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The structure of visuospatial memory in adulthood

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ABSTRACT

The present study aimed to investigate the structure of visuospatial memory in adulthood. Adults 40–89 years of age (n = 160) performed simple storage and complex visuospatial span tasks. Simple storage tasks were distinguished into three presentation formats: (i) visual, which involved maintaining shapes and textures; (ii) spatial-sequential, which involved maintaining sequentially-presented locations; and (iii) spatial-simultaneous, which involved maintaining patterns of locations. Confirmatory factor analyses showed that, among the domain-differentiated models, the one considering visuospatial memory in its simple visual, spatial-sequential and spatial-simultaneous components and complex visuospatial memory yielded a good fit to our data. Structural equation modeling also showed that age had a direct effect on visual, spatial-sequential and spatial-simultaneous memory, and on complex visuospatial memory. Altogether these results suggest the importance of considering both the type of processing involved (in simple storage vs. complex visuospatial tasks) and the presentation format of the stimuli in the visuospatial domain.

1. Introduction

According to Baddeley (1986, 2000), working memory – WM – consists of four different components: (*i*) the central executive (Miyake & Friedman, 2012; Miyake et al., 2000), which coordinates two slave systems, i.e. (*ii*) the phonological loop, where verbal material is maintained, and (*iii*) the visuospatial sketchpad (also called visuospatial working memory — VSWM), where spatial and object memories are maintained; and (*iv*) the episodic buffer, a multi-dimensional store dedicated to binding information to form integrated episodes (Allen, Hitch, Mate & Baddeley, 2012; Baddeley, Allen, & Hitch, 2011). In the first version of their model, VSWM tended to be seen as a unitary system.

Further studies have analyzed the structure of VSWM in more depth. Specifically, Logie distinguished between a visual store (*visual cache*) that provides a temporary store for visual information (e.g. colors, shapes and textures) and a rehearsal mechanism (*inner scribe*) that retains information about movement sequences and provides a mechanism for rehearsing visual information in WM. A large body of evidence has shown a dissociation between visual and spatial memory based on the selective interference paradigm (e.g. Logie & Marchetti, 1991; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999), on neuropsychological evidence (Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001), and on developmental data (e.g. Hamilton, Coates, & Heffernan, 2003; Pickering, Gathercole, & Peaker, 1998; Gathercole & Pickering, 2000). Lecerf and de Ribaupierre (2005), on the other hand, considered three types of encoding instead of two, comprising an extra-figural encoding responsible for anchoring objects in relation to an external reference frame and an intra-figural encoding based on the relationships between different items in a pattern, the latter being further divided into a pattern encoding (leading to a global visual image) and a path encoding (leading to spatial-sequential positions). Cornoldi and Vecchi (2003) and Mammarella, Pazzaglia, and Cornoldi (2008) likewise distinguished between visual WM tasks requiring the memorization of shapes, symbols, textures and colors, and two kinds of spatial task, both requiring the recall of patterns of spatial locations, but differing in their presentation format and the type of spatial processes involved, being simultaneous in one case and sequential in the other. Evidence collected in various groups of children supports a separation between visual and spatial-simultaneous processes (Mammarella, Cornoldi, & Donadello, 2003), and between spatial-simultaneous and spatial-sequential processes (Mammarella et al., 2006).

It has also been suggested that a distinction between many different types of WM processes should be drawn as regards not only the format/content of the information, but also the degree of attentional control required by the task. This latter distinction has been described in many ways, differentiating for instance between simple storage and complex span tasks (e.g. Unsworth & Engle, 2005), or between passive and active processes (involving simple storage and complex span tasks, respectively) (Cornoldi & Vecchi, 2003). The relationship between simple storage and complex span tasks, in terms of visuospatial format and executive functions, has shown that visuospatial tasks

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correlate strongly with executive functions, unlike verbal tasks (adults: Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; children: Alloway, Gathercole, & Pickering, 2006).

All these studies only focused on storage vs. processing tasks, however. According to the continuity model proposed by Cornoldi and Vecchi (2003), tasks can be distinguished according to two dimensions: a vertical and a horizontal continuum. In the vertical continuum, tasks can be divided into passive memory tasks, or *simple storage tasks* (based on the rote rehearsal of items strictly related to the nature of the stimuli to retain), and active memory tasks, or *complex span tasks* (requiring both the retention and a concurrent processing of information). The horizontal continuum distinguishes tasks between different presentation formats (i.e. verbal vs. visuospatial; visual vs. spatial-sequential vs. spatial-simultaneous). Based on this assumption, Mammarella, Pazzaglia, and Cornoldi (2008) tested a group of 162 third- and fourth-grade children, comparing different theoretical models of WM, also distinguishing between the degree of controlled activity and the presentation format. Structural equation modeling was used to test different WM models. The authors found that the model distinguishing between a verbal and three visuospatial simple storage components, plus a visuospatial complex span component (as suggested by Cornoldi & Vecchi, 2003) provided the best fit for the data. They concluded that WM tasks, and visuospatial WM tasks in particular, can be distinguished not only in terms of content and presentation format, but also according to the degree of attentional control required.

Based on the above, the aim of the present study was to analyze the structure of visuospatial memory across the adult lifespan, from 40 to 80 years of age. No studies to date have examined the structure of visuospatial memory throughout adulthood, considering both the task presentation format and the degree of attentional control demanded by visuospatial tasks. Most studies on aging have analyzed either age-related differences between younger and older adults in the verbal and visuospatial domain, or the structure of WM. Studies on age-related differences in visuospatial task are somewhat confusing: some have revealed a more severe age-related memory decline for simple storage visuospatial tasks (Bopp & Verhaeghen, 2007; Myerson, Emery, White, & Hale, 2003; Verhaeghen et al., 2002) and complex visuospatial tasks (Hale et al., 2011) than for verbal tasks; while others have reported a similar decline, irrespective of the domain, for simple storage tasks (Hale et al., 2011) and complex span tasks (e.g. Borella, Carretti, & De Beni, 2008; Borella, Ghisletta, & de Ribaupierre, 2011; Park et al., 2002; for a discussion see Fiore, Borella, Mammarella, & De Beni, 2012). Only two studies (Hale et al., 2011; Park et al., 2002) examined the general structure of WM across the adult lifespan, the outcome of which indicates that WM can be separated into visuospatial and verbal stores, and that verbal and visuospatial WM is associated with domain-specific, short-term stores.

The present study focused on the architecture of VSWM. In particular, unlike previous research (see Hale et al., 2011), we concentrated on visuospatial tasks alone, considering both simple storage tasks involving various presentation formats, and complex visuospatial span tasks. The simple storage tasks were chosen on the basis of Cornoldi and Vecchi (2003), and distinguished between visual tasks (involving the retention of meaningless shapes and textures), spatial-sequential tasks (requiring the recall of the presentation order of spatial locations) and spatial-simultaneous tasks (involving the memorization of a pattern of spatial locations presented at the same time) (i.e. Mammarella, Pazzaglia, & Cornoldi, 2008). The complex span tasks were chosen from the literature to ensure a variety of task types and they all involved recalling and simultaneously processing visuospatial information.

