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Evidence for different components in children's visuospatial working memory.

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Abstract

There are a large number of studies demonstrating that visuospatial working memory (VSWM) involves different sub-components, 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 thirteen tests was used to assess working memory and, in particular, the hypothesized mechanisms involved in the tasks, i.e. active processing and passive recall of visual *vs.* sequential-spatial *vs.* simultaneous-spatial *vs.* 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.

Introduction

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 sub-components. 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 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 which 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 respectively the presentation of irrelevant pictures and unseen arm movements, 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 performance 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 (memorising 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 which have mostly been used, until now, to measure the visual and spatial working memory sub-components (Pickering, 2001a; 2001b), could be interpreted within Logie's (1995) model postulating a distinction between the visual and the spatial sub-components 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), i.e. 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 *vs.* 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, differently 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 *vs.* processing, but do not distinguish between different presentations 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 *vs.* spatial memory and static *vs.* dynamic format (Pickering & Gathercole, 2001). The tasks were the VPT *vs.* the Corsi blocks task and the Static mazes *vs.* 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 locations of each filled cell in the learning matrix need 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 subject can see a visual pattern (for example 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 subject cannot be confused with the basic process involved in performing the task: following a similar reasoning, if a person visualises the numbers during the maintenance of the digit span test, one should conclude that it is a visual task. Differently, 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, Cornoldi, Pazzaglia, Toso, Grimoldi, & Vio, 2006) distinguished between visual WM tasks, which require memorisation 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), sequential in the other (i.e. in the Corsi blocks task). Evidence collected with 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 both of the format/content of information and of 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 to distinguish 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 comes 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 subjects, 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 (Lanfranchi, Cornoldi, & Vianello, 2004) and children with Attention Deficit Hyperactivity Disorder (Cornoldi, Marzocchi, Belotti, Caroli, De Meo, & Braga, 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, i.e. 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 which 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 (2003) which distinguished between active visuospatial tasks, visual passive tasks, 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 3 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 ($SD=.68$) 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 randomised across participants. For each test, participants were presented with trials of

increasing levels of complexity until they were unable to solve at least two items out of three 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 last three items correctly solved were the first two on the third level and one on the fourth level, then the child's score was $3 + 3 + 4 = 10$.

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 3 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 (1997) 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 MT, 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).

Insert Figure 1 about here

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 in the grid, for 3 seconds. The grids increase in size from the smallest (4 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 memorising different positions in matrices of various dimensions. After the presentation phase, in which participants memorise 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 three 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 (see Figure 1). Immediately after presentation, the participant has to recognise the target houses within a set comprising 4 stimuli. Then a set of 3 houses is presented for the same length of

time and the participant must recognize them among a total of 6 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 MT 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 three seconds before being removed from view and being 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, 1997). 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 of 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 the memory of the complete drawing presented but also spatial active working

memory processes as s/he 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 2x2 to 6x6) 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 in the backward order (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 9 sequences of syllables are orally presented to the child. The three trials of sequences vary in length: from two to nine 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.

Insert Table 1 about here

Internal reliability for the visuospatial tests was verified computing Cronbach's alpha coefficient. As shown in Table 1 alpha 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.

Insert Table 2 about here

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 model we considered the χ^2 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 fits 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 nested² and for this reason we did not employ the chi-square difference to compare their fit but we used the Akaike Information Criterion (AIC) (e.g. 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 *vs.* 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, i.e. visual *vs.* spatial (Logie, 1995) or static *vs.* 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) which 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 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 which 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 summarised 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-square 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.

Figure 2 about here

The Three Slaves Systems model distinguishes among verbal, visual and spatial constructs, but there is no mention of complex *vs.* simple span tasks. Specifically, the verbal latent variable involves the Syllables Span Test and both Forward and Backward Digit Span Test; 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-square value is highly significant ($p=.001$), although the fit indices (CFI, GFI, AGFI) are acceptable, the RMSEA is medium (.063), and the parsimony (PGFI=.62) is good.

