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Acta Psychologica 118 (2005) 211–228

acta psychologica

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Difficulties in the control of irrelevant visuospatial information in children with visuospatial learning disabilities

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Received 19 June 2003; received in revised form 7 August 2004; accepted 7 August 2004
Available online 28 October 2004

Abstract

This research tested the hypothesis that children's difficulties in visuospatial working memory (VSWM) may mirror difficulties found with verbal working memory tasks in other categories of children. Two experiments compared the number of correct responses and errors in groups of visuospatial learning disabled children (VSLD) and Controls who were engaged in an active task testing visuospatial working memory. Children were presented with sequences of positions on a 4 × 4 matrix and were subsequently asked to remember only the last position of each series. In the first Experiment, VSLD children showed greater difficulty in both recalling the last positions and avoiding the irrelevant non-final positions compared with Controls. In the second experiment children of different age groups (second-graders and fifth-graders) were also required to stress, by tapping on the table, the irrelevant positions whenever the experimenter pointed to a coloured cell. Results showed that the number of errors was greater in the VSLD children, and the pattern of errors differed with their grade. In particular, the increased activation of stressed locations produced an increase of correct responses, and a decrease of intrusion errors, except in the case of VSLD second-graders, who made a higher number of intrusions for stressed than for unstressed locations.

Results confirm that children with VSLD show a specific deficit in active VSWM, and in particular, in the ability to avoid intrusion errors. In general, the control of irrelevant information appears critical for a successful use of VSWM.

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0001-6918/$ - see front matter
doi:10.1016/j.actpsy.2004.08.004

PsycINFO classification: 2343; 3253
Keywords: Visuospatial working memory; Non-verbal learning disabilities

1. Introduction

The working memory model proposed by Baddeley (1986) and Logie (1995) interprets memory not only as a system capable of retaining information, but also as a structure which is able to organise and manipulate materials retrieved from long-term memory as well as generated by sensory inputs. This model includes three main components, i.e. the central executive (attentional amodal component), the articulatory loop and the visuospatial component (modality specific components).

The study of specific impairments in the working memory components has helped to understand the nature of working memory. A large number of studies have examined articulatory loop impairments both in adults and children, however little attention has been devoted to specific impairments in the visuospatial component of children. This paper intends to show how the study of a specific clinical group of children with visuospatial learning disabilities may cover this aspect and offer support to the comprehension of the organization of visuospatial working memory (VSWM). The organization of VSWM has been differently explained: Logie (1995) described the visuospatial working memory system as independent of the central executive and the articulatory loop, and further divided it into two major components: the visual cache, which consists of a passive visual store, for processing visual materials, and an active rehearsal mechanism, the inner scribe, for processing spatial information and movement sequences. In the model, complex visuospatial mental operations were referred to the Central Executive. An alternative view developed by Cornoldi and Vecchi (2000, 2003; Cornoldi, 1995) comprises two fundamental dimensions: (1) the horizontal continuum, related to the different types of material (e.g. verbal, spatial, visual) which are thought to be processed semi-independently; and (2) the vertical continuum, related to the type of process, requiring more or less active elaboration and control of information (Cornoldi & Vecchi, 2003). According to the latter view, it is possible to distinguish between more passive processes (simple recall of previously acquired information) and different degrees of active processing (manipulation of information to produce an output different from the original inputs). Importantly, this model, predicts that subgroups of individuals can be found with difficulties associated with both a specific modality and a particular degree of control. This prediction is consistent with evidence suggesting that executive processes may also be modality specific (e.g. Palladino, Mammarella, & Vecchi, 2003). For example, by using a battery of verbal and non-verbal working memory tasks, Cornoldi, Dalla Vecchia, and Tressoldi (1995) tested a group of children with high linguistic and low visuospatial abilities and found that they failed only in active visuospatial tasks. In another study, Cornoldi, Rigoni, Tressoldi, and Vio (1999) investigated the generation and manipulation of mental images in working memory and found that visuospatial learning disabled (VSLD) children also failed in active tasks which required the generation of mental images.

In fact, over the past few years interest has increased in learning disabled children whose non-verbal and/or visuospatial abilities are lower than their verbal abilities. In contrast with most other learning disabled children, they have good school achievements in linguistic areas (reading and writing) but have difficulty in school tasks involving visuospatial processes (parts of mathematics, drawing, science etc.). These children, who are described as having a visuospatial learning disability (Cornoldi et al., 1995), a non-verbal learning disability (e.g. Rourke, 1989), or a right hemisphere learning disability (e.g. Nichelli & Venneri, 1995), perform normally in verbal tasks but score poorly in visuospatial tasks and show a discrepancy between verbal IQ and non-verbal IQ. According to Pelleiter, Ahmad, and Rourke (2001), these children may experience three main categories of dysfunction: (1) *motor*—lack of psychomotor coordination, difficulties with fine graphomotor skills and complex motor skills; (2) *visual spatial organizational*—with impairments in non-verbal problem solving, mathematics, concept-formation, difficulties with mental images and spatial relations; (3) *social*—lack of ability to comprehend non-verbal communication often leading to eventual isolation, withdrawal and difficulties in dealing with novel situations (Harnadek & Rourke, 1994; Pelleiter et al., 2001). A recent series of studies focused on the second point, and in particular considered the importance of visuospatial working memory (VSWM) in understanding the cognitive impairments of VSLD children (Cornoldi et al., 1999). In fact, a difficulty in VSWM could explain the failures met by these children not only in visual and spatial tasks clearly relying on VSWM, but also in motor tasks which have been shown to depend on VSWM (Logie, 1995).