The primary goal of the present study was to elucidate the structure of visuospatial memory across an adult's lifespan, using confirmatory factor analyses. Various VSWM models were tested, with some difficulty in referring to previous WM models because they usually involved both verbal and visuospatial components (whereas the former were not considered here). Thus, the following models were compared: (1) a one-factor model that predicts visuospatial memory as a single construct; (2a) a model distinguishing between a visual and a spatial component; judging from the literature (Logie, 1995; Logie & Pearson, 1997), the visual memory component is involved in tasks in which shapes, textures and patterns of locations are presented, while the spatial component is tested in tasks in which spatial locations are presented sequentially; (2b) a two-factor model distinguishing between visuospatial complex span and visuospatial simple storage components, as proposed by Baddeley & Hitch, 1974; Baddeley, 1986; (3a) a three-factor model, representing Logie's (1995) model (see also Baddeley & Logie, 1999) expanded to include a distinction between the two visuospatial components (see Model 2a), i.e. visual vs. spatial (Logie, 1995), and involving the previously-mentioned tasks, but including visuospatial complex span components too; (3b) a three-factor model coming close to the distinction drawn by Mammarella, Pazzaglia, and Cornoldi (2008) (see also Pazzaglia & Cornoldi, 1999; Lecerf & de Ribaupierre, 2005) between visual and spatial components of VSWM, in which the two simple storage components involved tasks requiring the recall of spatial locations presented both simultaneously and sequentially, while the visual tasks involved recalling shapes and textures, but also contained a complex visuospatial component; (4) a four-factor model, distinguishing between complex and simple storage components, as in Models 3a and 3b, except that the simple storage components in this case were divided into three presentation formats: visual, spatial-sequential and spatial-simultaneous.

In line with the continuity model (Mammarella, Pazzaglia, & Cornoldi, 2008; Cornoldi & Vecchi, 2003), we would expect to be able to represent the visuospatial tasks along a vertical continuum on the one hand, that distinguishes between simple storage and complex span tasks, and along a horizontal continuum on the other, considering the tasks' presentation format.

Another goal of our study was to test the relationship between age and visuospatial memory using a structural equation modeling (SEM) approach. Specifically, we examined whether age-related differences carry a similar weight irrespective of the demands of the memory tasks administered, in terms of the processes and presentation format involved. Judging from previous findings, we would expect to see either that age is linked directly to VSWM performance (Hale et al., 2011), with age exerting a different influence depending on the attentional control demanded by the tasks (e.g. Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009), or that age-related differences in simple storage tasks mediate the influence of age on visuospatial complex span factors (e.g. Park et al., 2002).

2. Method

2.1. Participants

The study involved 160 people aged in the range of 40 to 83 years, with 35 to 52 participants in each age decade from the 40s to the 70s (see Table 1); participants aged 80 or more were pooled with those in their 70s to obtain groups of similar size.

Participants were all native Italian speakers and volunteered for the study. They were community dwellers and recruited by word of mouth. The older adults were selected on the basis of a physical and mental health questionnaire and none of them met the exclusion criteria suggested by Crook et al. (1986). All participants had normal or corrected-to-normal vision. Their visual acuity was also screened by asking participants to read words in various font sizes aloud, and to name colored patches on a screen.

Table 1
Demographic characteristics of participants in the four age groups.

Age	40–49		50–59		60–69		>70	
Gender	18 F		24 F		19 F		27 F	
N	35		35		38		70	
	M	SD	M	SD	M	SD	M	SD
Background								
Age	44.11	2.85	54.11	2.84	64.82	2.71	77.42	4.04
Vocabulary	52.17	7.75	53.09	7.46	51.79	7.70	46.60	5.44

The characteristics of the samples in the four age groups are summarized in Table 1.

The numbers of females and males did not differ significantly across the four decades. All participants had a level of formal education corresponding to at least the full cycle of compulsory education in Italy (i.e. at least 8 years of schooling), and all except the oldest participants had attended secondary or high schools. The participants' vocabulary scores (Wechsler, 1981) did not differ across the decades considered.

2.2. VSWM measures

Participants were presented with 12 tests, 11 of them part of a standardized Italian VSWM test battery (Mammarella, Lucangeli, & Cornoldi, 2010; Mammarella, Toso, Pazzaglia, & Cornoldi, 2008), and the last was the dot matrix test derived from Miyake et al. (2001). Nine tests were simple (passive) storage tasks, while three were complex (active). The simple storage tasks were divided into visual, spatial-sequential and spatial-simultaneous (Mammarella, Pazzaglia, & Cornoldi, 2008; and Pazzaglia & Cornoldi, 1999) formats. The spatial-sequential and spatial simultaneous tasks involved the same stimuli, and only the presentation format (sequential vs. simultaneous) changed. Examples of the tasks used are presented in Fig. 1.

2.3. Simple storage tasks

A change detection recognition paradigm was used for the simple storage tasks. Participants had to decide whether a series of figures/locations was the same as or differed from the one previously presented: after a first stimulus had been presented, either the same stimulus was presented or one with just one element having changed, followed by a response screen containing two letters: U (*uguale* = the same) and D (*diverso* = different). Participants had to respond by pressing one of two keys on the keyboard. For each test, the correct answer for half the items was “the same”, while for the other half it was “different”.

The tests progressed from the second level (involving two stimuli) to the eighth (containing eight stimuli), and included three items at each level. Before administering each task, participants were given two practice trials with feedback.

2.3.1. Visual tasks

2.3.1.1. The meaningless shapes task. Participants were presented with a series of meaningless figures and asked to decide whether or not they were identical to previously-seen figures. Two figures were presented at the second level, three at the third, and so on. At the beginning of the procedure a blank screen appeared for 1500 ms, then the meaningless figures (for 3000 ms) followed by another blank screen for 500 ms. After presenting a fixation point for 1500 ms, either the same series of figures was presented, maintaining the same spatial arrangement, or a series with one different figure was presented for the recognition task, followed by a response screen where participants were asked to respond by pressing one of two keys on the keyboard.

2.3.1.2. Water animal recognition task. Participants were presented with series of 2–8 fish, in which both the shapes and the spatial arrangement of the fish remained the same but the texture of one fish changed. Presentation times and other procedural aspects were the same as for the meaningless shapes task.

2.3.1.3. The balloons recognition task. Participants had to recognize whether textures inside balloons were the same or different. Both the shapes and the spatial arrangement of the balloons remained the same, but the texture of one of the balloons changed. The timing of the balloons' presentation and other procedural aspects were the same as in the previous visual tasks.

2.3.2. Spatial-sequential tests

2.3.2.1. The sequential light bulbs recognition task. In this task, a gray screen was presented for 1000 ms then a large ring consisting of 12 small blank circles was shown for 250 ms. Immediately afterwards, one of the small circles was lit up (became yellow) for 1000 s, followed by a 250 ms interval (when none of the circles were alight), then one or more different circles were lit up sequentially. Two circles were lit one after the other at the second level, three at the third, and so on. A delay of 500 ms was allowed after the last circle had been lit up, followed by a fixation point for 1000 ms and another delay of 500 ms, then either the same sequence or one in which two circles were lit in reverse order was presented at the same rate; the locations of the circles did not vary.

