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Evidence for different components in children's visuospatial working memory

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There are a large number of studies demonstrating that visuospatial working memory (VSWM) involves different subcomponents, but there is no agreement on the identity of these dimensions. The present study attempts to combine different theoretical accounts by measuring VSWM. A battery composed of 13 tests was used to assess working memory and, in particular, the hypothesized mechanisms involved in the tasks, that is, active processing and passive recall of visual versus sequential-spatial versus simultaneous-spatial versus verbal tasks. The battery consisted of a number of tests already used in previous studies and new tests developed to examine specific components of working memory. We analysed the psychometric characteristics of the tests, the correlations amongst measured variables and estimated the measured variables with structural equation modelling in children attending third and fourth grades. Results revealed that the best model was composed of a specific verbal factor, three visuospatial passive factors (sequential-spatial, simultaneous-spatial, and visual) and one visuospatial active factor.

Within the domain of cognitive psychology, a great deal of research has been carried out to examine the nature of working memory (WM) and, in particular, of visuospatial working memory (VSWM). Much of this research has taken, as a theoretical framework, the WM model developed originally by Baddeley and Hitch (1974, Baddeley, 1986). In the original version of Baddeley's model, WM is described as a non-unitary function comprising three distinct components, a central executive and two slave systems: a verbal working memory component (the phonological loop) and a visuospatial working memory (VSWM) component (the visuospatial sketchpad).

In the last 20 years, each of these components has been studied intensively and subjected to a series of different revisions. In particular, concerning VSWM, visual and spatial information seem to be maintained and processed by two different, but complementary, visual and spatial subcomponents. According to Logie's (1995) model, the visuospatial sketchpad consists of a visual store, known as the *visual cache*, and a rehearsal mechanism, known as the *inner scribe*. The visual cache provides a temporary

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store for visual information (colour and shape), while the inner scribe handles information about movement sequences and provides a mechanism through which visual information can be rehearsed in WM. There are a large number of studies that have shown a dissociation between visual and spatial memory, very often using the paradigm of selective interference, based on the assumption that two tasks tapping into the same cognitive function cannot be executed concurrently without a decrement in their performance. Outcomes from studies which used selective interference have often been interpreted as supporting the distinction between visual and spatial WM components (see Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Logie & Marchetti, 1991; Quinn & McConnell, 1996; Hamilton, Coates, & Heffernan, 2003, Exp. 2). For example, Logie and Marchetti (1991) found that one visual and one spatial interference task, involving the presentation of irrelevant pictures and unseen arm movements, respectively, caused a decrement in the performance of only primary tasks of the same nature.

Also developmental data were collected in support of a distinction between a visual and a spatial component. In a study by Logie and Pearson (1997), children aged 5–6, 8–9, and 11–12 years were administered the Corsi blocks task (Corsi, 1972; Milner, 1971) and an adapted version of the visual pattern test (VPT) (Della Sala, Gray, Baddeley, & Wilson, 1997). Results showed that performance in both tasks increased with age. However, the performance in the VPT developed much more rapidly than that in the Corsi blocks task. This pattern was similar to that found by Wilson, Scott, and Power (1987). Also, Hamilton and colleagues (2003) employed tests to assess visual (memorizing a series of locations presented simultaneously) and spatial memory (remembering a repeated sequence of spots) and found that visual measures developed faster than spatial ones, concluding that the two kinds of tasks tapped into different cognitive functions.

Experimental results using the Corsi-type and the VPT-type tasks, the two tasks that have mostly been used, until now, to measure the visual and spatial working memory subcomponents (Pickering, 2001a; 2001b), could be interpreted within Logie's (1995) model postulating a distinction between the visual and the spatial subcomponents of VSWM, with the VPT presented as a test tapping into the visual component, and the Corsi blocks task associated with the spatial component. However, the same results could be interpreted differently, based on an analysis of the task's characteristics. The point is that the differences between the Corsi blocks task and the VPT may be considered from other perspectives. For example, it has been argued that they also differ with respect to the modality by which the memory content is presented (Gathercole & Pickering, 2000; Pickering, Gathercole, Hall, & Lloyd, 2001; Pickering, Gathercole, & Peaker, 1998; Gathercole, 1999), that is, static (like in the VPT) as opposed to dynamic (like in the Corsi blocks task). In order to support this latter view, Pickering *et al.* (2001) compared the developmental pattern of two VSWM tasks, a matrix task, similar to the VPT, and a maze task, both presented either in a static or a dynamic format. Although the dynamic and the static formats of each test were made up of identical material, they resulted in a different developmental pattern: performance in the static format was higher and, importantly, increased more steeply with age. According to Pickering and colleagues, a mere distinction between visual and spatial processes cannot explain these results.

Several studies have also distinguished processing components versus domain-specific storage systems. Daneman and Carpenter (1980) differentiated between short-term and working memory by referring to maintenance and processing components where short-term memory maintains information, whilst working memory is involved in both maintaining and processing it. In a recent study, Bayliss, Jarrold, Gunn, and Baddeley (2003) challenged this view by examining the extent to which maintenance and processing functions could predict the performance in complex span tasks. Their results indicated that complex span performance depended not only on maintenance and processing, but also on their coordination. These data support a multiple component view, distinguishing between complex (active) and simple storage (passive) processes within WM. Along this line, Miyake, Friedman, Rettinger, Shah, and Hegarty (2001) examined the relationship between simple storage and complex span tasks in visuospatial format and executive functions. The authors found that simple storage and complex visuospatial span tasks were equally strongly related to executive functions, different from verbal tasks. Similar results were obtained by Alloway, Gathercole, and Pickering (2006) in children between the ages of 4 and 11 years. Alloway *et al.* also demonstrated that the link between simple visuospatial storage tasks and complex processing tasks was higher in younger children. All of these studies share the focus on storage versus processing, but do not distinguish between different presentation formats (visual vs. spatial, static vs. dynamic).