The study of VSWM deficits in learning disabled children also offers the opportunity of finding an effect symmetrical to the one described for verbal material in the classical study by Daneman and Carpenter (1980) and then replicated in an impressive number of studies (see Daneman & Merikle, 1996 for a meta-analysis). In particular, a series of studies (e.g., De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001) investigated this issue in verbal working memory tasks with linguistically-disabled individuals. De Beni et al. (1998) showed that success in verbal working memory span tasks (requiring subjects to process sentences or strings of words and then recall the last word of each sentence or string) was correlated with a decreased number of intrusion errors. These errors were due to the recall of processed, but irrelevant information from the same pool of materials as the relevant information (i.e. non-final words). This result is important because it shows that working memory tasks are not only related to a loss of target information but are also related to an inappropriate control of irrelevant information, probably due to a poor inhibitory ability.

In accordance with the observation that individuals having difficulties in activities assumed to involve verbal working memory (such as reading) also have problems in working memory (Daneman & Carpenter, 1980; De Beni et al., 1998), we assume that a similar pattern of results can be found for VSWM in a different group of individuals. Therefore we expect children with visuospatial disabilities to be characterized by poorer recall of correct targets and a higher recall of irrelevant information in a VSWM task. These outcomes could enrich existing knowledge on the development of VSWM and help in understanding the mechanisms of VSWM. In this area, some studies have already pinpointed more specific components within VSWM on the basis of distinct developmental patterns. For example, Logie and Pearson (1997) tested children aged between 5 and 12 years and found a "developmental fractionation" between visual and spatial memory since the memory for a visual pattern developed much more rapidly than memory for a spatial sequence. However, Hamilton, Coates, and Hoffernan (2003) suggested that more specific processes of VSWM should be considered, like speed of processing, VSWM capacity and VSWM processing efficiency. The present study is specifically focused on the active component of VSWM and on a mechanism which could produce a failure in this area. In fact, it is not clear whether developmental changes or difficulties in active VSWM can be explained in terms of general principles such as differences in "capacity" (Halford, 1982), general resources (Swanson, 1996), processing speed (Kail, 1993), increased knowledge and experience which allow a more efficient use of strategies (Anderson, 1992; see also Cowan, 1997; Pickering, 2001), or in terms of a more specific factor such as control and inhibition of irrelevant visuospatial information. In fact some authors (Dempster, 1992; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2000) argued that individual differences in measures of working memory capacity reflect the ability to use controlled attention to prevent distraction from the environment and interference from events stored in long-term memory.

In conclusion, the present study tested the hypotheses that children diagnosed with visuospatial learning disability symptoms would have difficulty in an active VSWM task and that they would present a particularly pronounced difficulty in controlling previously processed irrelevant information. To examine these issues, the study adopted a procedure proposed by Cornoldi, Marzocchi, et al. (2001) in their research with ADHD children (see also Cornoldi & Mammarella, submitted for publication). The procedure was based on the presentation of 4 × 4 matrices in which the experimenter pointed to sequences of positions. Participants were presented with series of 2, 3, or 4 consecutive matrices. In an empty matrix, participants had to then indicate the last position for each matrix following the order of presentation. The participant's main task was, in fact, to remember only the last location indicated in each matrix. Responses were correct when children reported the final positions for a given series following the presentation order. An error was defined as "intrusion" if the response for a given series was an irrelevant location which had however just been presented (i.e. the recall of a non-final position within the same series), and as "invention" if the response for a given series of matrices was a position never pointed at by the experimenter in that particular series.

In the first Experiment three groups of children (VSLD, language disability and control) had to perform the matrix end-position task in conjunction with a secondary alignment-judgment task. The inclusion of a language-disabled group offered an opportunity of examining the specificity of the VSWM deficit. In fact, there is a large debate as to whether the working memory difficulties of children with language disabilities are modality specific, since some studies have reported that these difficulties can also involve the spatial sphere (Morris et al., 1998). On the contrary, Cornoldi, Carretti, and De Beni (2001) argued that working memory difficulties in specific learning disabilities should be related to specific modalities and, in particular, that children with language disabilities should fail only in verbal working memory tasks whilst VSLD children should fail only in visuospatial working memory tasks. In the second Experiment, using different stimuli, the secondary task consisted of deciding whether both non-final and end-positions presented in a matrix corresponded to a group of grey coloured cells. In this way, it was possible to better vary the locations of the irrelevant positions and to examine whether the stress of identifying locations in the grey cells affected the error pattern.

