

Working Memory Structure in Children: Comparing Different Models During Childhood

Estructura de la Memoria Operativa: Comparando diferentes modelos en la infancia

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Working Memory (WM) is an active memory system responsible for the temporary storage and concurrent processing of information. Different authors have considered WM as a complex but unitary system, whereas others have suggested that the system is multidimensional. In this line, the model developed by Baddeley and Hitch (1974) is one of the most well known; it proposes two modality-specific components - the phonological loop and the visuo-spatial sketchpad - and a supervisory executive system - the central executive. This paper contributes to the debate on WM structure by investigating three groups of children of different ages and assessing different models using confirmatory factor analysis. The Working Memory Assessment Battery Test (Alloway, 2007; Injoque-Ricle, Calero, Alloway & Burin, 2011) was administered to 180 monolingual Spanish-speaking children. The three age groups consisted of 6-, 8-, and 11-year-old children (n = 60 participants per group). The results suggest that the WM structure is not uniform across the different age groups tested, showing progressive differentiation and specialization during childhood. This structure would appear to form between the ages of 6 and 8 years and become more complex as adolescence is approached.

Keywords: Working Memory; Confirmatory Factor Analysis; Children; AWMA.

La Memoria Operativa (MO) es un sistema de memoria activa responsable del almacenamiento temporal y procesamiento concurrente de información. Diferentes autores han considerado a la MO como un sistema complejo pero unitario, otros sugieren una estructura más compleja. Uno de los modelos más aceptados es el de Baddeley y Hitch (1974) que propone dos componentes de modalidad específica, el Bucle Fonológico y la Agenda Viso-Espacial, y un sistema ejecutivo supervisor, el Ejecutivo Central. El objetivo de este trabajo es contribuir al debate de la estructura de la MO en tres grupos de edades de niños, evaluando diferentes modelos, a través de un análisis factorial confirmatorio. Se administró la Batería Automatizada de Memoria Operativa (Alloway, 2007; Injoque-Ricle, Calero, Alloway & Burin, 2011) a 180 niños de habla española, distribuidos en tres grupos de edades (60 sujetos cada uno) de 6, 8 y 11 años. Los resultados sugieren que la estructura de la MO no sería uniforme entre los grupos evaluados, mostrando una diferenciación y especialización a lo largo de la infancia. Entre los 6 y los 8 años comienza a observarse una estructura y se complejiza hacia la adolescencia.

Palabras clave: Memoria Operativa; Análisis Factorial Confirmatorio; Niños; AWMA.

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In the last decades there has been an increasing interest on Working Memory (WM), its neural substrate (e.g. Conway, Moore, & Kane, 2009), its development (e.g. Hitch, Towse, & Hutton, 2001; Hulme, Thomson, Muir, & Lawrence, 1984; Luciana, Conklin, Hooper, & Yarger, 2005), and its relation with different cognitive functions such as language and vocabulary acquisition (e.g. Adams & Gathercole, 2000; Baddeley, Gathercole & Papagno, 1998; Gathercole & Baddeley, 1989, 1990; Gathercole, Willis, Emslie & Baddeley, 1992), reading comprehension (e.g. Cain, Bryan & Oakhill, 2004; Daneman & Carpenter, 1980; Friedman & Mikaye, 2004; Just & Carpenter, 1992; Leather & Henry, 1994), arithmetic skills (e.g. Bull & Scerif, 2001; Fürst & Hitch, 2000; Logie, Gilhooly, & Wynn, 1994; Reuhkala, 2001), planning (e.g. Owen, Doyon, Petrides & Evans, 1996; Phillips, Wynn, Gilhooly, Della Sala & Logie, 1999), inhibition (e.g. Conway & Engle, 1994; Rosen & Engle, 1996; Redick, Heitz & Engle, 2007; Robert, Borella, Fagot, Lecerf & de Ribaupierre, 2009), impulsivity (e.g. Hinson, Jameson & Whitney, 2003), and intelligence (Ackerman, Beier & Boyle, 2005; Alloway & Chiara Passolunghi, 2011; Colom, Abad, Quiroga, Shih & Flores-Mendoza, 2008; Colom, Flores-Mendoza & Rebollo, 2003; Engel, Conway & Gathercole, 2010; Kyllonen & Christal, 1990; Schmiedek, Oberauer, Wilhelm, Süb & Wittmann, 2007; Süb, Oberauer, Wittmann, Wilhelm & Schulze, 2002; Swanson, 2008), among others. The study of WM and its relationship with so many cognitive and behavioral skills at different ages shows its importance in everyday abilities. WM is an active memory system responsible for temporary storage and concurrent processing of information (Baddeley, 1986, 2007; Baddeley & Hitch, 1974). It involves “the control, regulation, and active maintenance of task-relevant information in the service of complex cognition” (Shah & Miyake, 1999, p. 450). WM is assessed by tasks that require maintenance of a limited amount of information (e.g., letters, numbers, words, non-word, figures) during a short period of time. If the tasks requires immediate serial recall it is usually called simple span or short term memory task, and if it involves concurrent processing or double task it’s called complex span or working memory task (Unsworth, Redick, Heitz, Broadway & Engle, 2009).