In summary, referring back to the studies by Logie and Pearson (1997) and by Pickering *et al.* (2001), these authors employed four tasks to demonstrate a dissociation between visual versus spatial memory and static versus dynamic format (Pickering & Gathercole, 2001). The tasks were the VPT versus the Corsi blocks task and the static mazes versus the dynamic mazes. The main problem associated with the definition of the VPT as a visual test is that the core features of visual content (like shape, texture, colour, etc.) are lost. In fact, if we consider the task's characteristics, in the VPT, matrices composed of partially filled squares are shown to participants whose task is to memorize and then reproduce them in the available empty matrices. In this task, the location of each filled cell in the learning matrix needs to be correctly encoded and retrieved in order to reproduce the correct pattern inside the empty testing matrix. Therefore, the locations and not the visual characteristics are crucial. If it is true that in some matrices a participant can see a visual pattern (e.g. the shape of an L created by the filled cells), this does not mean that this strategy can be used in all the matrices. Furthermore, the strategy eventually employed by a participant cannot be confused with the basic process involved in performing the task: following a similar reasoning, if a person visualizes the numbers during the maintenance of the digit span test, one should conclude that it is a visual task. In contrast, in the Corsi blocks task, locations are presented sequentially and thus the presentation order of locations is paramount. On this basis, Pazzaglia and Cornoldi (1999, see also Lecerf & de Ribaupierre, 2005; Mammarella *et al.*, 2006) distinguished between visual WM tasks, which require memorization of shapes and colours, and two kinds of spatial tasks sharing the requirement to memorize patterns of spatial locations, but differing in presentation format and, therefore, in the type of spatial processes involved: simultaneous in one case (i.e. in the VPT) and sequential in the other (i.e. in the Corsi blocks task). Evidence collected from different groups of children gave support to the differentiation between visual and spatial processes (Mammarella, Cornoldi, & Donadello, 2003) and between simultaneous-spatial and sequential-spatial processes (Mammarella, Cornoldi *et al.*, 2006).

The distinction between visual, simultaneous-spatial, and sequential-spatial tasks is linked to the continuity model proposed by Cornoldi and Vecchi (2000, 2003), which considers the possibility of distinguishing between many different WM types of processes, on the basis of both the format/content of information and the degree of controlled activity which are involved. The authors distinguished not only between different types of processes related to different types of content/format, but also between passive and active processes: the first refer to the retention of information that has not been modified after encoding, and the latter require transformation and manipulation of stored information. Furthermore, at higher control levels, tasks partially (but not completely) lose their specificity and the distance between different components is reduced. The possibility of distinguishing between verbal and visuospatial processes, for example, is always present, but different visuospatial processes tend to lose their specificities. Evidence of the distinction between active and passive processes come primarily from studies on individual differences in WM due to gender (Vecchi & Girelli, 1998) and age (Vecchi & Cornoldi, 1999; Richardson & Vecchi, 2002) and from studies on particular categories of participants, such as visuospatial learning disabled children (Cornoldi, Dalla Vecchia, & Tressoldi, 1995; Cornoldi, Rigoni, Tressoldi, & Vio, 1999; Mammarella & Cornoldi, 2005), blind people (Vecchi, Monticelli, & Cornoldi, 1995; Vecchi, 1998), mentally retarded people (Lanfranchi, Cornoldi, & Vianello, 2004), and children with attention deficit hyperactivity disorder (Cornoldi *et al.*, 2001). Despite the fact that the dimensions are considered as continuous, Cornoldi and Vecchi (2003) assume that some basic differentiations of processes can be identified, that is, first between the verbal and the visuospatial ones, and, second within the visuospatial ones, between passive visual, passive simultaneous-spatial, passive sequential-spatial, and active visuospatial processes.

In conclusion, research on VSWM progressed significantly in the past 25 years (Miyake & Shah, 1999; Cornoldi & Vecchi, 2003; Cowan, 2005), but a number of theoretical issues still need to be investigated further, and different theoretical positions examined. In particular, the specification of different components of VSWM and their relationship with development has yet to be resolved. The present paper aimed to compare different theoretical accounts concerning WM, and in particular VSWM, and analyse, through structural equation modelling, the best theoretical factor model fitting the data. In particular, we compared: *a*) a model involving two simple storage systems (verbal vs. spatial) and one complex span system (representing the classical Baddeley's model); *b*) a model involving two VSWM and one verbal component (visual vs. spatial – or static vs. dynamic – vs. verbal) without distinctions between storage and processing measures; *c*) a model distinguishing between complex span tasks and simple verbal, visual, and spatial tasks; and, finally, *d*) a model involving three different VSWM components (visual vs. simultaneous-spatial vs. sequential-spatial), one verbal and one active visuospatial component (representing the continuity model). Children were tested with a working memory test battery (Mammarella, Pazzaglia, & Cornoldi, 2006). The battery had the advantages of meeting the two requests implied by the present study. First, it included the same materials and tasks that were administered in the main studies proposing differentiations within VSWM and therefore potentially offered data comparable and compatible with those differentiations. Second, the tasks offered a direct reference to the continuity model proposed by Cornoldi and Vecchi, which distinguished between active visuospatial, visual passive, passive simultaneous-spatial, and passive sequential-spatial tasks. All the 13 tests of the battery used in the present study (10 tests tapping VSWM and three control tests tapping verbal WM) have a standard administration and scoring format. Specifically, they involve the typical span self-terminating procedure (proceeding from the shortest to the longest sequences and stopping when the child repeatedly fails) with the score defined by the longest sequences correctly reproduced.

Method

Participants

Participants were 162 children (87 boys and 75 girls), 72 third graders and 90 fourth graders with a mean age of 8.52 years ($SD = 0.68$) from different state schools in north-eastern Italy. Informed parental consent was obtained for all children prior to administration of the WM tests.