2. Experiment 1

In this experiment, we examined children with a visuospatial learning disability (VSLD) in a task which specifically measures the active components of visuospatial working memory. VSLD children were compared to two other groups; one group consisted of children with a normal development and the other group of children experiencing learning difficulties in the language domain (LD). The inclusion of this latter group also offered the possibility of examining whether VSWM difficulties are generically related to a cognitive weakness, or exclusive to the VSLD group.

2.1. Method

2.1.1. Participants

From an initial sample of 392 children, aged between 12 and 14, who were attending seventh and eighth grades in secondary schools in North-Eastern Italy, we selected a group of 22 Visuospatial Learning Disabled (VSLD) children composed by 9 seventh-graders (3 boys and 6 girls) with a mean age of 151.6 months (SD = 6.6) and 13 eighth-graders (4 boys and 9 girls) with a mean age of 159.5 months (SD = 4.7) as well as two comparison groups, a Linguistic Learning Disabled group (LD) of 18 children, 8 seventh-graders (6 boys and 2 girls with a mean age of 148.8 months, SD = 5.8) and 10 eighth-graders (7 boys and 3 girls with a mean age of 158.8 months, SD = 2.3) and a Control Group of 24 children composed by 4 males and 7 females attending seventh grade (mean age of 147.3 months, SD = 2.9) and 8 males and 5 females attending eighth grade (mean age of 159 months, SD = 4.2). We received informed consent from the participants' parents. The children of the VSLD group were described by teachers as poor learners and obtained a low score (below 30%) in the "Spatial Reasoning" test included in the PMA battery (Thurstone & Thurstone, 1963). The test requires choosing, from different alternatives the pattern which corresponds to a reference stimulus after rotation. The LD group was identified on the basis of teachers' referrals and scores (below 20%) in a foreign-language achievement test. Children in the VSLD and LD groups did not have a general cognitive deficit, and scored above 50% (IQ > 100) in a subtest of the PMA intelligence battery, which did not relate to their specific problem. Performance on this test matched those of Controls. On the PMA "Verbal Meaning", a subtest based on the identification of synonyms, the VSLD group had a mean score of 20.18 (SD = 2.48) and the Controls obtained a mean score of 20.29 (SD = 1.94). On the already-mentioned "PMA-Spatial Reasoning" the LD group obtained a mean score of 25.61 (SD = 8.23) and Children in the Control Group a mean score of 25.00 (SD = 7.51). All these mean scores were not significantly different and, according to test norms, all children obtained a score above 50%. Groups were similar for socio-cultural level and matched for grade, age and schooling.

2.1.2. Material and procedure

A 4 × 4 board, comprising 16 wooden cubes (each cube 4 × 4 × 4 cm) was used and different configurations were presented. For each matrix, the experimenter pointed to three contiguous positions at the rate of one position per second with an interval of two seconds after each matrix. Each child, tested individually, was engaged in an alignment-judgement task, that is, he/she had to decide for each matrix whether the three positions indicated were along the same line (horizontal, vertical or diagonal). The correct response was "yes" in 50% and "no" in 50% of cases. This secondary task was introduced in order to be sure that all the positions pointed at by the experimenter were processed by the child. Series of 2, 3 or 4 matrices were presented. For example, a series of two matrices involved the presentation of two matrices; in each of them three positions were presented and the participant's task was to immediately give the alignment-judgement and later to recall the last position of each matrix. In fact, at the end of each series, immediately after the alignment-judgement concerning the last matrix, the child was invited to indicate on the cube board the last positions pointed at by the experimenter in each matrix of that series, following the order in which the matrices were originally presented. The task was divided into 6 blocks, each of them including one series of 2, one of 3 and one of 4 matrices. In order to have a sufficiently large number of positions which were not pointed at, in any matrix of a series, it was necessary, in some cases, to set a target position for each series length to coincide with a non-final position in a preceding matrix of the same series. For example, a non-final position in the first matrix became a final position in the second. An example of the material is given in Fig. 1.

Children were tested individually in a quiet room at their school. The experimenter illustrated the task in detail and checked for proper understanding with several practice trials. The experiment lasted about 30 min.

2.2. Results

All participants understood the task well and were able to meet its requirements. However, a child of the VSLD group could not be included in the analysis since he did not attend the whole experimental session. There were very few incorrect

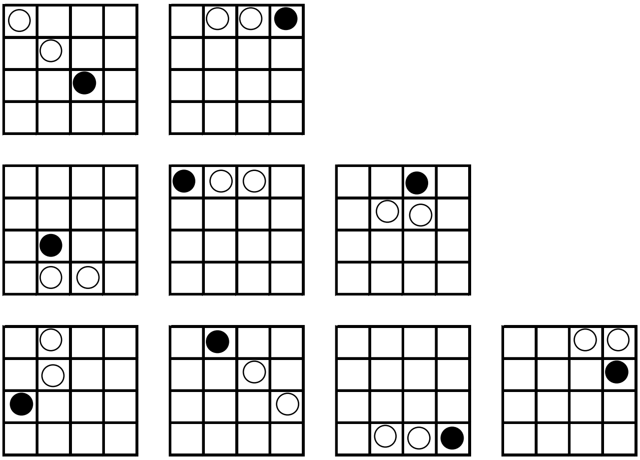

Fig. 1. Example of material used in Experiment 1; black circles represent the target positions.

responses in the alignment task, i.e. children were generally correct in judging whether the three positions indicated in a matrix were aligned. This meant that there were no trade-off effects due to the fact that children compensated different levels of performance in the alignment judgements with corresponding different levels in the memory task.