Figure 3 about here

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), 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 χ^2 value is significant ($p=.02$).

Figure 4 about here

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), *vs.* visual (Houses Recognition test and Symbols Reproduction test) *vs.* simultaneous-spatial (VPT, Static Mazes, Dots Reproduction test) *vs.* 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 χ^2 value of this model is not significant ($p=.069$), 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 which 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 χ^2 results.

Figure 5 about here

Table 3 about here

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 (e.g. 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 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, i.e. verbal, visual and spatial (Logie, 1995; Gathercole & Pickering, 2000).

Obviously, we limited our consideration to a limited number of models, based on the fact they had already been applied in developmental studies on VSWM and could be easily operationalised with reference to the available tests. However we cannot exclude that further more 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, i.e. 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 multi-dimensional store which allows different systems to be integrated. The Episodic 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 *vs.* spatial (Logie, & Pearson, 1997; Hamilton et al., 2003) or between static *vs.* 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 which 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 from 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 squared 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 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 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 old, the link between the domain specific visuospatial construct and the domain general processing construct was higher when compared to older children, but that the structural organization of WM only had minor changes in children between the ages of 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 generalised to older age samples. However, only further research can support this hypothesis.

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Footnotes

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, i.e. 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.

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, e.g., by constraining a free parameter to equal one or more other parameters.

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

	Reliability (Cronbach's α)	3 rd graders					4 th graders				
		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: ($N = 158$) * = $p < .05$. ** = $p < .01$

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 (Fig.2)	109.39	63	1.74	.0003	.95	.91	.86	.068	165.39	.63
Three Slaves Systems (Fig.3)	101.38	62	1.64	.001	.96	.91	.87	.063	159.38	.62
Three Slaves + Processing (Fig.4)	86.13	62	1.39	.02	.97	.92	.89	.05	144.13	.63
Continuity Model (Fig.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.

χ^2 not significant at the .05 level indicate that the models provided reasonable fits.

Values above .95 for CFI and GFI indicate good fit.

$\chi^2/df < 2$ indicates a good fit

Figure Captions

Figure 1: The thirteen measures of working memory used in the test battery according to the distinctions between Verbal vs. Visuospatial WM, and Active vs. Passive. In the battery, the passive visuospatial tests are also distinguished between visual (left), simultaneous-spatial (centre) and sequential-spatial (right).

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.

Figure 3: The Three Slaves Systems model (Visual, Spatial, Verbal).

Figure 4: The Three Slaves plus Processing model (Complex span measures = Complex, Verbal, Visual, Spatial).

Figure 5: The Continuity Model (Active visuospatial=ActiveVS, Verbal, Visual, Sequential-spatial=Seq-sp., Simultaneous-spatial=Sim-sp.).

Figure 1

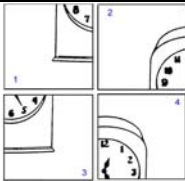
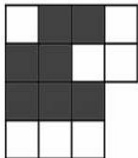
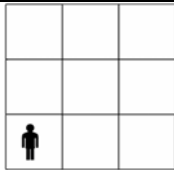

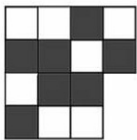


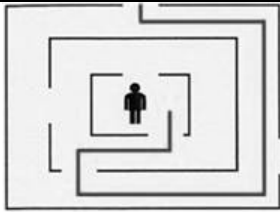
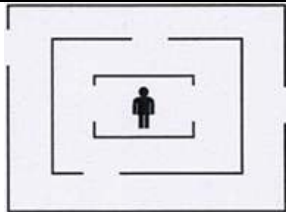
VISUOSPATIAL WORKING MEMORY			VERBAL WORKING MEMORY
ACTIVE (Complex Span) TASKS			
Jigsaw Puzzle task	Active VPT	Pathway Span Task	Backward Digit Span
			1 8 7
PASSIVE (Simple Span) TASKS			
Houses Recognition test	VPT	Dots Reproduction test	Forward Digit Span
			9 5 3
Symbols Reproduction test	Static Mazes	Dynamic Mazes	Syllables Span
			Ba La Si