Materials and procedure

Tests were administered in a quiet room of the school during a single individual session according to the procedure defined for the battery (Mammarella, Pazzaglia, *et al.*, 2006). In order to avoid some tests being systematically affected by the effects of prolonged testing, test order was varied and randomized across participants. For each test, participants were presented with trials of increasing levels of complexity until they were unable to solve at least two out of three items for each level. The procedure stopped when the child was not able to solve two items of the same level. On the contrary, successful identification on two out of three items led to the subsequent complexity level (for a similar procedure, see Logie & Pearson, 1997). Each item was assigned a value equal to the level in which the item was included, so that items on the second level had a value of 2, on the third level a value of 3, and so on. Final scores were the sum of the three most complex items solved. For example, if the lasts three items correctly solved were the first two on the third level and one on the fourth level, then the child's score was $3 + 3 + 4 = 10$.[1]

The working memory test battery

The battery used in the present study consists of 13 tests (Mammarella, Pazzaglia, *et al.*, 2006; see also Mammarella, Cornoldi, *et al.*, 2006). Among these, 10 are visuospatial and three verbal. Some tests were derived from the literature and adapted to become a self-terminating procedure like the jigsaw puzzle test presented by Vecchi and Richardson (2000) as an active test, the houses recognition test (Mammarella *et al.*, 2003), considered a visual passive test, the static and the dynamic mazes (Pickering *et al.*, 1998), the Corsi blocks task (Corsi, 1972), the visual pattern test (Della Sala *et al.*, 1997), and the symbols reproduction test (Cornoldi & Gruppo, 1992). The pathway span task, the active version of the VPT, and the dots reproduction test were specifically used for this study. The three verbal working memory tests were the forward and the backward digit span tests (Wechsler, 1974), respectively, a passive and an active verbal task, and a serial recall of syllables (the syllable span test) as the second passive task (Figure 1 shows examples of the tests).

Passive visuospatial working memory tests

The Visual Pattern test (*VPT*) (adapted from Della Sala *et al.*, 1997). Children are presented with random square matrices created by filling in half the number of squares

[1] *The scoring system employed in the present study may be less accurate than the partial credit scoring procedures suggested by Conway* et al. *(2005) and by Friedman and Miyake (2005). However, it was not possible to implement these methods because our procedure was self-terminating, as in many classical span tasks, that is, stopped when the child was not able to solve two items of the same level and a successful identification on two out of three items led to the subsequent complexity level. Consequently, different children experienced different trial sequences.*

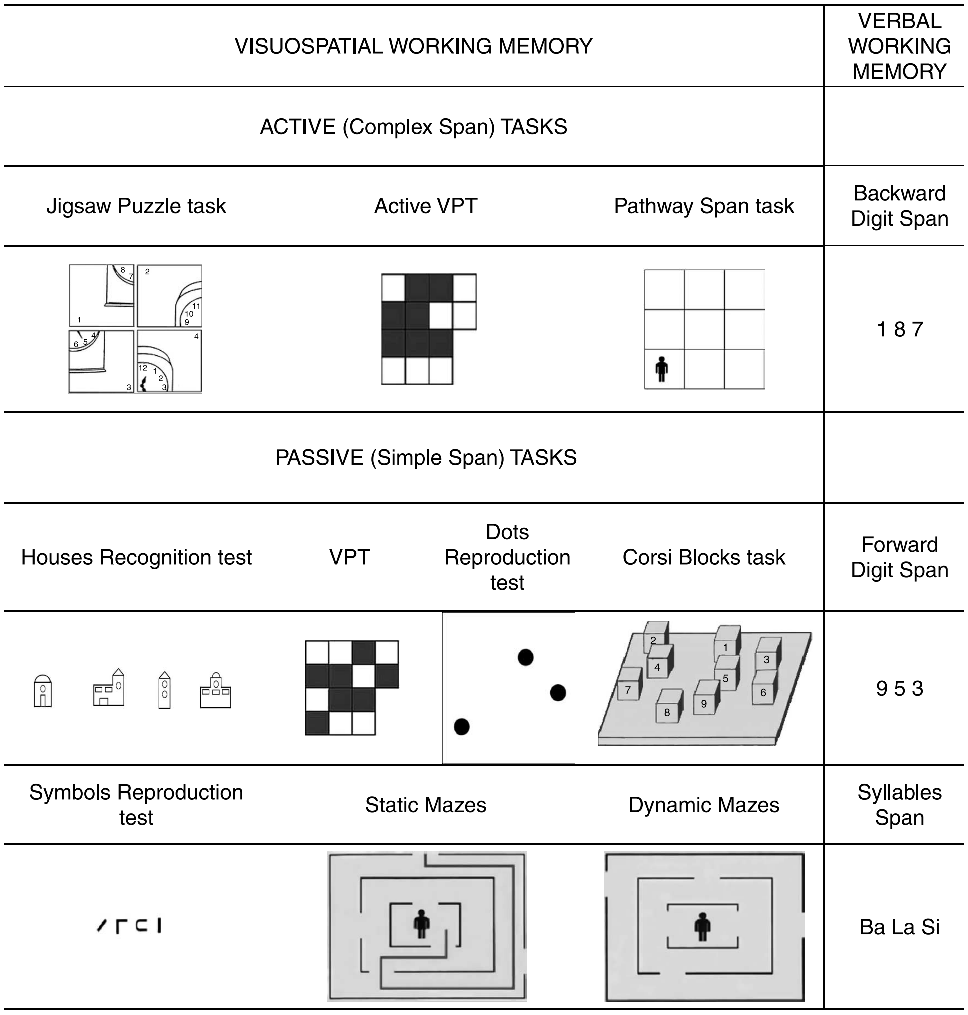

Figure 1. The 13 measures of working memory used in the test battery according to the distinctions between verbal versus visuospatial WM, and active versus passive. In the battery, the passive visuospatial tests are also distinguished between visual (left), simultaneous-spatial (centre), and sequential-spatial (right).

in the grid, for 3 seconds. The grids increase in size from the smallest (four squares in the first level, with two filled cells) to the largest (22 squares in the last level with 11 filled cells). The task requires memorizing different positions in matrices of various dimensions. After the presentation phase, in which participants memorize the filled squares, the initial stimulus is removed and children are presented with a blank test matrix in which they have to indicate the filled squares previously occupied by the targets. The level of complexity is defined as the number of filled cells in the matrix (from 1 to 10).

Static Mazes (*Static*) (adapted from Pickering *et al.*, 1998). In the static mazes, the child is presented with figures with a red line extended from the outside of the maze to the central figure. Each maze is displayed for 3 seconds before being removed from view and is replaced by an identical maze that does not show the route. The task involves drawing the route through the maze shown in the study item.

Dynamic Mazes (*Dynamic*) (adapted from Pickering *et al.*, 1998). In this task, the difference with respect to the static mazes is that on the target maze, the route to be recalled is traced by the examiner's finger in full view of the child and the task consists in drawing the route through the maze shown in the study item.