Although children were instructed to report only the final positions they could remember, it must be noted that they tended to give a response for each matrix presented. The scoring system was based on a procedure, which emerged as the most simple and informative one in preceding studies using the same methodology (Cornoldi & Mammarella, submitted for publication; Cornoldi, Marzocchi, et al., 2001). We computed the absolute numbers and then the percentage of correct responses and different types of errors. A response was considered correct when the child pointed, in the correct order, to the location presented as the last one in a matrix. When the child pointed to a different location, i.e. made an error, we classified the error according to two distinct categories: i.e. an invention or an intrusion. A response was considered an invention if the location indicated was never pointed at by the experimenter in the last series of matrices. For example, in the three matrices series of Fig. 1, second line, no position in the last column was pointed at by the experimenter therefore if a child pointed at one of these, the response would be considered an invention. On the contrary, for the same series, the second and the third cell in the last row were pointed at by the experimenter but they were not the final ones therefore if the child pointed at one of these, the response would be considered an intrusion error.

Using this system for differentiating the two types of errors meant that, for one series, the number of locations potentially involved in an intrusion error was not the same as the number of locations involved in an invention error. For example, for the two matrix series in Fig. 1, four positions involved a potential intrusion error and then an invention error. For this reason we computed a percentage score obtained by dividing the total number of a type of response by the total number of positions potentially interesting that type of response. This scoring system does not seem to be affected by the particular characteristics of the specific series and offers a better general view of the results (Cornoldi & Mammarella, submitted for publication). Furthermore, as percentage scores can affect the data distribution, we made a preliminary analysis in order to control for the normality of the distributions. Where the distribution did not appear normal, we transformed the data in arc-sine data, as is suggested for similar cases (Cohen, Cohen, West, & Aiken, 2003; see also Myers, 1972).

Table 1 reports the overall scores obtained by the three groups of children, with respect to correct responses, intrusion and invention errors.

A one-way ANOVA on the mean percentages of correct responses revealed a significant Group effect, $F(2,60) = 20.17$, MSE = 23.50, $p < .001$; $\eta_p^2 = .39$. A post-hoc comparison with Bonferroni's correction showed that the VSLD group differed significantly from both the other groups ($p < .001$), whereas the two other groups (Controls vs. LD) were not significantly different.

Kolmogorov–Smirnov tests on the percentage scores for intrusions and invention errors were not normal (Kolmogorov–Smirnov $z > 1$). Analyses of errors were then carried out with arc-sine values. A 3 (group: VSLD, LD and Controls) × 2 (type of errors: intrusions vs. inventions) mixed ANOVA revealed a significant main effect of Group, $F(2,60) = 26.29$, MSE = .001, $p < .001$; $\eta_p^2 = .47$. A post-hoc comparison using the Bonferroni's correction showed that the VSLD group differed significantly from the LD and Control Groups ($p < .001$), but Controls and the LD group were not significantly different. The main effect of error type was not significant, but the interaction between the two variables was significant, $F(2,60) = 4.15$, MSE = .001, $p = .021$; $\eta_p^2 = .12$; a Tukey-test revealed that the VSLD group made significantly more intrusion errors than inventions ($p < .01$), whereas percentages of intrusions

Table 1
Mean percentages, standard deviations (SD) and confidence intervals (CI 95%) of correct responses, intrusions, and invention errors by the three groups of children (Controls, Visuospatial Learning Disability Children—VSLD, Learning Disabled Children—LD). Percentages of intrusions and inventions were computed by dividing the number of errors by the number of potentially interested positions

Groups		Mean	SD	CI 95%	
				Inferior limit	Superior limit
Controls	Correct	87.02	7.01	82.78	91.25
	Intrusion	2.87	3.03	1.59	4.15
	Invention	3.23	2.17	2.31	4.15
VSLD	Correct	72.10	10.00	66.06	78.14
	Intrusion	8.86	3.85	7.11	10.62
	Invention	5.59	3.51	3.99	7.19
LD	Correct	85.03	9.25	78.41	91.65
	Intrusion	3.13	3.09	1.59	4.67
	Invention	3.73	3.45	2.01	5.44

were not statistically different from percentages of inventions in Control and LD groups; furthermore the VSLD group differed significantly from the other two groups in intrusion errors but not in invention errors.

The mean number of intrusions due to aligned positions (as for example in the second and third matrix of the four-matrices series in Fig. 1) was very similar to the mean number of intrusions related to positions not aligned with the final one (as for example in the first and fourth matrices).

2.3. Discussion

In conclusion, Experiment 1 offers a clear pattern of results as regards the specific working memory deficit of VSLD children. It shows that it is possible to find a visuospatial working memory difficulty in VSLD children which mirrors the difficulties found in low verbal comprehension abilities groups when performing verbal working memory tasks (Daneman & Merikle, 1996).