Figure 2: Tripartite Model

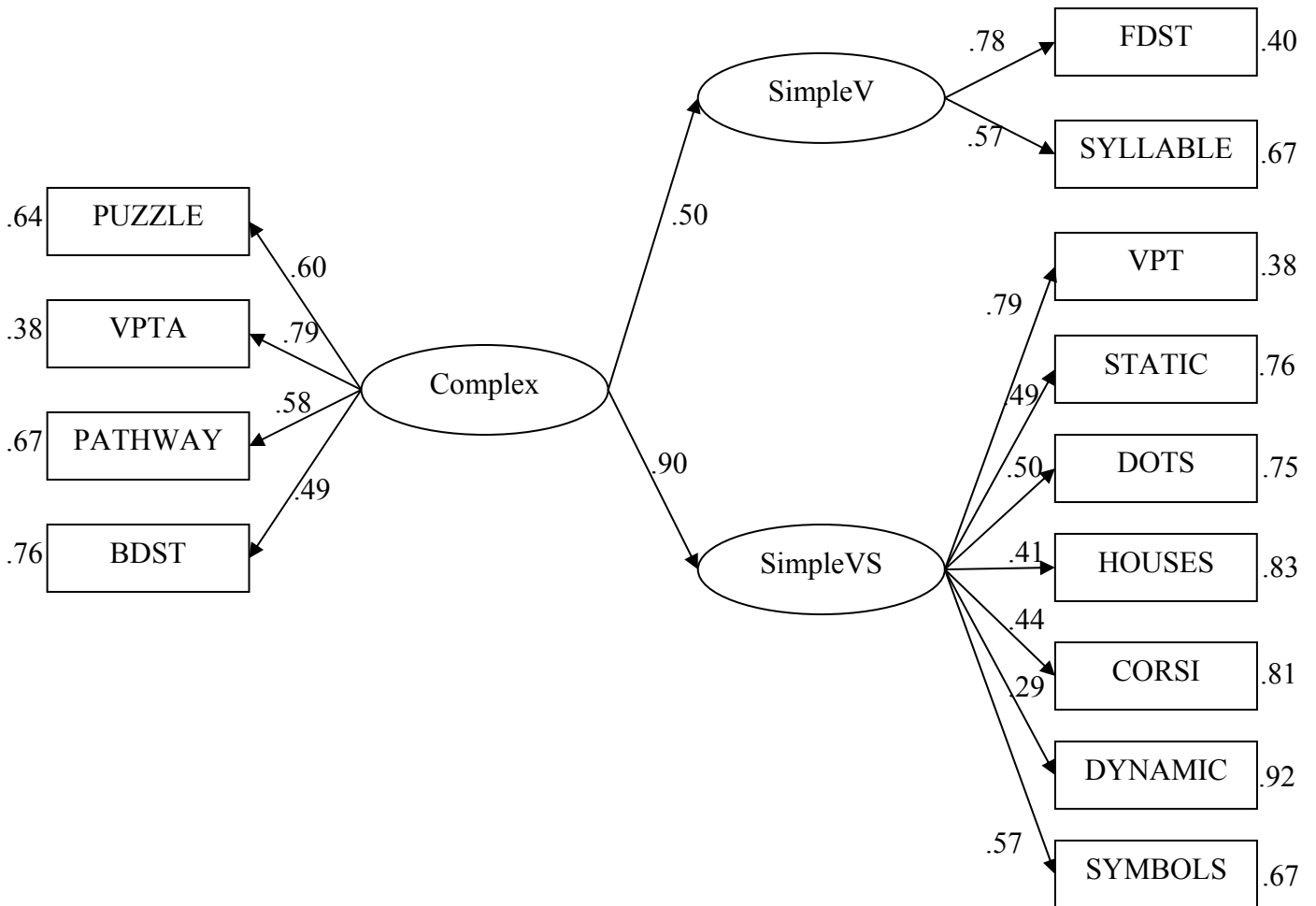


Figure 3: Three