The Corsi Blocks test (*Corsi*) (adapted from Corsi, 1972). This test consists of a series of nine blocks arranged irregularly on a board. On the experimenter's side of the board, the cubes are numbered to facilitate administration; the blocks are tapped by the examiner in a random sequence, and the participants' task is to reproduce the same sequence of increasing length. Items are presented at a rate of one cube per second.

The Houses Recognition test (*Houses*) (adapted from Mammarella *et al.*, 2003). The stimuli are schematic drawings of houses seen from the front. Initially, a set of two houses is shown for 2 seconds (Figure 1). Immediately after presentation, the participant has to recognize the target houses within a set comprising four stimuli. Then a set of three houses is presented for the same length of time and the participant must recognize them among a total of six houses, and so on. The level of complexity is defined as the number of houses to be recognized (from 2 to 6).

The Symbols Reproduction test (*Symbols*). The child is presented with stimuli composed of a series of simple symbols like lines and semicircles differently oriented inspired by Cornoldi and the Group (1992). Each stimulus is displayed for 3 seconds before being removed from view and replaced by a blank response sheet. The child has to reproduce the symbols in the exact order. The level of complexity is defined as the number of symbols to be reproduced (from 1 to 8).

The Dots Reproduction test (*Dots*). This task comprises a series of dots ordered in different locations on a blank sheet. The level of complexity is defined by the number of dots drawn on the sheet, and ranges from a minimum of one (in the first level) to a maximum of eight (in the last level). Each stimulus is displayed for 3 seconds before being removed from view and replaced by a blank response sheet. The child has to draw the dots in the exact location; if the dot is drawn with a distance of more than 5 cm from the target stimulus, the trial is considered incorrect.

Active visuospatial working memory tests

The Jigsaw Puzzle task (*Puzzle*) (adapted from Vecchi & Richardson, 2000). This consists of 27 drawings derived by Snodgrass and Vanderwart (1980). Each drawing is fragmented into between two and ten numbered pieces forming a puzzle. Drawings represent common inanimate objects with a high value of familiarity and image agreement. Each complete drawing is presented for 2 seconds together with its verbal label and is then removed. The material of each puzzle and the response sheet (a blank matrix with a number of cells corresponding to the number of pieces) are displayed in front of the participant with the pieces in a non-ordered way. Puzzles have to be resolved not by moving the pieces but by writing down or pointing to the corresponding number of each piece on a response sheet. The level of complexity is given by the number of pieces composing each puzzle (from 1 to 10). The task involves visuospatial working memory since the child must take advantage of not only the memory of the complete drawing presented but also spatial active working memory processes as one must actively reconstruct the original pattern and hold in memory the operations carried out, without the help of an actual placement of the pieces on the response sheet.

The Visual Pattern Test, Active Version (*VPTA*) (inspired by Della Sala *et al.*, 1997). The only, but crucial, difference between this test and the classic VPT is that participants are asked to reproduce the pattern on a completely blank matrix by filling the squares corresponding to the positions in a row below the row filled in the presentation matrix. For example, if in the presentation matrix the second square in the first row is filled, the participant's task is to fill the square in the second row (in the presentation matrices, the last row is always completely blank). The test was introduced to provide a visuospatial task with an active requirement: according to Cornoldi and Vecchi (2003), the required active manipulation changes the status of the task from passive into an active one.

The Pathway Span task (*Pathway*) (inspired by Cornoldi *et al.*, 1995). This task was introduced to have an active visuospatial task. Children are required to mentally visualize a pathway followed by a little man moving on a blank matrix. At the end of a series of statements regarding directions given by the experimenter (i.e. forward, backward, left, or right), participants have to indicate the man's final position in the same matrix. The complexity of the task may vary according to the size of the matrices (from 2×2 to 6×6) and the length of the pathway described (levels vary from 1 to 10).

Verbal working memory tests

The Digit Span Tests (*forward and backward versions*, *FDST and BDST*). The tests involve the presentation of spoken sequences of digits for immediate serial recall. The sequences vary from 3 to 9 digits in the forward version and from 2 to 8 in the backward version (see Wechsler's procedure, 1974). The experimenter orally presents a sequence of digits at the rate of one item per second; children have to repeat the digits in the forward and backward orders (according to the proposed version of the test). The forward version of this test is used to evaluate the passive processing of verbal working memory and the backward version evaluates the active one.

The Syllables Span Test (*Syllable*). In this test, three trials of nine sequences of syllables are orally presented to the child. The three trials of sequences vary in length: from 2 to 9 syllables. Each list of syllables is spoken aloud by the experimenter at the rate of one syllable per second. The children are instructed to listen and then to repeat the list of syllables following the presentation order. The syllables span test is considered a measure of passive verbal working memory.

Results

Descriptive statistics and correlational analyses

Descriptive statistics for each working memory test are shown in Table 1.

Internal reliability for the visuospatial tests was verified computing Cronbach's alpha coefficient. As shown in Table 1, scores of the visuospatial tests ranged from $\alpha = .68$ for the Dots reproduction test to $\alpha = .92$ for the pathway span task, reflecting a high degree of internal reliability within the tests of the battery.

Correlations between WM measures are reported in Table 2. As expected, the three verbal tests (forward and backward digit span and syllables span tests) correlate with each other. By contrast, the visuospatial tasks show a variable pattern of correlations.

Model estimation

To compare how the data would fit alternative models, structural equation models using the LISREL 8.7 statistical package (Jöreskog & Sörbom, 1996) were computed. For each

Table 1. Descriptive statistics of raw scores obtained by third and fourth graders in the visuospatial (VSWM) and verbal (VWM) working memory tests