2.3.2.2. The sequential lines task. (Derived from Miyake et al., 2001). Participants were presented with 5 × 5 matrices composed of 25 small black dots. The presentation times were the same as in the previous task. The sequentially-presented stimuli were black lines joining up the dots, which appeared one at a time. Participants had to decide whether or not the sequence of lines presented was in the same order as in the previous series.

2.3.2.3. The sequential dots task. The task involved 5 × 5 matrices in which red dots appeared one at a time, with the same timing as in the previous tasks. Participants had to decide whether or not the order in which the red dots were presented remained the same or differed. The locations of the red dots did not vary, while the sequential order in which two red dots appeared was inverted.

2.3.3. Spatial-simultaneous tests

2.3.3.1. The simultaneous light bulbs recognition task. The same display was used as in the above-described sequential light bulbs recognition task, except that this time the small circles were initially all lit up (turned yellow) together. After a gray screen had been shown for 1000 ms, a display of 12 small circles appeared for 500 ms on the screen, then a variable number of small circles were lit up for 2500 ms, followed by another delay of 500 ms. After a fixation point had been shown for 1000 ms, the presentation was repeated but the circles that were alight might be in a different location. During the test, participants had to decide whether the new pattern of yellow circles was the same as the one presented just before, or whether one yellow circle appeared in a different location.

2.3.3.2. The simultaneous lines task. The same 5 × 5 matrices were used as in the above-described sequential lines test, the only difference being that the lines joining the dots appeared simultaneously in this case and participants had to decide whether or not one of the lines appeared at a different location. The timing of presentation and other procedural aspects were the same as for the simultaneous light bulbs recognition task.

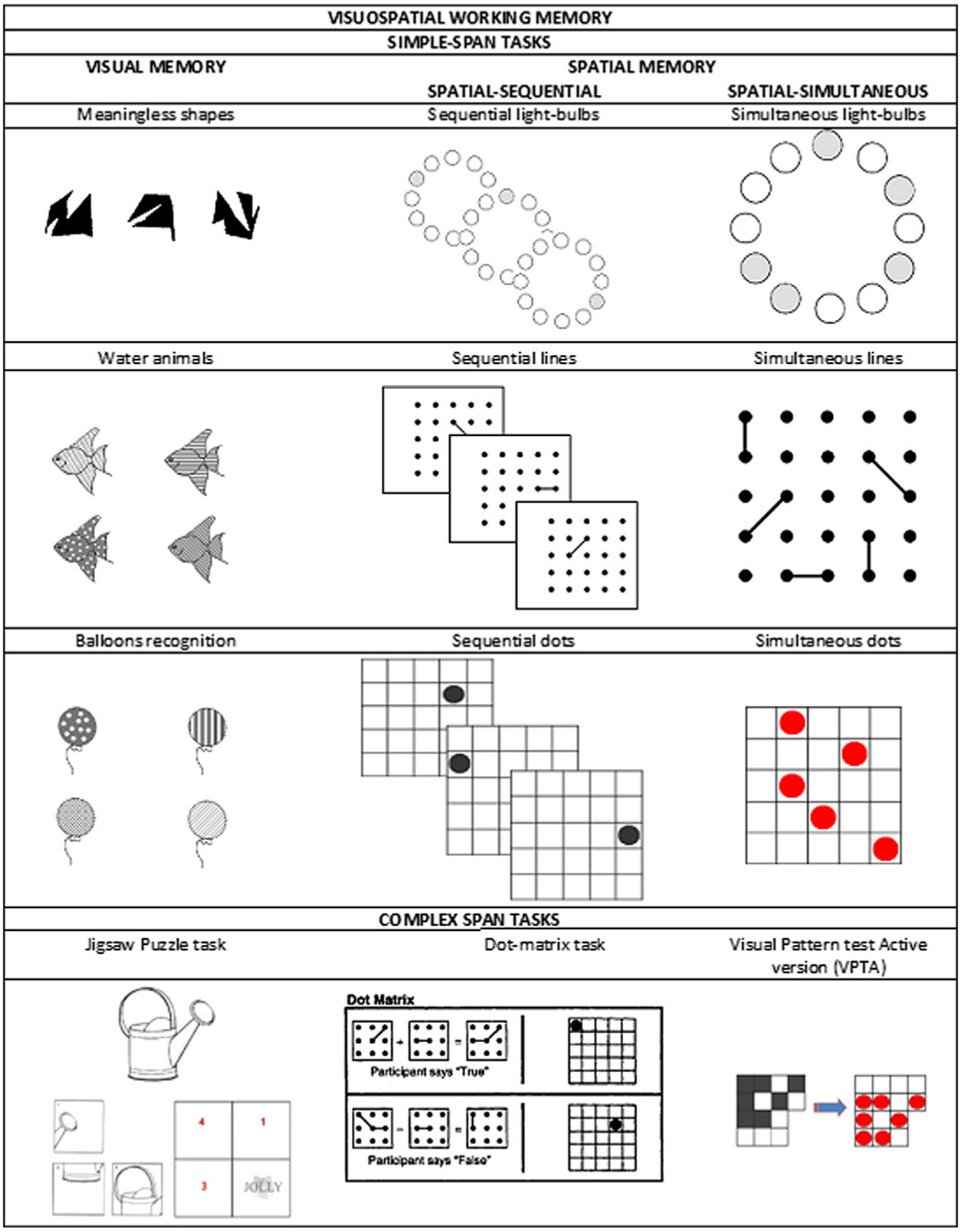

Fig. 1. VSWM measures distinguished as simple- and complex-span tasks and by presentation format (visual, spatial-sequential and spatial-simultaneous).

2.3.3.3. The simultaneous dots task. The same stimuli were used as in the sequential dot matrix test, but the red dots appeared simultaneously. The presentation times were the same as in the previous simultaneous tests, and participants had to decide whether one of the dots changed location.

2.4. Complex span tasks

In the complex span tasks participants had to simultaneously process and retain: (i) visual objects (i.e. jigsaw puzzle task); (ii) spatial-sequential information (i.e. dot matrix task); and (iii) spatial-simultaneous information (i.e. visual pattern test, active version).

The tests progressed from a second level (with 2 stimuli) to a tenth (with 10 stimuli), with three items for each level (except for the dot matrix task, which went from a second level to a fifth). Before administering each task, participants were given two practice trials with feedback.

The *jigsaw puzzle task* (adapted from Vecchi & Richardson, 2000) consists of 27 drawings developed by Snodgrass and Vanderwart (1980), each of which is broken down into 2–10 numbered pieces, forming a puzzle. Each whole drawing is presented for 2000 ms, together with its verbal label, and then removed. The puzzles have to be solved not by moving the pieces but by writing down the number corresponding to each piece on a response sheet.

The *dot matrix task* (derived from Miyake et al., 2001) involves participants checking a matrix equation while simultaneously remembering a dot's location in a 5×5 matrix. A trial involves a set of matrix equations to check, each followed by a 5×5 matrix containing one dot. The matrix equation display shows a simple addition or subtraction equation. Participants were given 4500 ms to check whether the result of adding (or subtracting) two segments presented in succession corresponded to a third pattern presented after the previous two. Immediately afterwards, a 5×5 matrix containing a dot in one cell was displayed on the screen for 1500 ms. After a series of 2–5 equations and matrices had been presented, participants had to recall (in any order) which cells in the 5×5 matrix had contained dots (by clicking in the empty cells with the mouse).