Slaves Systems

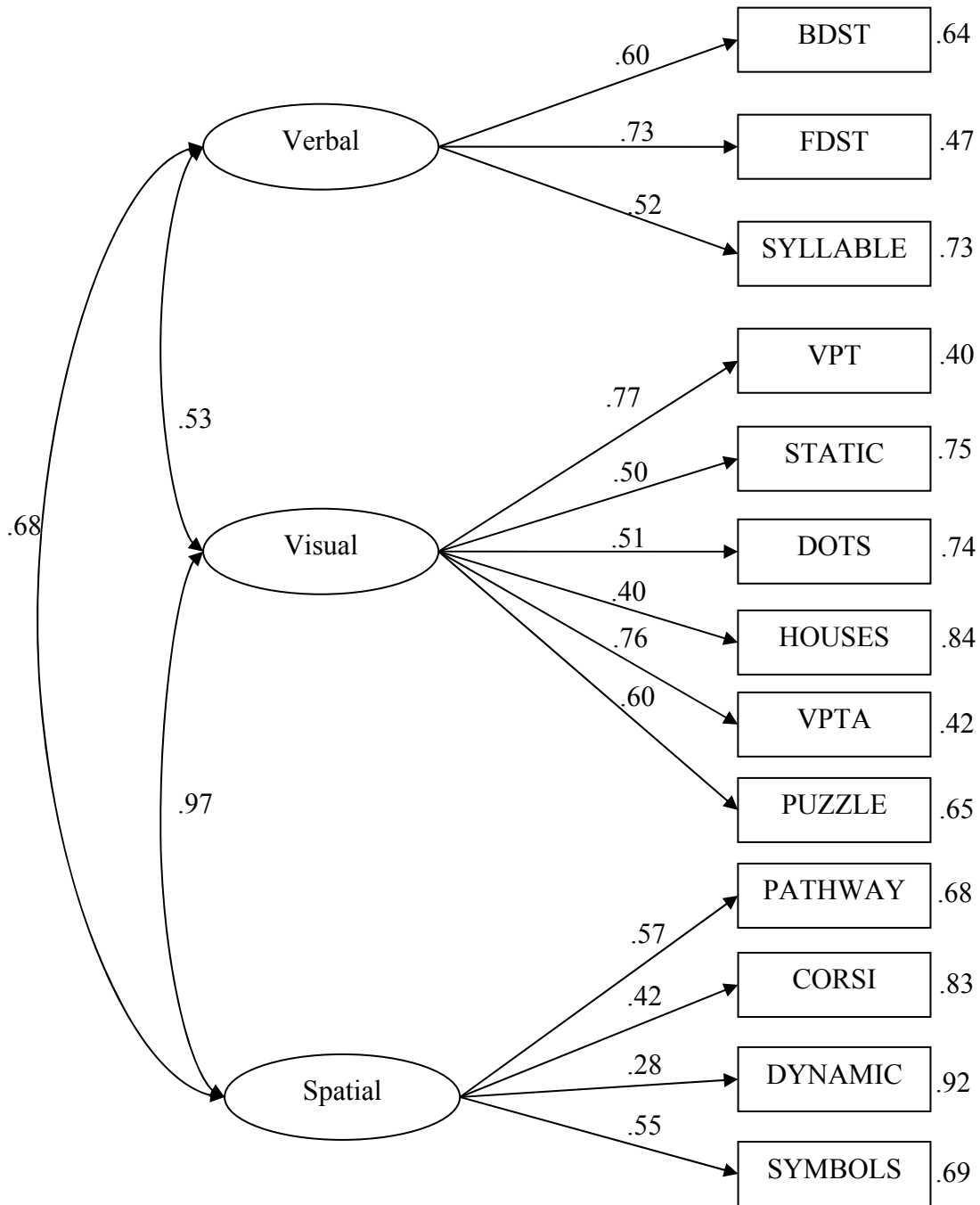


Figure 4: Three Slaves + Processing

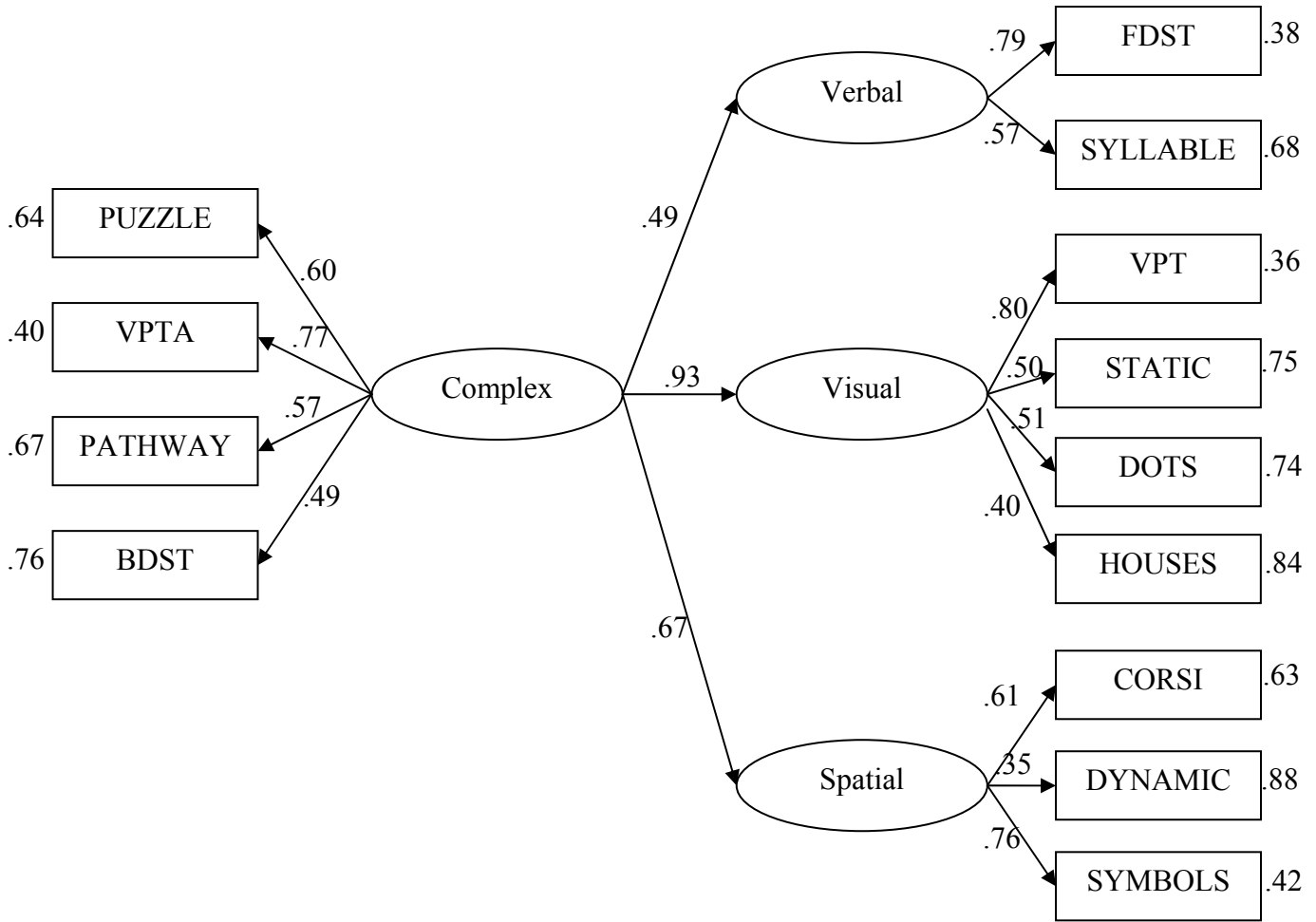


Figure 5: Continuity Model