	Reliability	Third graders					Fourth graders				
	(Cronbach's α)	*M*	*SD*	Range (min–max)	Skewness	Kurtosis	*M*	*SD*	Range (min–max)	Skewness	Kurtosis
Visuospatial tasks											
Houses	.72	7.19	2.37	2–13	.25	−.09	8.24	2.16	2–14	.53	.12
Symbols	.83	7.64	3.33	2–16	−.08	−.22	10.13	2.58	3–16	.15	.26
Puzzle	.84	15.85	5.44	6–29	.13	−.06	18.41	4.01	6–29	−.58	1.76
VPT	.84	15.22	3.53	7–31	1.1	4.7	18.62	3.35	13–28	.34	−.43
Static	.85	11.09	3.75	2–19	.23	−.78	14.26	3.05	7–22	.62	−.005
Dots	.68	3.15	1.45	1–8	.84	1.31	5.26	2.49	1–13	.56	.18
VPTA	.89	12.17	4.84	2–22	−.56	−.21	17.49	3.54	3–25	−.70	2.52
Dynamic	.83	13.75	4.03	7–23	.59	−.35	15.92	4.77	7–28	.21	−.71
Corsi	.79	11.89	3.23	4–19	−.008	−.44	13.32	2.47	8–19	.13	−.48
Pathway	.92	14.57	5.89	6–29	.81	.16	17.52	5.29	8–30	.39	−.33
Verbal tasks											
FDST	n.a.	13.08	2.65	6–22	.45	1.23	13.88	2.47	8–23	.57	1.36
BDST	n.a.	10.01	2.31	6–19	.76	1.87	10.72	1.93	7–20	1.45	5.09
Syllables	n.a.	13.63	2.20	10–19	.51	−.12	14.17	2.03	10–19	.36	−.32

n.a., not available.

Table 2. Correlation matrix for measures from the working memory tests in third and fourth graders

	1	2	3	4	5	6	7	8	9	10	11	12
1. Houses	1											
2. Symbols	.26*	1										
3. Puzzle	.24*	.38*	1									
4. VPT	.29*	.42*	.47*	1								
5. Static	.24*	.21*	.22*	.42*	1							
6. Dots	.19**	.27*	.28*	.39*	.33*	1						
7. VPTA	.24*	.39*	.51*	.56*	.39*	.42*	1					
8. Dynamic	.22*	.22*	.09	.16**	.26*	.07	.16**	1				
9. Corsi	.19**	.47*	.16**	.33*	.10	.18*	.26*	.29*	1			
10. Pathway	.29*	.17**	.29*	.45*	.28*	.25*	.47*	.14	.15	1		
11. FDST	.22*	.24*	.13	.31*	.10	.06	.24*	.16**	.22*	.30*	1	
12. BDST	.15	.31*	.25*	.38*	.12	.19**	.36*	.14	.24*	.26*	.41*	1
13. Syllables	.12	.06	.14	.19**	.02	.13	.23*	.09	−.001	.24*	.45*	.27*

Note. ($N = 158$).
*$p < .01$; **$p < .05$.

model, we considered the chi-squared test of significance, the root mean square error of approximation (RMSEA) as a descriptive measure of the overall model fit; the Bentler's comparative fit index (CFI), the goodness-of-fit index (GFI), and the adjusted goodness-of-fit index (AGFI) as goodness-of-fit indices based on model comparisons and finally, the parsimony goodness-of-fit index (PGFI) as a descriptive measure of model parsimony. It should be noticed that the models were not nested[2] and for this reason we did not employ the chi-squared difference to compare their fit but we used the Akaike information criterion (AIC) (Widaman & Thompson, 2003; Schermelleh-Engel, Moosbrugger, & Müller; 2003).

According to Baddeley (1986) and other researchers (Alloway *et al.*, 2006), a tripartite WM model involves complex span measures and two separate domain-specific resources for verbal and visuospatial information. The first model tested, therefore, represents Baddeley's original WM model (tripartite model, Figure 2). Furthermore, a second tested model was based only on the distinction between verbal, visual, and spatial constructs, without involving the distinction between complex versus simple span measures (Three Slaves Systems model, Figure 3). Moreover, since the original tripartite WM model (1986) has been expanded with a further distinction between the two visuospatial components, that is, visual versus spatial (Logie, 1995) or static versus dynamic (Pickering *et al.*, 2001), but also includes the central executive component associated with attentional processing of information, we tested a third model (three slaves plus processing model, Figure 4). Finally, we considered Cornoldi and Vecchi's model (2003) that proposes the differentiation between verbal, visual, simultaneous-spatial, and sequential-spatial passive measures, and a measure of active VSWM, on the basis of the assumption that passive tasks can be better divided on the basis of their content and presentation format than active tasks, and at least three different

[2] *A specific model (Model A) is said to be nested within a less restricted model (Model B) with more parameters and less degrees of freedom than Model A, if Model A can be derived from Model B by fixing at least one free parameter in Model B or by introducing other restrictions, for example, by constraining a free parameter to equal one or more other parameters.*

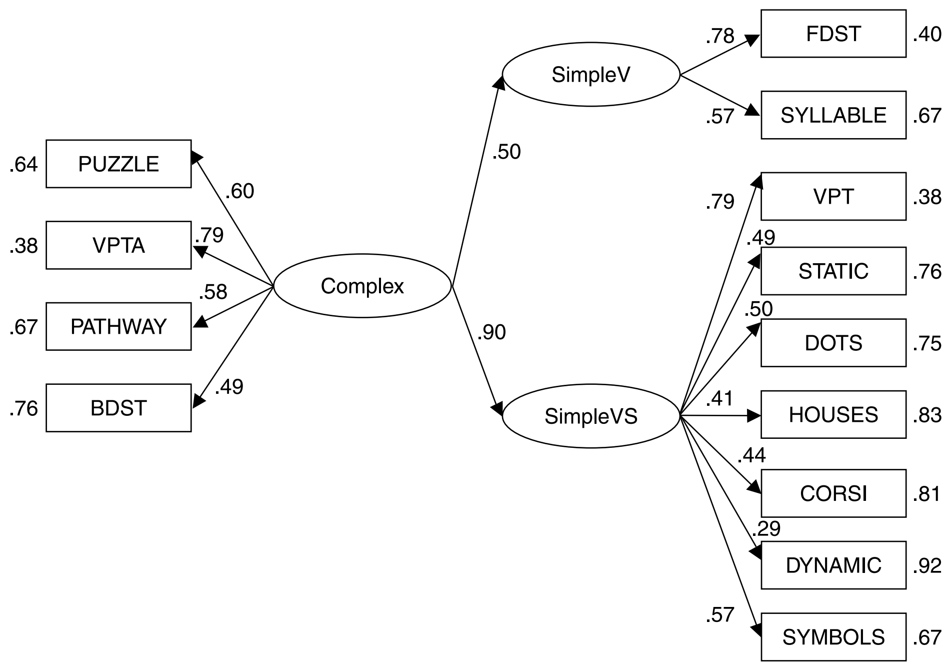

Figure 2. The tripartite model distinguishing among complex span measures (complex), simple verbal (simpleV) and visuospatial (simpleVS) measures. Single-headed arrows represent standardized factor loadings. The numbers at the end of the observed variables are error terms.

components can be individuated within the visuospatial domain. Therefore, in the fourth model tested, we considered four passive components (the three visuospatial and the verbal ones) and in the active constructs we included only active VSWM tasks (Continuity Model, Figure 5).