In the visual pattern test, active version (VPTA; derived from Della Sala, Gray, Baddeley, & Wilson, 1997) participants were presented for 3000 ms with random numbers of filled cells in a matrix created by filling in half the cells in the matrix. The matrices increased in size from the smallest (4 squares with 2 cells filled) to the largest (20 squares with 10 cells filled). After the presentation phase, participants were presented with a blank test matrix on which they had to reproduce the same pattern by filling in the cells but one row *lower down* with respect to the pattern seen in the presentation matrix. For example, if the second cell in the first row of the presentation matrix had been filled, participants had to fill in the second cell in the second row in the recall test.

For scoring purposes in all the tasks, each item was attributed a value equating to the level of the task's complexity at the point where it was included, i.e. items on the second level scored 2, those on the third scored 3, and so on.

The final scores were obtained from the sum of the three items identified correctly on the most complex levels reached; for instance, if the last three correctly identified items were the first two on the third level and one on the fourth, then the participant's score was 3+3+4=10.

2.5. General procedure

The tests were presented on a laptop computer with a 15-inch screen (screen resolution: 1024×768 pixels), in a quiet room at two individual sessions, and they were arranged in a preset sequence during the two sessions. Participants were seated about 60 cm away from the front of the screen. The order of presentation was as follows, session 1: vocabulary test, meaningless shapes task, sequential light bulbs recognition task, jigsaw puzzle task, simultaneous light bulbs recognition task, balloons recognition task; session 2: the sequential lines task, dot matrix task, simultaneous lines task, balloons recognition task, sequential dots task, VPTA, and simultaneous dots task. The material was programmed using E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA, USA).

A self-terminating procedure was used for all the tasks, i.e. the simplest trials were administered first and their complexity gradually increased; participants continued for as long as they were able to give a correct answer for at least two of the three items at any given level (for a similar procedure, see Logie & Pearson, 1997).

3. Results

3.1. Descriptive statistics

Preliminary analyses were run to assess the reliability of the measures (Cronbach's alpha), which was found acceptable in all cases (see Table 2).

The participants' performance is shown in Table 2 and represented graphically in *z* scores, for the whole sample, in Fig. 2.

Correlations between visuospatial measures are shown in Table 3. Negative and generally large correlations were found between age and performance in the visuospatial tasks.

3.2. Confirmatory factor analyses

The degree to which the data fitted other models of visuospatial memory was formally tested using confirmatory factor analysis (Bollen, 1989). The R program (R Development Core Team, 2011) was used with the "lavaan" library (Rosseel, 2012). Since the variables observed were not exactly normally distributed, a maximum likelihood estimation was used, obtaining robust standard errors and a Satorra–Bentler scaled test statistic (Satorra & Bentler, 1988). The following fit indices were also considered: the Comparative Fit Index (CFI; Bentler, 1990), the Tucker–Lewis Index (TLI or NNFI; Tucker and Lewis, 1973), the Standardized Root Mean square Residual (SRMR; Jöreskog & Sörbom, 1981), the Root Mean Square Error of Approximation (RMSEA; Steiger & Lind, 1980) and the Bayesian Information Criterion (BIC; Schwarz, 1978). Finally, the BIC differences between the null model and other models (Δbic) were calculated: a positive Δbic value implies that a given model is better than the null model (Raftery, 1993). All the fit indices are given in Table 3.

Table 2
Descriptive statistics and reliability estimates on the measures of interest.

Age	40–49		50–59		60–69		>70		Cronbach's alpha
	M	SD	M	SD	M	SD	M	SD	
Simple storage tasks									
Meaningless shapes	15.80	6.16	15.31	5.70	12.32	4.84	8.58	4.50	.89
Water animals	18.57	5.04	16.71	4.60	14.76	5.06	9.27	4.22	.88
Balloons	16.63	6.07	14.46	5.02	13.58	5.03	8.46	2.91	.86
Sequential light bulbs	17.43	3.91	16.46	4.10	16.95	4.58	10.31	5.82	.89
Sequential lines	19.06	3.36	19.09	3.36	17.37	5.04	11.87	5.18	.87
Sequential dots	17.74	4.22	16.00	3.86	16.42	5.37	11.29	5.28	.91
Simultaneous light bulbs	21.54	3.32	20.57	2.28	19.34	3.83	15.29	5.52	.88
Simultaneous lines	21.66	3.09	21.20	2.82	19.82	3.76	16.85	5.05	.85
Simultaneous dots	19.71	4.73	16.8	4.68	16.95	4.82	12.62	5.47	.90
Complex span tasks									
Jigsaw puzzle	21.29	3.86	20	4.43	15.95	4.65	11.04	4.24	.84
Dot matrix	10.40	1.22	10.17	1.07	8.61	2.65	5.94	2.35	.79
VPTA	21.71	3.60	20.54	3.89	15.26	3.74	10.00	2.77	.89

Note. Seq: = sequential; Sim = simultaneous; VPTA = visual pattern test, active version; Puzzle: jigsaw puzzle task.