Study 1 shows that the difficulties met by the VSLD group cannot be attributed to a non-specific cognitive difficulty, since another group of children (LD), with another pattern of cognitive difficulties, was different in both their correct performance and the pattern of errors manifested. The experiment also confirmed De Beni et al.'s (1998) findings that failure in working memory may be associated with an increase in intrusion errors. In the present case, intrusions were not the only plausible error that individuals who have difficulty remembering the correct positions could make. They could also have made invention errors. Despite this, the VSLD group made a higher percentage of intrusion than invention errors, an effect which was not observed in the other two groups. The fact that the intrusion superiority effect was not particularly evident and could not be generalized to all participants is different from the results obtained in other studies (Cornoldi, Marzocchi, et al., 2001). This result could be due to the particular age of the children participating in the present experiment and to the modest difficulties they met in the task (the percentages of correct responses of control and LD children were above 85%), suggesting that the patterns of performance with lower rates of correct responses should also be examined.

3. Experiment 2

Experiment 2 was intended to generalize the results of Experiment 1 by introducing different task conditions and groups. A particular modification of the procedure was aimed at excluding contiguity effects in the production of intrusion errors. In fact, since non-final positions were contiguous to final ones in Experiment 1, intrusion errors could be affected by this contiguity. In other words, children may have a poor memory of the exact position of a final item but remember the area or line in which it was located, using it as a cue for the memory response.

To address this issue, non-target non-final positions were randomly chosen in each matrix. Furthermore a new task was used, requiring subjects to tap on the table whenever the experimenter touched a coloured cell in the matrix. For this reason, matrices contained both coloured and white cells. We expected coloured (stressed) cells to enhance memory traces due to their perceptual salience. This manipulation should thus increase the probability of a correct response, as has been observed when using a similar methodology in a verbal working memory task (Carretti, Cornoldi, De Beni, & Palladino, 2004), but could also affect the number of intrusion errors in two opposite ways. In fact, coloured cells could have the effect of increasing the activation of the incorrect non-final locations (and therefore their tendency to be erroneously recalled), or increase their discriminability from target items.

We predicted that VSLD children would be affected more than controls by the stress (colour) manipulation of irrelevant information. In particular, children with lower cognitive maturation and then with lower VSWM and inhibitory capacities (Bull & Scerif, 2001; Cornoldi & Vecchi, 2003) could be especially disturbed by salient and activated irrelevant information.

3.1. Method

3.1.1. Participants

From an initial sample of 416 children aged between 7- and 11-years old, we selected a group of 21 visuospatial learning disability children and a Control Group of 25 children, who attended the second and fifth-grades of elementary schools in North-Eastern Italy. More specifically, the VSLD groups included 11 children attending second grade, 9 boys and 2 girls (mean age of 87.1 months, SD = 3.5) and 10 children (4 boys and 6 girls) attending fifth grade of elementary school (mean age of 125 months, SD = 4.0), while the Control groups comprised 13 second-graders (9 boys and 4 girls, mean age of 89.1 months, SD = 3.1) and 12 fifth-graders (4 boys and 8 girls, mean age of 125 months, SD = 3.8).

The VSLD group was identified on the basis of specific school and visuospatial difficulties and a discrepancy between spatial (low) and verbal (high) intelligence. The two groups were similar for socio-cultural level and matched for grade, age and schooling, and both scored above 50% in the subset "Verbal Meaning" of the PMA battery (Thurstone & Thurstone, 1963). Only children who obtained a score above 50% in the visuospatial test were included in the Control Group. We received informed consent from participants' parents.

3.1.2. Material and procedure

In this experiment, a paper version of the material adopted in Experiment 1 was used. Series of positions in two-dimensional 4 × 4 matrices, comprising 16 empty cells (each cell measured 4 × 4 cm) were used. Seven series of three matrices were presented to all children. Experimental series were preceded by practice series, until the child showed sufficient mastery of the task. Furthermore, each series of three matrices was accompanied by another series, in the case of second-graders by a series with only two matrices and, in the case of fifth-graders, by a series of four matrices. The presentation order of the series was counterbalanced across participants. The procedure was the same as in Experiment 1, the only difference being that the positions presented within each matrix were randomly chosen and the alignment judgement

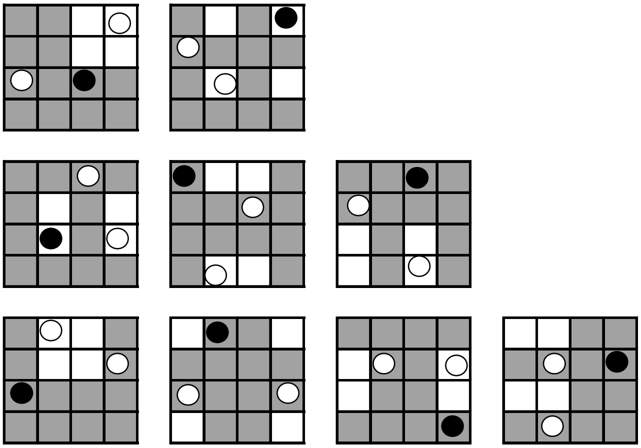

Fig. 2. Example of material used in Experiment 2.

task was replaced by a new secondary task. In Experiment 2, in each matrix two rows and two columns were marked by the colour grey. The position of the coloured columns and rows was counterbalanced across the different sets. Participants were asked to tap on the table if the position pointed at by the experimenter fell within the coloured areas (see example in Fig. 2).