The tripartite model involves three latent variables that distinguish among complex span measures (backward digit span test, pathway span task, VPTA and jigsaw puzzle task) and simple verbal (syllables span test and forward digit span test) and visuospatial span tasks (dots reproduction test, symbols reproduction test, houses recognition test, Corsi blocks test, static and dynamic mazes and VPT). The model is summarized in Figure 2 and fit statistics are shown in Table 3.

The tripartite WM model does not provide a good fit for the data; the chi-squared value is highly significant ($p = .0003$) suggesting a discrepancy between model and data; although fit indices (CFI, GFI, AGFI) are satisfactory, the RMSEA is medium (.068) indicating a good fit, and the parsimony (PGFI $= .63$) is good.

The three slaves systems model distinguishes among verbal, visual, and spatial constructs, but there is no mention of complex versus simple span tasks. Specifically, the verbal latent variable involves the syllables span test and both forward and backward digit span tests; the visual latent variable includes the dots reproduction test, the static mazes, the houses recognition test, the jigsaw puzzle task and both VPT and VPTA; finally, the spatial latent variable involves the symbols reproduction test, the pathway span task, the Corsi blocks test, and the dynamic mazes. The model is shown in Figure 3 and the results reveal that it does not provide a satisfactory fit of the data; the chi-squared value is highly significant ($p = .001$), although the fit indices

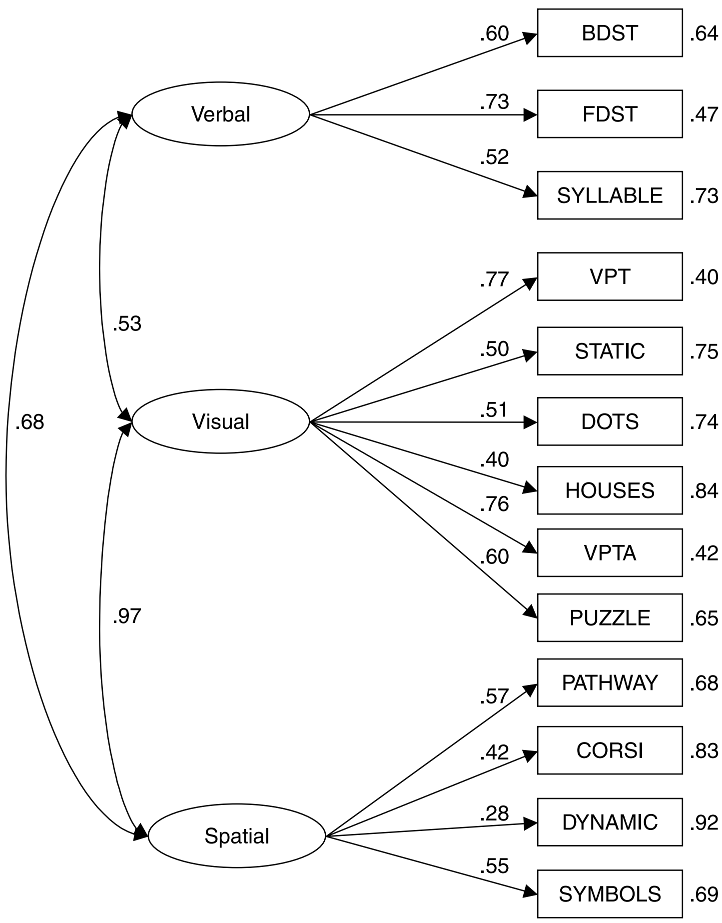

Figure 3. The three slaves systems model (visual, spatial, verbal).

(CFI, GFI, AGFI) are acceptable, the RMSEA is medium (.063), and the parsimony (PGFI = .62) is good.

The three slaves plus processing model is based on the distinction of two VSWM components and is shown in Figure 4. In particular, the four latent variables represent complex span measures (backward digit span test, pathway span task, VPTA, and jigsaw puzzle task) and visual (VPT, static mazes, dots reproduction test, houses recognition test), spatial (Corsi blocks test, dynamic mazes and symbols reproduction test), and verbal (syllables span test and forward digit span test) modality-specific factors. The fit indices (CFI, GFI, AGFI) are acceptable, the RMSEA is low (.05) and the parsimony (PGFI = .63) is good; however, the chi-squared value is significant ($p = .02$).

Finally, the continuity model (represented in Figure 5) is based on the model (Cornoldi & Vecchi, 2003) distinguishing among an active visuospatial construct (pathway Span task, VPTA, and jigsaw puzzle task) and four passive latent variables: verbal (forward and backward digit span test and syllables span test), versus visual (houses recognition test and symbols reproduction test) versus simultaneous-spatial (VPT, static mazes, dots reproduction test) versus sequential-spatial (Corsi blocks test and dynamic mazes). As is reported in Table 3, the indices are better than those for the preceding models. In particular, the chi-squared value of this model is not significant