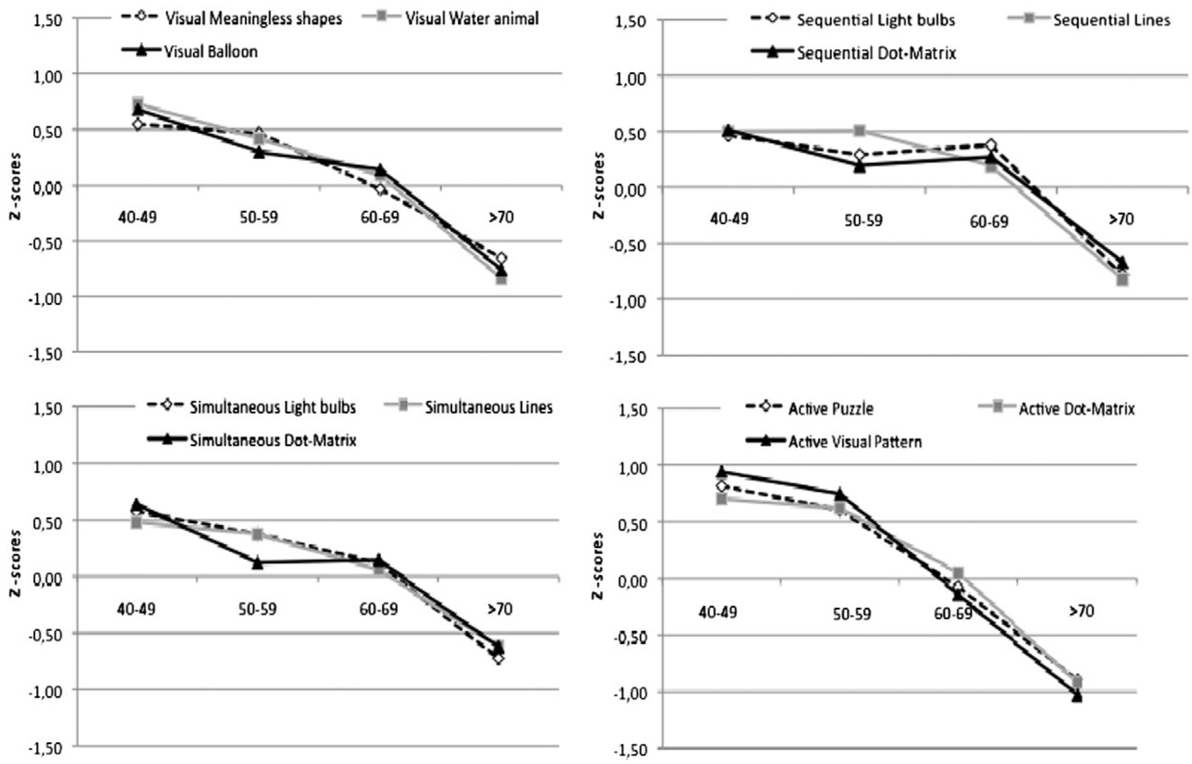

Fig. 2. Lifespan measures for visuospatial memory (visual, sequential, simultaneous and complex span tasks) (raw scores converted into z-scores).

First, a null model was tested in which the covariances among all manifest variables were set to zero. Then different models were compared in the light of the literature (see Fig. 4). The first predicted visuospatial memory as a single construct (Model 1). The second (Model 2a) predicted a distinction between two factors, i.e. a visual and a spatial component. In this latter model, the visual factor included tasks that involved maintaining textures, shapes and pattern of locations (Logie, 1995), while the spatial factor included tasks in which sequentially-presented locations had to be retained. Model 2b represented a two-factor model distinguishing between visuospatial complex span tasks and visuospatial simple storage tasks, as proposed by (Baddeley & Hitch, 1974; see also Baddeley, 1986). A third, three-factor model (Model 3a) represented a distinction between the two visuospatial components, i.e. visual vs. spatial (Logie, 1995), as defined in Model 2a, but with the addition of a factor for measuring visuospatial complex span tasks (as in Logie, 1995; Baddeley & Logie, 1999). Another three-factor model (Model 3b) was used to draw a distinction between the two visuospatial components defined in Model 2b and a factor measuring visuospatial complex span tasks, resembling the distinction drawn by Mammarella, Pazzaglia, & Cornoldi, 2008 (see also Lecerf & de Ribaupierre, 2005; Pazzaglia & Cornoldi, 1999). Finally, a four-factor structure (Model 4) was tested, in which distinctions were drawn between complex visuospatial memory tasks and visual, spatial-sequential and spatial-simultaneous simple storage tasks. This differs from model 3b in that the spatial factor is split into a spatial-sequential

Table 3
Correlation matrix for VSWM measures and age.

	Age	1	2	3	4	5	6	7	8	9	10	11
1. Meaningless shapes	−.50***	–										
2. Water animals	−.59***	.48***	–									
3. Balloons	−.53***	.42***	.51***	–								
4. Seq. light bulbs	−.52***	.21**	.41***	.43***	–							
5. Seq. lines	−.57***	.35***	.40***	.37***	.66***	–						
6. Seq. dots	−.47***	.21***	.34***	.30***	.74***	.71***	–					
7. Sim. light bulbs	−.54***	.23**	.35***	.29***	.62***	.59***	.53***	–				
8. Sim. lines	−.48***	.29***	.42***	.40***	.53***	.54***	.47***	.52***	–			
9. Sim. dots	−.48***	.23***	.32***	.31***	.59***	.60***	.59***	.58***	.52***	–		
10. Puzzle	−.71***	.47***	.54***	.52***	.47***	.54***	.35***	.46***	.51***	.43***	–	
11. Dot matrix	−.64***	.50***	.46***	.49***	.22**	.30***	.10	.28**	.22***	.17*	.56***	–
12. VPTA	−.81***	.46***	.64***	.56***	.46***	.54***	.38***	.44***	.48***	.48***	.80***	.58***

Note. (N = 201).
Seq: = sequential; Sim = simultaneous; VPTA = visuospatial pattern test, active version; Puzzle: jigsaw puzzle task.
*** p<.001.
** <.01.
* p<.05.

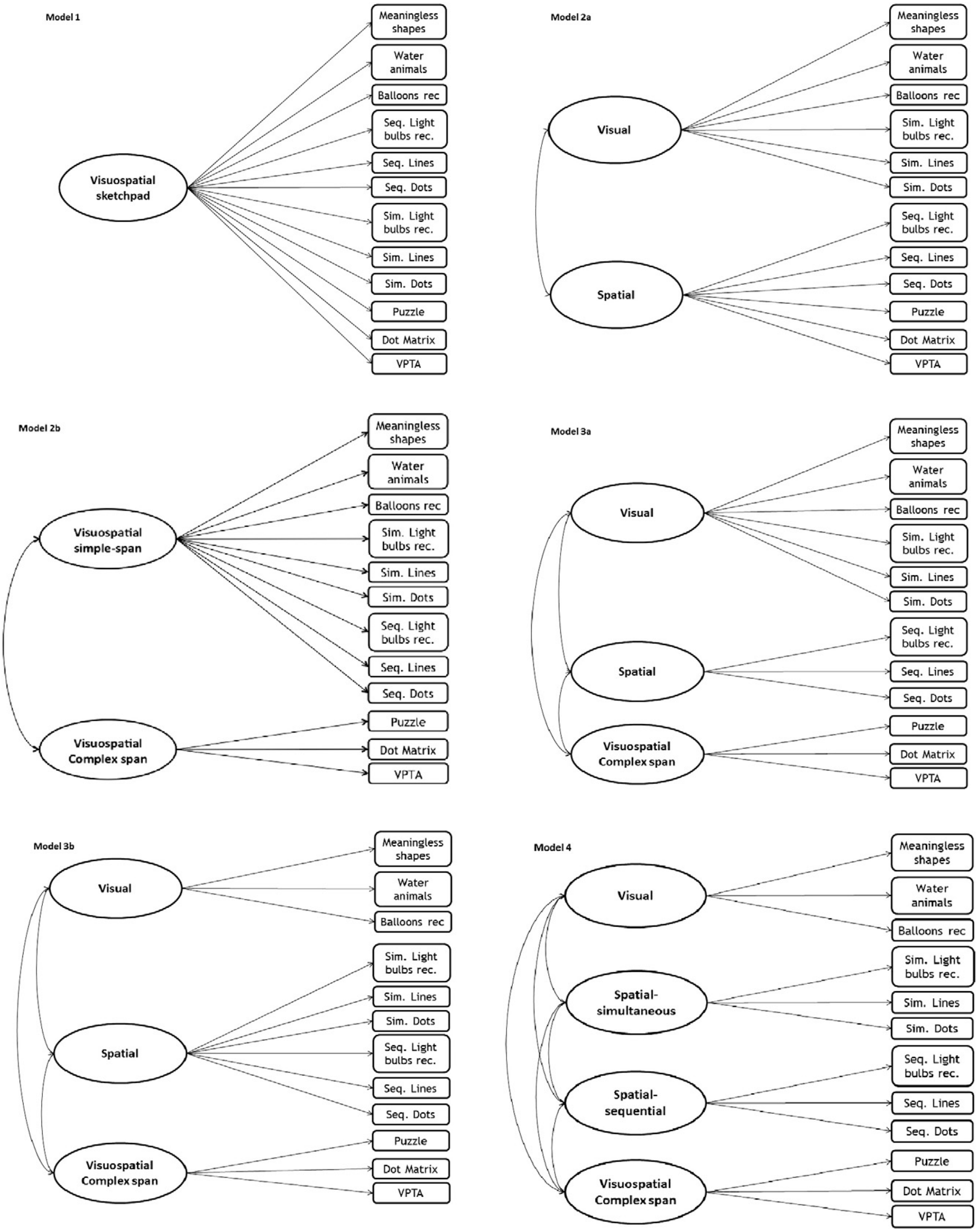

Fig. 3. Schematic representations of the one-, two-, three-, and four-factor models used to examine the structure of visuospatial memory.