Approximately, a third of both the final and non-final positions in all series were *stressed*, i.e. fell in the grey coloured areas, thus arguably receiving enhanced perceptual and attentional resources. In particular, for the seven series of three matrices, 5 out of 21 correct responses were unstressed and 16 stressed; 14 out of the 42 locations potentially involving intrusions were unstressed and 28 stressed. The empty test matrix in which the recalled final positions were to be indicated did not contain any coloured cells. The total experiment lasted approximately 30 min.

3.2. Results

The scoring system was the same as in Experiment 1. We will focus only on the comparisons of the two groups' performances in the three matrices series, which were presented to both age groups.

Table 2 reports the mean percentages of correct responses and error rates of VSLD children and Control Groups attending the second and the fifth grade. A Kolmogorov–Smirnov test showed that the unstressed intrusions did not have a normal distribution (Kolmogorov–Smirnov $z = 2.17$; $p < .001$). Analyses of errors were then carried out with arc-sine values.

A 2(second vs. fifth grade) × 2(VSLD vs. Controls) × 2(stressed positions vs. unstressed) ANOVA on correct responses showed a significant effect of grade, $F(1,42) = 14.36$, $p < .001$, MSE = 521.82, $\eta_p^2 = .26$, indicating that fifth-grade children performed better than second-grade children (77.19% vs. 59.05% of correct responses) and a significant main effect of group $F(1,42) = 6.54$, $p = .014$, $\eta_p^2 = .14$, due

Table 2
Mean percentages, standard deviations (SD) and confidence intervals (CI 95%) of correct responses, intrusion and inventions errors made in the series of three matrices by the two groups of children (Controls and Visuospatial Learning Disability Children, VSLD) according to grade and stress (*S*)

Second graders		Mean	SD	CI 95%	
				Inferior limit	Superior limit
VSLD	Correct-*S*	51.00	27.58	32.48	69.54
	Correct	50.00	21.65	35.45	64.54
	Intrusion-*S*	15.07	9.17	8.90	21.23
	Intrusion	9.00	15.41	−1.36	19.35
	Invention	8.27	5.66	4.47	12.07
Controls	Correct-*S*	77.51	19.96	65.44	89.57
	Correct	57.69	18.78	46.34	69.04
	Intrusion-*S*	6.55	5.06	3.49	9.61
	Intrusion	20.31	25.34	4.99	35.62
	Invention	5.09	2.94	3.31	6.87
Fifth graders					
VSLD	Correct-*S*	80.75	12.70	71.66	89.39
	Correct	66.25	25.03	48.34	84.16
	Intrusion-*S*	5.12	2.93	3.03	7.21
	Intrusion	33.30	27.35	13.73	52.87
	Invention	4.43	4.58	1.15	7.71
Controls	Correct-*S*	87.81	8.97	82.11	93.51
	Correct	73.96	16.39	63.54	84.37
	Intrusion-*S*	4.07	2.53	2.45	5.67
	Intrusion	2.75	9.52	−3.30	8.80
	Invention	3.85	3.28	1.77	5.95

to the fact that VSLD were poorer than Controls. Finally, also the main effect of stress was significant $F(1,42) = 14.01$, $p < .001$, $\eta_p^2 = .25$, due to an improvement in performance (correct-stressed = 74.27 vs. correct unstressed = 61.98).

A 2(second vs. fifth grade) × 2(VSLD vs. Controls) × 2(total intrusions vs. inventions) ANOVA on error rates in arc-sine transformation showed a significant main effect of group, $F(1,42) = 7.29$, $p < .01$; MSE = .013; $\eta_p^2 = .15$, (VSLD = 12.91 vs. Controls = 6.50). The effect of type of errors was statistically significant $F(1,42) = 12.47$, $p < .001$; MSE = .013; $\eta_p^2 = .23$, (intrusion errors = 13.10 vs. inventions = 5.39). The interaction type of errors by grade by group was also significant, $F(1,42) = 5.16$, $p = .03$; MSE = .02; $\eta_p^2 = .11$. A post-hoc comparison using the Tukey test showed that VSLD and Control fifth-graders differed in the total number of intrusion errors made ($p < .01$) but not in the number of invention errors made, whereas the differences between the groups of second-graders on both intrusion and invention errors only approached significance.