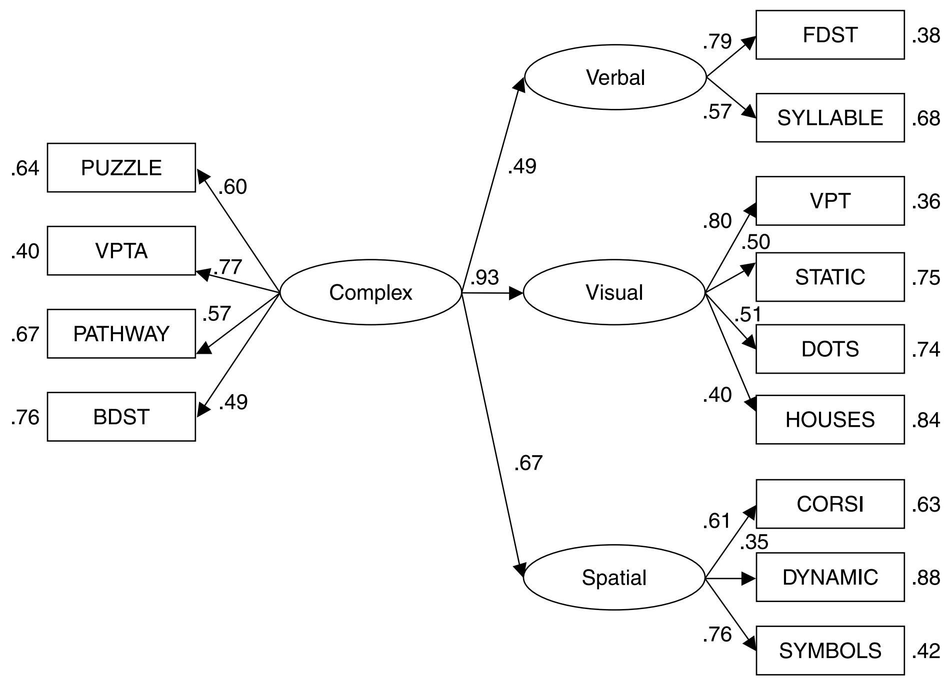

Figure 4. The three slaves plus processing model (complex span measures = complex, verbal, visual, spatial).

($p = .069$), the fit indices (CFI, GFI, AGFI) are good, the RMSEA is low (.042), and the parsimony (PGFI = .62) is also good.

In order to compare competing models, we looked at the AIC that is suitable for models that are not nested (Schermelleh-Engel, Moosbrugger, & Müller, 2003). Thus, within a set of models for the same data, the model with the minimum AIC value is regarded as the best fitting model. As is reported in Table 3, the continuity model showed the lower AIC value, confirming the fit indices and the chi-squared results.

Discussion

Until now, there has been no report of clear and unquestioned taxonomies of the different VSWM components in children and adults. Although some studies have proposed different classifications of WM (Gathercole, Pickering, Ambridge, & Wearing, 2004; Alloway *et al.*, 2006), for the VSWM tasks (Pickering *et al.*, 2001; Miyake *et al.*, 2001), there is no agreement on the processes involved. Recent studies also demonstrated that the architecture of the WM system appears more complex than initially suggested and that the complexity of the system is not only a matter of the number of distinct boxes, or relatively independent components. Specifically, concerning VSWM, there is now considerable data showing that a greater differentiation of the involved processes is necessary.

The main goal of the present research was to compare different distinctions of WM with particular attention to the VSWM, and to study the implications of a test battery for the organization of WM in children attending primary school, using a great number of tasks administered in previous studies. In our view, one of the reasons for the

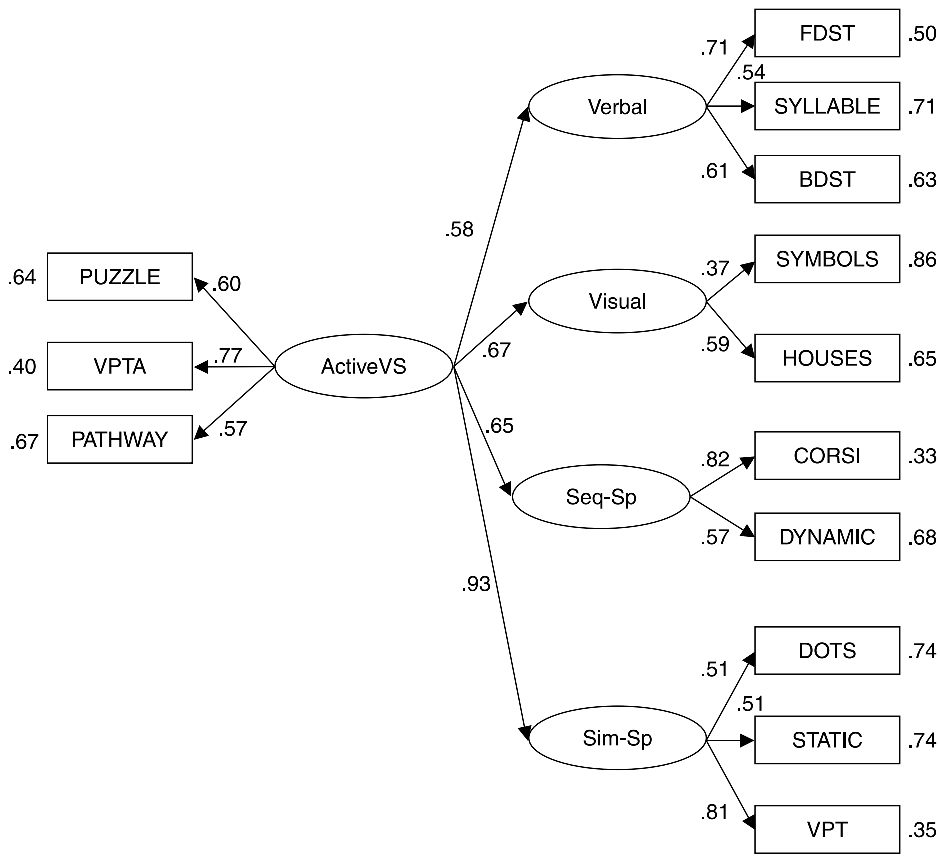

Figure 5. The continuity model (active visuospatial = activeVS, verbal, visual, sequential-spatial = seq-sp., simultaneous-spatial = sim-sp.,).

disagreement in classifying VSWM tasks could be due to the fact that in preceding studies limited pools of tasks were employed and, frequently, these tasks were not the same in different studies. For this reason, in the present study, we tried to include all the main tasks already administered in developmental studies on VSWM. The main result of the present study is that the distinction between three visuospatial components suggested by Cornoldi and Vecchi (2003) provides the best fit of our data. This model fitted the data better than the classical tripartite WM model (Baddeley, 1986), a model distinguishing between the verbal, visual, and spatial dimensions and a modified working memory model, involving three slave systems, instead of two, that is, verbal, visual, and spatial (Logie, 1995; Gathercole & Pickering, 2000). Obviously, we limited our consideration to a limited number of models, based on the fact that they had already been applied in developmental studies on VSWM and could be easily operationalized with reference to the available tests. However, we cannot exclude that furthermore recent distinctions of WM could lead to different results. Specifically, this consideration could apply to the revised Baddeley's model (2000) which includes a new component, that is, the episodic buffer. This is assumed to be a limited capacity store that binds together information to form integrated episodes. It is also assumed to be a multidimensional store that allows different systems to be integrated. The episodic