and a spatial-simultaneous factor. This model reflects the continuity model (Cornoldi & Vecchi, 2003; see also Mammarella, Pazzaglia, & Cornoldi, 2008), according to which simple storage and complex span tasks are arranged in two different dimensions, i.e. a vertical continuum (referring to complex span tasks) and a horizontal continuum (referring to simple storage tasks, distinguishing between visual, spatial-sequential and spatial-simultaneous latent variables) (Fig. 3).

Table 4
Fit statistics for different confirmatory factor analyses based on all participants.

	df	SBχ^2	p	CFI	TLI	SRMR	RMSEA	BIC	Δbic (null model)	Δbic compared with Model 4
Null model	66	1208.56	<.001	.00	-.00	.40	.33	11901.13		
Model 1	54	255.54	<.001	.82	.78	.10	.15	11148.42	752.71	−200.71
Model 2a	53	254.62	<.001	.82	.78	.10	.15	11153.39	747.74	−205.68
Model 2b	53	183.46	<.001	.89	.86	.10	.12	11045.88	855,25	- 98.17
Model 3a	51	141.89	<.001	.92	.90	.08	.11	11010.27	890.87	−62.56
Model 3b	51	91.62	<.001	.96	.95	.06	.07	10945.60	955.53	2.11
Model 4	48	79.19	=.003	.97	.96	.05	.06	10947.71	953.42	

Note: SBχ^2: Satorra–Bentler scaled chi-square; CFI: comparative fit index; TLI: Tucker–Lewis index; RMSEA: root mean square error of approximation; SRMR: standardized root mean square residual; BIC: Bayesian information criterion; Δbic: differences between null model and other models.

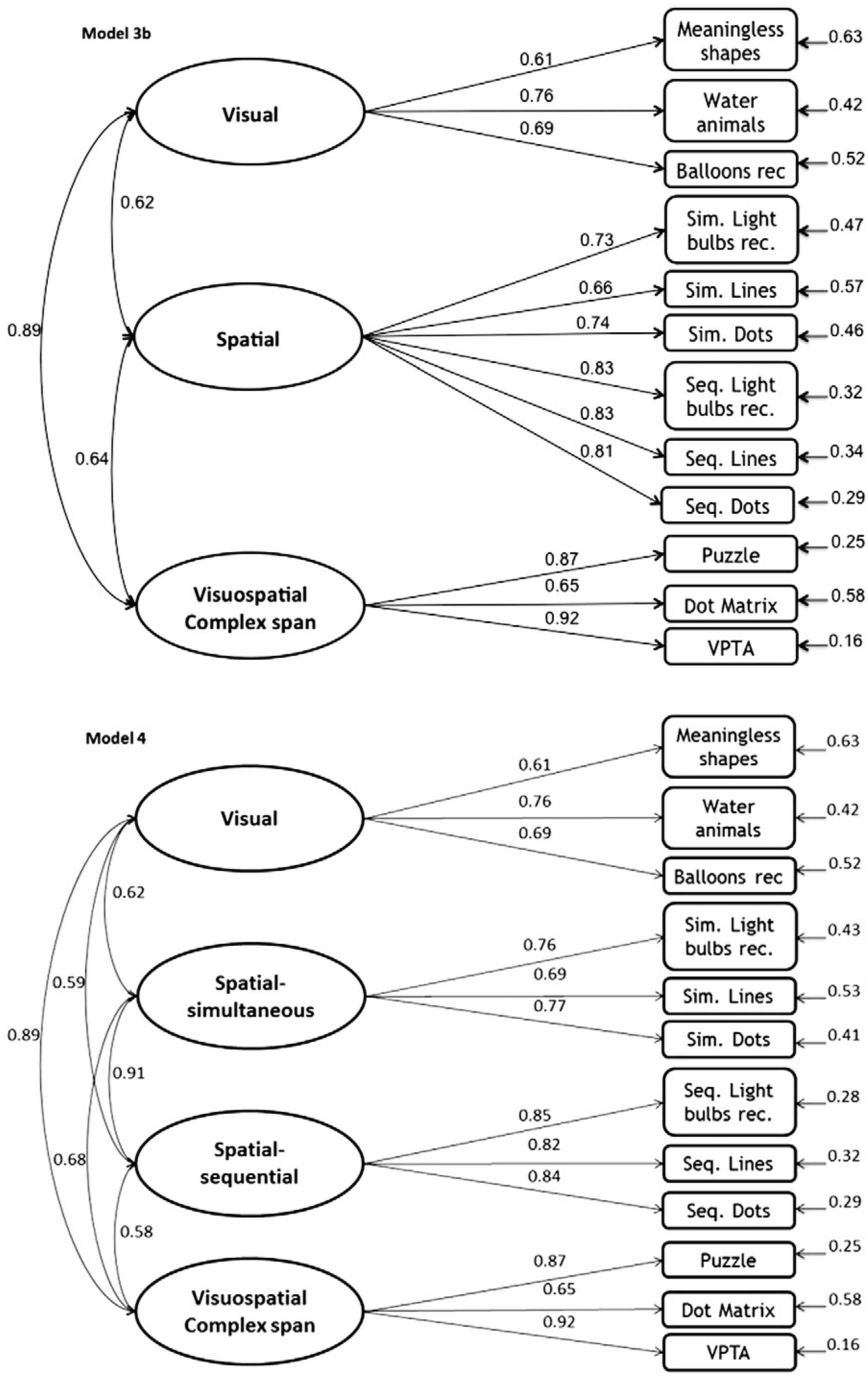

Fig. 4. Structural model: best-fitting measurement models. The completely standardized solution is presented for each path in each model.

As shown in Table 4, Models 3b and 4 revealed a better fit than the other models (see also Fig. 4).[1]

To compare models 3b and 4, we performed a bootstrap resampling (1000 replicates) using the Bollen–Stine method (Bollen & Stine, 1992). The estimated overlapping area was 91.2%, so the models could be onsidered statistically equivalent.

Confirmatory factor analyses thus showed that visuospatial tasks can be reasonably assumed to be represented either by three different latent constructs (as proposed by Lecerf & de Ribaupierre, 2005; Mammarella, Pazzaglia, & Cornoldi, 2008) or by four different latent constructs (consistently with Cornoldi & Vecchi, 2003, and Mammarella, Pazzaglia, & Cornoldi, 2008).