A 2(second vs. fifth grade) × 2(VSLD vs. Controls) × 2(stressed vs. unstressed positions) ANOVA on intrusion errors transformed in arc-sine values revealed a significant main effect of group $F(1,42) = 4.74$, $p = .35$, MSE = .027; $\eta_p^2 = .10$; also the main effect concerning the stress manipulation was significant $F(1,42) = 8.22$,

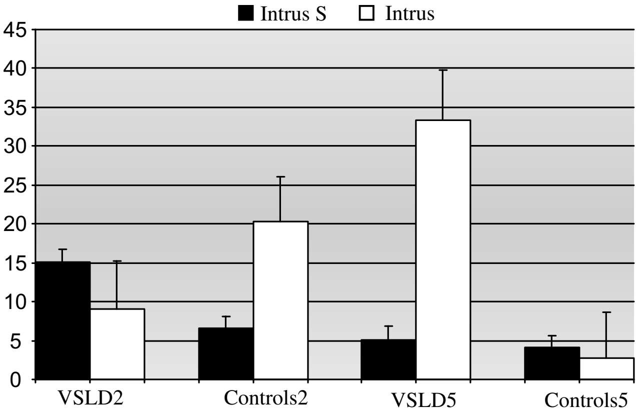

Fig. 3. Mean percentages (the whiskers correspond to the standard errors) of intrusion errors, for stressed (Intrus-*S*) and unstressed (Intrus) locations, made in the series of three matrices by Controls and Visuospatial learning-disabled children (VSLD) attending second (2) and fifth (5) grade.

$p < .01$, MSE = .025; $\eta_p^2 = .16$. The interaction grade by group $F(1,42) = 7.32$, $p < .01$, MSE = .027; $\eta_p^2 = .15$, and the three way interaction were also significant $F(1,42) = 15.74$, $p < .001$, MSE = .025, $\eta_p^2 = .27$.

The complex pattern of effects due to the stress manipulation is illustrated in Fig. 3. It can be noticed that the stress produced by tapping on the coloured positions did not increase but tended to reduce the risk of an intrusion error in all groups except VSLD second-graders. Post-hoc comparisons with the Tukey-test revealed that the difference between stressed and unstressed errors was significant (although not always in the same direction) for all groups, except for the fifth graders' Control group. Furthermore, VSLD second-graders made significantly more errors than Controls for stressed positions and significantly less errors for unstressed positions than Controls ($p < .05$); as for fifth-graders, VSLD children differed from the Control group only in intrusion errors of unstressed positions ($p < .01$).

3.3. Discussion

In conclusion, the data of Experiment 2 replicated, using a different methodology and subjects, the main effects found in the preceding research, i.e. that VSLD children gave less correct responses and made—in general—more errors compared with Controls.

In this experiment the percentage of correct responses was lower and intrusion errors were generally more frequent than in Experiment 1. More specifically, the children's general tendency was to make more intrusion than invention errors and this tendency was present to a greater extent in VSLD children. Therefore, as one of the main methodological differences between this and the previous experiment was that intrusion errors could also be found in positions, which were not contiguous to target positions. The experiment revealed that the intrusion superiority effect cannot be attributed to item contiguity.

The stressing of positions, produced by the combination of the perceptual emphasis due to the coloured cells and the tapping request, seems to enhance memory activation. In fact, stressed targets were recalled better than unstressed target positions. However, the stress effect on non-final positions varied between groups. The group with the lowest performance (VSLD second graders) was negatively affected by the increased stress of irrelevant positions. This could be due to a particularly severe deficit in the inhibition of highly activated information (Bull & Scerif, 2001). Differently from this group, the group of fifth-graders VSLD took advantage of the stress in order to avoid intrusion errors, probably because they had a good memory of it and could more accurately discriminate it from a target item. In other words, it is possible that both second-grader and fifth-grader VSLD had a higher activation of the stressed positions than of the unstressed positions, but used the activation in a different way. Second graders VSLD simply recalled the position; fifth graders were able to reject it.

The comparison between the two age groups of children should be cautiously considered, as the number of children in each age subgroup was small. However, it shows that development can interact with the child's cognitive disability and have a complex influence in VSWM performance, as it does not only affect the quantitative level of recall, but it also affects the qualitative pattern of errors.

4. General discussion

Our data offer some insight into both the characteristics of VSLD children and the organization of working memory, in particular of VSWM. Since the pioneering study of Daneman and Carpenter (1980) it has been suggested that different working memory tests examine different components of working memory. In particular, Daneman and Carpenter (1980) designed active (reading or listening) span tests aimed at measuring the processing components of working memory. The tests required selective memory for parts of the processed material, i.e. recall of the last part of different verbal strings. In the present research VSLD children were presented with a visuospatial working memory test which shared some features with Daneman and Carpenter's (1980) span tests, in that only the last part of the material presented had to be remembered. This active VSWM task offered results similar to those observed in the verbal active span tests and hence both extends results from previous research and appears to be a good candidate for examining active VSWM; even more so given that it is simple, manageable, and can be easily understood by children.

An important result of this research is the evidence that failure in VSWM is typically associated with specific patterns of errors. The main findings can be summarized as follows: First, a particular difficulty in the VSWM task was related to an increase in the number of intrusion errors, which in our study was comparatively higher than for inventions. Second, under certain conditions, the proportion of intrusion errors was particularly high for VSLD children. Third, an increased stress on some irrelevant information affected the pattern of errors of VSLD children, reducing the intrusion errors for older and Control children, increasing them for second-graders VSLD children.

