities only in raw values.

#### Appendix 1a

Participants	Grade	Age (months)	Gender	VS Score	Percentiles	Verb. Score	Percentiles	General Abilities	Vocabulary	Block Design
1	4	120	M	16	5	5	30	3	37	30***
2	4	127	F	16	5	4	20	3	50 +	40*
3	4	122	M	21	10	7	70	4	37	34**
4	3	121	M	21	10	4	20	3	41	33***
5	5	132	M	21	10	5	30	2	43	36**
6	4	121	F	18	7	5	30	2	44	40*
7	3	111	M	20	9	6	40	2	43	40*
8	4	121	M	19	8	5	30	2	44	40*
9	3	116	M	17	6	8	90	3	55 ++	42
10	4	123	F	19	8	5	30	3	37	18***
11	4	120	M	20	9	4	20	3	45	17***
12	3	108	F	20	9	4	20	2	41	34**
13	3	109	F	21	10	4	20	3	37	38*
14	3	108	F	20	9	4	20	4	29 *	28***
15	3	108	M	21	10	5	30	2	43	32***
16	4	120	M	21	10	5	30	2	41	34**
17	3	108	M	19	8	7	70	2	34	13***
18	3	108	M	20	9	7	70	2	32 *	32***

**Appendix 1b**

Subjects	Grade	Age	Gender	VS		Verb.		General Abilities	Verbal IQ	Spatial IQ
		(months)		Score	Percentiles	Score	Percentiles			
1	2	83	M	21	10	7	70	2	98	77
2	2	84	M	22	12	5	30	3	103	71
3	2	91	M	19	8	6	50	3	105	80
4	2	85	M	23	14	6	50	3	98	86
5	2	93	M	28	30	5	30	3	110	86
6	2	86	F	28	30	5	30	2	105	83
7	2	85	M	26	23	6	50	3	105	74
8	2	92	M	28	30	6	50	4	115	80
9	2	84	M	23	14	5	30	2	100	89
10	2	88	F	20	9	5	30	3	105	68
11	2	87	M	28	30	7	70	4	100	80
12	5	119	M	28	30	7	70	4	109	84
13	5	127	F	28	30	7	70	3	100	90
14	5	125	M	20	12	6	50	2	100	87
15	5	130	F	20	12	5	30	2	116	84
16	5	130	M	28	30	6	50	4	116	90
17	5	120	F	28	30	5	30	3	116	74
18	5	125	F	28	30	6	50	3	108	87
19	5	120	F	28	30	6	50	3	119	90
20	5	126	M	28	30	6	50	4	112	90
21	5	127	F	25	20	7	70	4	119	74

*Note.* Spatial IQ and Verbal IQ: scores based on the Italian adaptation manual of the PMA (Primary Mental Ability) (Thurstone & Thurstone, 1985).