Table 3. Goodness-of-fit statistics for the different measurement models ($N = 162$)

Model	χ^2	*df*	χ^2/df	*p*	CFI	GFI	AGFI	RMSEA	AIC	PGFI
Tripartite model (Figure 2)	109.39	63	1.74	.0003	.95	.91	.86	.068	165.39	.63
Three slaves systems (Figure 3)	101.38	62	1.64	.001	.96	.91	.87	.063	159.38	.62
Three slaves + processing (Figure 4)	86.13	62	1.39	.02	.97	.92	.89	.05	144.13	.63
Continuity model (Figure 5)	78.05	61	1.28	.07	.98	.93	.90	.042	138.05	.62

Note. CFI, Bentler's comparative fit index; GFI, goodness-of-fit index; AGFI, adjusted goodness-of-fit index; RMSEA, root mean square error of approximation; model AIC, Akaike information criterion; and PGFI, parsimony goodness-of-fit index. Chi-square not being significant at the .05 level indicates that the models provided reasonable fits. Values above .95 for CFI and GFI indicate good fit. $\chi^2/df < 2$ indicates a good fit.

buffer was not taken into account in the present study because the battery did not include visuospatial tasks directly associated with the buffer functions. With reference to verbal material, one would expect that sentence repetition ability (postulated as a measure of the Episodic Buffer) will be associated not only with a specific component but also with both the phonological loop (see Willis & Gathercole, 2000) and the central executive latent factor (Alloway, Gathercole, Willis, & Adams, 2004). It remains for future research to incorporate appropriate measures for testing the episodic buffer.

In this study, the comparison between structural equation models suggests that the distinction of more than two VSWM components could describe children's abilities better, extending the distinctions proposed in preceding results, in which researchers differentiated either between visual and spatial (Logie & Pearson, 1997; Hamilton *et al.*, 2003) or between static and dynamic (Gathercole & Pickering, 2000) components. Specifically, the results of the present study are in favour of a distinction in VSWM between: *a*) a visual factor, including tests able to assess the ability to recall visual appearances; *b*) a simultaneous-spatial factor, containing tasks that require recall of locations presented simultaneously; and *c*) a sequential-spatial factor consisting of tests in which participants are required to recall the order in which a series of locations are presented. Neuropsychological studies also support the differentiations proposed here. In fact, Postle, Berger, Taich, and D'Esposito (2000) showed that the ventrolateral and dorsolateral areas of the prefrontal cortex are involved, respectively, in the maintenance and manipulation of spatial information. Furthermore, Zarahn, Anguirre, and D'Esposito (2000) found that the dorsolateral areas of the prefrontal cortex were also involved in the maintenance of information concerning the relative location of sequentially presented stimuli. Also, data regarding non-verbal (visuospatial) learning disabled children documented a double dissociation between sequential-spatial and simultaneous-spatial working memory tasks (Mammarella, Cornoldi, *et al.*, 2006).

Only further studies will be able to better clarify the characteristics of the VSWM components, although our results seem to agree with a distinction, based on the type of content to be processed and the consequent cognitive processes involved, between the visual, simultaneous-spatial, and sequential-spatial components in VSWM. Actually, structural equation modelling showed that VSWM tasks can be distinguished not only on the basis of their content and presentation format but also on the basis of the degree of active control. In fact, in the continuity model (Cornoldi & Vecchi, 2003), active measures partially maintain a distinction based on domain-specific aspects, contrary to Baddeley's original model (1986) in which executive processes are completely independent of the presentation format. In the continuity model, as every task can occupy a specific portion of both vertical and horizontal dimensions, it is clear that the backward digit span is more active than the forward one, but in the latent factors model it is closer to the latter than to the active version of the VPT, for example. In other words, in the specific model tested in the present study (in which only three verbal tasks were included), the backward digit span was closely linked to the other passive verbal tasks, because, as demonstrated by Lanfranchi *et al.* (2004), that task is only moderately active and its verbal features are more relevant. We cannot exclude that, using a similar number of verbal and visuospatial tasks, a clearer or partially different pattern of results might emerge. It must be noticed that, although the chi-square for the alternative models tested in the present research were significant, the goodness-of-fit indices were acceptable also for such models.

Our study also confirmed results obtained in previous studies (Miyake *et al.*, 2001; Gathercole *et al.*, 2004; Alloway *et al.*, 2006), demonstrating that visuospatial working memory is related to the complex span measures (see also the tripartite model, Figure 2). Moreover, the present study supports the notion of visuospatial constructs not all being similarly linked to the active visuospatial component. In fact, if we look at the final model, it emerges that the simultaneous-spatial latent construct shows the highest correlation with the active visuospatial one, whereas the sequential-spatial and the visual constructs reveal correlations similar to the verbal component with the active visuospatial measures. Thus, the present paper also suggests that not all our visuospatial tasks are equally related to the active visuospatial dimension. The simultaneous-spatial tasks used in this study could be closer to the active visuospatial working memory tasks because they may be prime strategic controlled processes, like, for example, creating a global shape of the given information, which needs to be integrated in a unique pattern.

In conclusion, WM tasks employed in this study represent useful tools to analyse children's WM and to guide the investigation of subcomponents of VSWM. Furthermore, the present research identified a structural organization of WM which distinguishes active and passive tasks and also differentiates verbal passive tasks from three main visuospatial passive measures. However, we must remember that the models tested in the present research were based on data collected in primary schools. In this respect, Alloway *et al.* (2006) found that in children aged between 4 and 6 years, the link between the domain-specific visuospatial construct and the domain general processing construct was higher when compared with older children, but that the structural organization of WM only had minor changes in children between the ages 4 and 11 years. Previous studies (Gathercole, 1998; Gathercole *et al.*, 2004) also demonstrated that VSWM measures reach an asymptote at about 11 years and they do not develop much further in adults. For this reason, we expect only slight changes in similar models tested in adults. Thus, in our view, the present results could be generalized to older age samples. However, only further research can support this hypothesis.

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