The next step was to use SEM to test the age-related variance in both Model 3b and Model 4. Age was thus used as the exogenous variable in the model. The latent variables were defined as explained above and only the relationships between the latent variables were modified.

It was assumed in Models 5 (derived from Model 3b) and 6 (derived from Model 4) (see Fig. 5) that age has a direct influence on all factors, i.e. that there are age-related differences in both the visuospatial complex span factor and the simple storage factors.

Models 7 (derived from Model 3b) and 8 (derived from Model 4) assumed that age-related differences in the visuospatial complex span factor are explained by an age-related decline in performance in the simple storage tasks (i.e. a direct effect of age on simple storage factors, but not on visuospatial complex tasks: the simple storage factors had a direct effect on the visuospatial complex span factor).

The Δbic index (see Raftery, 1995) was also used to compare the fit of the models 5 vs. 6, 5 vs. 7, and 6 vs. 8 (see Table 5).

Models 5 and 6 described the data efficiently (see Fig. 5), while some parameters were not significant ($p > .05$) in Models 7 and 8.

To further analyze whether age-related differences had a similar weight for the four factors, depending on the nature and presentation format of the WM tasks, we tested Models 5 and 6 with and without the constraint of equal gamma (γ) parameters. Our results showed that the model in which the structural relationships were constrained revealed a worse fit than our final model (model 5: $\chi^2 = 157.78$ df = 62 $p < .001$, CFI = 0.93, TLI = 0.92 RMSEA = 0.09 SRMR = 0.09; model 6: $\chi^2 = 121.32$ df = 59 $p < .001$, CFI = 0.96, TLI = 0.94 RMSEA = 0.08 SRMR = 0.07). These findings indicate that the parameters cannot be considered equal, and suggest that the path between age and complex span tasks (i.e. −.87 in both Models 5 and 6) is stronger than the paths between age and the other factors.

4. Discussion

The purpose of the present study was to investigate the structure of visuospatial memory in adults. To our knowledge, this is the first study to examine: *i)* whether visuospatial memory could be seen as a unitary factor, or separated into different components; and *ii)* how age affects the structure of visuospatial memory.

Concerning the first issue, much of the research examining the nature of visuospatial memory has been done within the framework of the (Baddeley, 1986; Baddeley & Hitch, 1974). The main results of the present study show, however, that our data fitted poorly with the following models: a unitary visuospatial model; a two-factor model distinguishing between visual and spatial components (e.g. Logie, 1995), or between simple storage and complex span tasks (Baddeley, 1986; Baddeley & Hitch, 1974); a three-factor model representing Logie's (1995) model (see also Baddeley & Logie, 1999), which comprises complex span tasks and a distinction between the previously-tested visual and spatial components (e.g. Model 2a). Conversely, the distinction between a three-factor model (Model 3b) involving a complex visuospatial component and two simple storage components (i.e. a spatial one including spatial-sequential and spatial-simultaneous tasks, and a visual one (Lecerf & de Ribaupierre, 2005; Mammarella, Pazzaglia, & Cornoldi, 2008; Pazzaglia & Cornoldi, 1999) and a four-factor model (Model 4)), as suggested by Cornoldi and Vecchi (2003), produced the best fit with our data. The picture emerging from our findings thus suggests that visuospatial memory tasks in adulthood should be differentiated in terms not only of the attentional control demanded by the tasks, but also of the presentation format used. It is worth noting that Models 3b and 4 generated similar fit indices. In particular, Model 3b distinguished between a visuospatial complex span component, a visual simple storage component (involving tasks in which shapes and textures are presented) and a spatial simple storage component (involving tasks in which spatial locations are presented either simultaneously or sequentially). Unlike previous research, in which Corsi-type and VPT-type tasks were used to measure visual and spatial WM components, respectively (Logie, 1995; Pickering, 2001), in Model 3b the spatial-sequential (i.e. Corsi type) and spatial-simultaneous (i.e. VPT-type) tasks are included in a spatial factor, thus coming closer to the distinction drawn by (Lecerf & de Ribaupierre, 2005 and Mammarella, Pazzaglia, & Cornoldi, 2008; Mammarella et al., 2010) between visual and spatial components, in which the spatial components should be further separated into spatial-sequential and spatial-simultaneous elements. It is also worth noting that our spatial-simultaneous and spatial-sequential tasks differed only in their presentation format, not in the content of the stimulus. Model 4 therefore showed that, although the two factors are strongly correlated, a slightly better fit is achieved when a distinction is drawn between the spatial-sequential and spatial-simultaneous components, rather than considering them as a general spatial factor. It would nevertheless be worthwhile to use more classical tasks in future studies, such as the Corsi blocks task and the VPT, to examine the structure of visuospatial memory.

Our findings thus confirm the complexity of the WM system, and of the visuospatial memory system in particular, as well as reflecting the two dimensions proposed by Cornoldi and Vecchi (2003) in adulthood. Indeed, the present results suggest that visuospatial memory in adulthood should be considered as a composite system consisting of different components, as emerged from the work by Mammarella, Pazzaglia, and Cornoldi (2008) in a sample of developmental age (in a study that also involved verbal simple storage tasks). To our knowledge, apart from Mammarella, Pazzaglia, and Cornoldi (2008) most studies focusing on children (e.g. Alloway et al., 2006), adults (Kane et al., 2004; Miyake et al., 2001), and the full adult lifespan (Hale et al., 2011; Park et al., 2002) have drawn no distinction between the different presentation formats in VSWM.

The results obtained by Mammarella, Pazzaglia, and Cornoldi (2008) in children cannot be compared directly with those of the present study on adults, but the strength of the weightings for the visuospatial complex span and simple storage factors is clearly not the same for children and adults: a stronger relationship was apparent between the complex visuospatial and the spatial-simultaneous components in children (.93), and between the complex visuospatial and the visual components in our adults (.89). This difference could be due to the different types of task used. Future studies should examine the structure of VSWM across the lifespan using the same tasks in an effort to understand its architecture from childhood to late adulthood.

As for the second issue we investigated, our findings indicate that age has a direct influence on both simple storage factors and the

[1] Given the strong relationship between the visuospatial complex span factor and the visual factor, and between the spatial–simultaneous and the spatial–sequential factors, we tested a further two-factor model. Although this model has no theoretical support, it is characterized by a spatial factor that pools the simultaneous and sequential tasks together, and another factor combining the visual and complex span tasks. The model's fit was worse than for our Model 4, however ($\chi^2 = 100.39$ df = 53 $p < .001$, CFI = 0.96, TLI = 0.95 RMSEA = 0.07 SRMR = 0.06).