The finding that a failure in working memory tasks is associated with an increase in errors due to processed irrelevant information supports previous results obtained by De Beni et al. (1998), which showed that individuals who have difficulty with listening span tasks make a significantly higher number of intrusion errors. However, in De Beni et al.'s study (1998), individuals failing to recall target items (the last words in each string) did not have other plausible alternatives if they wanted to recall the required number of items. On the contrary, with the present method, a subject failing to recall a target (final) position could make invention as well as intrusion errors. In a certain sense, the invention error should occur even more frequently, because the corresponding not-processed location could not be associated to a specific label suggesting that the item should not be remembered. In fact, our results show that children who fail to remember the correct position could not take advantage of the possibility of excluding irrelevant processed locations. On the contrary, these irrelevant locations tended to be indicated more frequently than non-processed locations especially when the child's general memory was weak.

The stressing of a position, by association with a coloured cell and a tapping response, produced a clear advantage for the correct responses (thus confirming previous research, Carretti et al., 2004), but had peculiar effects on error patterns. In particular, VSLD children showed the opposite effect according to grade: VSLD second-graders made more errors for stressed than for unstressed locations, whereas the performance of VSLD fifth-graders was the opposite. Stressing a position could have two different effects on the children's processes. On one hand the grey positions, which involved a tapping response, could have acquired for some children a particular salience, making them more memorable and discriminable with respect to the other locations in the matrix. On the other hand, the tapping response could have increased the activation of the involved location with the consequence of becoming more difficult to inhibit its retrieval. Therefore, VSLD children could be affected by the highest activation when young, trying to compensate for their memory weakness on the basis of stimulus salience and helped by their better discriminability when older.

Until now, the literature on VSWM has not examined the role of irrelevant information explicitly, especially with reference to the active components of the system. Some studies have assumed that a loss of information in VSWM is due to a variety of different factors, including decay or an interference effect related either to a spatial attention conflict (e.g., Smith & Scholoy, 1994) or involvement of the Central Executive component of working memory (Klauer & Stegmaier, 1997). Our evidence suggests that a factor underlying failure in an active VSWM test can be associated with a tendency to recall intrusive, processed information. Our data make it difficult to provide a single explanation for the underlying mechanisms. For example, the effect could be related to attentional deficits, i.e. VSLD children could have difficulty in initially selecting the relevant information. Looking at the series of positions in each matrix, they may not pay enough attention to the last items and may not encode them properly. Another explanation is that VSLD children could have very weak memory of processed positions, so that they are not able to discriminate between final and non-final positions. In other words, VSWM may have been used to maintain not only relevant information, but also information which subsequently became irrelevant.

Our data could be also better interpreted within May and Hasher's view (1998; Hasher, Zacks, & May, 1999), which defines inhibition as a mechanism believed to prevent irrelevant or marginally relevant information from entering working memory and to dampen activation that was once relevant but later became inappropriate for current goals. The role of inhibition in working memory has been increasingly stressed in recent literature. For example Miyake et al. (2000), examined the role of the three main executive functions, i.e. shifting, updating and inhibition, and Bull and Scerif (2001), in particular, illustrated the critical role of inhibition failure in the field of developmental disabilities (see also Nigg, 2000 for a discussion of different types of inhibition). Intrusion errors reflect a higher memory activation of the irrelevant information, in association with poorer activation of target items; the recall process may be based on retrieval of the most activated information. In other words, children should process information in the task by activating it and then should retrieve the most activated information. In order to succeed in the task children must be able to immediately reduce activation of the no longer relevant (non-final) information, but some children may fail in this particular requirement.

Our study also offered more detailed evidence for the idea that VSLD children have difficulty in VSWM (Cornoldi et al., 1995, 1999). In fact our learning disabled individuals had difficulty in recalling the final target information. This result is important because it offers a window on the nature of failure in spatial tasks and the specific learning difficulties met by VSLD children. The fact that a similar pattern of difficulty was not observed, in Experiment 1, in linguistic learning disabled children, confirms the hypothesis that specific subtypes of learning disability are associated with specific subtypes of working memory difficulties, as hypothesized by Cornoldi, Carretti, et al. (2001). Our results not only show that the VSLD meet difficulties in active VSWM tasks, but also that their difficulties produce a different pattern of errors and this pattern may be more sensitive to development than in normally developing children.

While the present results help us to understand the nature of VSWM deficits in visuospatial learning-disabled children, we cannot exclude the possibility that adequate performance in our VSWM task most critically dependent on was also a result of increased knowledge and improved central executive functioning, rather than on the efficiency of a modality specific VSWM system. Our data show that specific functions are damaged in visuospatial learning disabled children, and differences in their working memory seem to reflect more subtle specifications, possibly based upon the active manipulation processes required by the VSWM tasks. As such, future studies might aim to extend these patterns of performance to other spatial tasks relying on VSWM.

Acknowledgments

We are grateful to Drs. C. Braga and L. Ungaro who helped to collect the data of Experiment 1 and to Dr. Nicola Mammarella for his suggestions and comments.

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