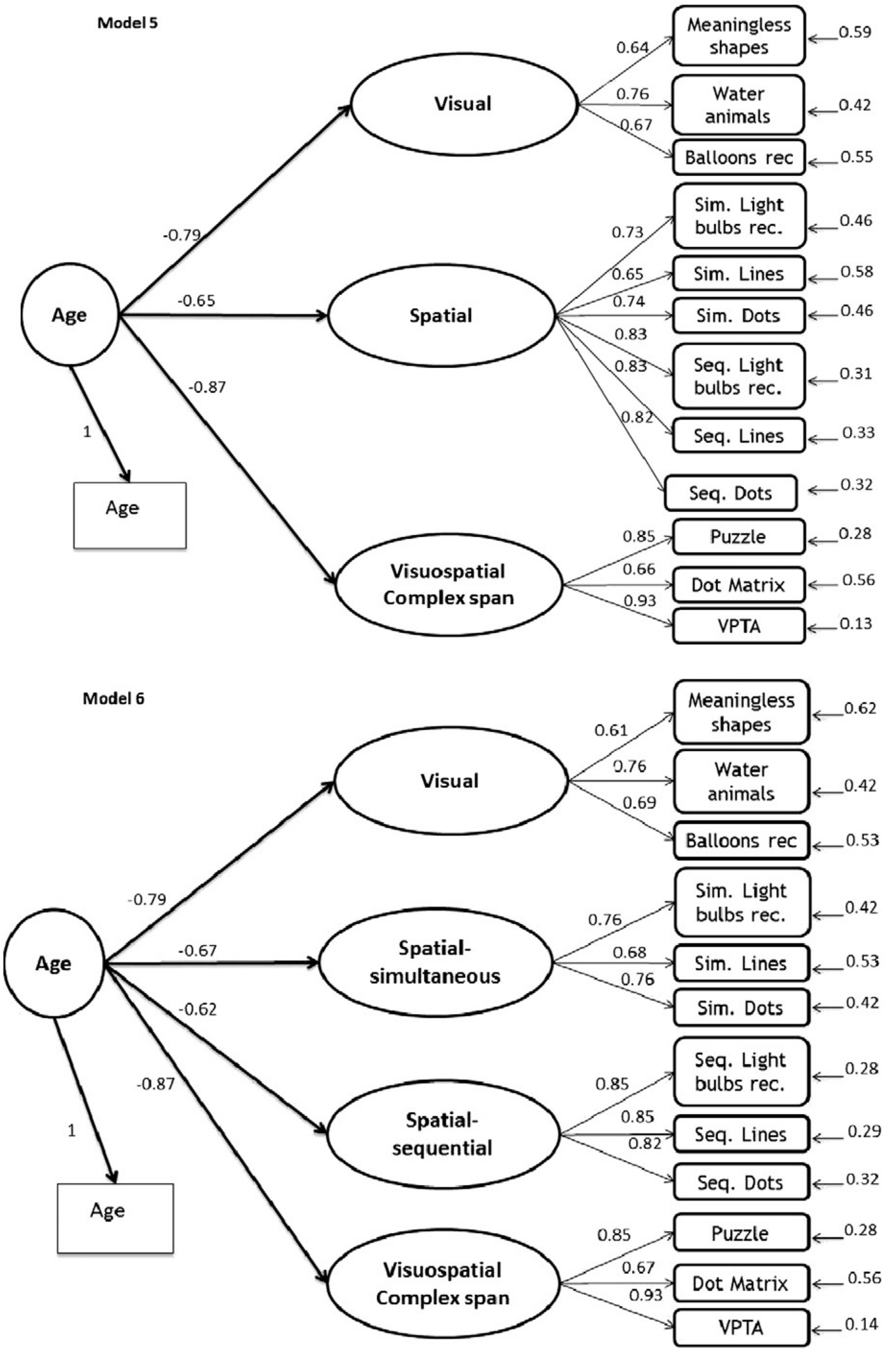

Fig. 5. Structural model with age: best-fitting measurement models. The completely standardized solution is presented for each path in each model.

visuospatial complex span factor, in both the three- and the four-factor models, fitting our data. In other words, we observed a general decline in VSWM with aging. Testing the strength of the structural relationships

Table 5
Fit statistics for the SEM analysis with age.

	df	*SB*χ^2	*p*	*CFI*	*TLI*	*SRMR*	*RMSEA*	*BIC*	Δbic
Model 5	60	107.70	<.001	.97	.96	.05	.07	12033.27	
Model 6	56	95.03	<.001	.97	.96	.05	.07	12040.30	−7.03[a]
Model 7	62	117.65	<.001	.96	.95	.06	.07	12034.31	−1.04[c]
Model 8	60	170.77	<.001	.92	.90	.11	.11	12108.53	−68.23[b]

Note. For fit statistics see note in Table 3.
[a] Δbic: differences between Models 5 and 6.
[b] Δbic: differences between Models 6 and 8.
[c] Δbic: differences between Models 5 and 7.

(gamma, γ) revealed, however, that the models in which the gamma were constrained (e.g. those derived from Models 5 and 6) achieved a worse fit than our final models, meaning that age had a different weight on the various factors, with a stronger relationship emerging between age and complex span tasks (−.87). This result is consistent with previous reports (Hale et al., 2011) of a more severe age-related memory decline for complex than for simple storage visuospatial tasks. It is worth adding, however, that Hale et al. (2011) compared visuospatial and verbal WM tasks, whereas only VSWM was investigated in the present study.

Although it offers some insightful findings, the present study has its limitations. The first is the small sample size in each age group, which prevents us from saying whether: i) VSWM is better represented by the three-factor model (i.e. visual, spatial, and complex span tasks) or the four-factor model (i.e. visual, spatial sequential, spatial simultaneous, and complex span tasks); ii) the structure of VSWM identified in the present study remains the same across the age groups considered, i.e. between younger and older participants (over 60-year-olds) at least. The present results will therefore need to be further tested in larger samples and assessing the measurement invariance of the structure of visuospatial memory across age groups throughout adulthood. The second limitation lies in that not all of the WM system was tested. Further studies should therefore test both verbal and visuospatial simple storage and complex span throughout adult life. The third limitation lies in that we did not analyze the relationship between long-term memory and VSWM. Unsworth and Engle (2005) found that individual differences in WM capacity relate to both the ability to keep information accessible in primary memory and the ability to draw on information in secondary memory (see also Hale et al., 2011). In addition, some of our tasks (like the jigsaw puzzle tasks) involve looking for the corresponding image in long-term memory and also retaining the various pieces in the VSWM in order to complete the puzzle, so further studies would need to analyze how long-term recall and VSWM processing are related. Finally, one of the limits of the Cornoldi and Vecchi (2003) model relates to the assumption that attentional control varies according to where each task is located in the vertical continuum, an aspect that was not assessed in the present study. In fact, few studies have tried to test the degree of attentional control required by the tasks (e.g. Lanfranchi, Cornoldi & Vianello, 2004, in individuals with intellectual disabilities, and Borella et al., 2009, in older adults). Future research should consequently analyze the continua hypothesis in VSWM tasks, differentiating between them on the basis of their presentation format.

To conclude, the novelties of the present study lie in: (a) the separate testing of adult visuospatial memory by means of simple storage tasks with different presentation formats (i.e. visual, spatial/visual, spatial-sequential and spatial-simultaneous) and visuospatial complex span tasks; and (b) the finding of a direct influence of age on all visuospatial memory skills, irrespective of the tasks' presentation format — although this influence depended on the requirements of the tasks concerned.

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