Different authors have considered WM as a complex but unitary system (e.g. Anderson, Reder & Lebiere, 1996 ; Colom *et al.*, 2003; Conway, Cowan, Bunting, Therriault & Minkoff, 2002; Kane, Poole, Tuholski & Engle, 2006). According to this approach, individual differences in WM are explained by variations in resources, the amount of activation available for storage and concurrent processing (Colom *et al.*, 2003; Daneman & Carpenter, 1980; Daneman & Tardif, 1987; Just & Carpenter, 1992; Kyllonen & Christal, 1990). For some authors this capacity refers to a pool of attentional or executive resources (Conway *et al.*, 2002; Conway & Engle, 1994; Engle, Tuholski, Laughlin & Conway, 1999; Kane *et al.*, 2006). For example:

When we use the term *working memory capacity*, we refer to the attentional processes that allow for goal-directed behavior by maintaining relevant information in an active, easily accessible state outside of conscious focus, or to retrieve that information from inactive memory, under conditions of interference, distraction, or conflict (Kane, Conway, Hambrick & Engle, 2007, p. 23).

Even when factor analysis has shown two different components in WM, a short term maintenance one and another for long term memory retrieval (Engle & Kane, 2004; Unsworth & Engle, 2007; Unsworth *et al.*, 2009), or a short term memory factor and a WM one (Conway *et al.*, 2002; Engle *et al.*, 1999; Kane *et al.*, 2004; Oberauer, Süb, Schulze, Wilhelm & Wittmann, 2000; Süb *et al.*, 2002), this research perspective has considered that due to the great amount of shared variance between the tests and their high correlations with different measures of cognitive abilities, the unitary model is the most plausible.

A second line of research suggests a fractioning within WM. One of the most accepted models is the one developed by Baddeley and Hitch (Baddeley, 1986, 1999a, 2007; Baddeley & Hitch, 1974). According to this model, WM has two modality specific components, the phonological loop (PL), for the maintenance of verbal material, and the visuo-spatial sketchpad (VSSP) for the maintenance of visuo-spatial information; and a supervisory executive system, the central executive (CE), amodal and devoid of storage resources. The CE is a flexible system responsible for the control and regulation of the two slave systems (Baddeley, 1999a, 1999b, 2007; Baddeley & Logie, 1999; Gathercole, Pickering, Ambridge & Wearing, 2004). The most recent version of the model includes a third subsystem: the Episodic Buffer. This subsystem uses multidimensional codes to form an episodic representation. Due to this integration it works as an interface between different subsystems (Baddeley, 2000). This new component doesn’t have the same empirical support than the original ones (Alloway, Gathercole, Willis & Adams, 2004; Repovs & Baddeley, 2006), so most WM research is based on the original model.

Another line of research has studied maintenance in the modal stores, and maintenance plus concurrent processing separately, sometimes referred as short-term and working memory, respectively (e.g. Baddeley, 1992, 2007; Conway *et al.*, 2002; Engle *et al.*, 1999; Gathercole & Baddeley, 1989; Gathercole & Hitch, 1993; Papagno & Vallar, 1992; Swanson & Howell, 2001; Tillman, Nyberg & Bohlin, 2008). Verbal information storage in the PL is assessed as verbal short term memory (VSTM), and the capacity to process verbal information while storing in the PL, is termed verbal working memory (VWM). The same happens when the information modality is visuo-spatial: visuo-spatial short term memory (VSSTM) or visuo-spatial working memory (VSWM) is assessed. Within VSWM a subdivision between visual WM and spatial WM (Baddeley & Logie, 1999; Logie, 1995; Logie & Pearson, 1997) has been suggested.

This debate has inspired several studies about the fractioning and development of WM in children. Chua and Maybery (1999) administered a verbal short term span task, a spatial one, and simple verbal and spatial processing speed tasks (speed of articulation, speed of tapping, and two simple search tasks), to a sample of school-aged children. Since partial correlation and regression analyses showed that age, articulation, and speed contributed to around ninety percent of the variance in verbal and spatial spans, regardless of modality, they concluded that a common source of development sustained WM growth. Further analyses of timing-of-recall in the spatial span task promoted the view that a common process underlies WM development, whereas other processes or structures would be age-unrelated. On the other hand, with a different approach, Gathercole *et al.* (2004) administered 9 tasks -three verbal storage tests, three visuo-spatial storage tests, and three processing and storage verbal tests- in four age groups: 6-7 years, 8-9 years, 10-12 years, and 13-15 years, to test two WM models. The first one was a two factor model, in which one factor included all six verbal tasks, and the second factor had the visuo-spatial tasks. The second model corresponded with Baddeley and Hitch original model (1974), but the factor that represented the CE only included verbal tasks. They found that the model that had better fit indexes in confirmatory factor analyses was the three factor model for all age groups. Alloway, Gathercole and Pickering (2006) administered the Automated Working Memory Assessment Battery (Alloway, Gathercole & Pickering, 2004) -three VSTM, three VWM, three VSSTM, and three VSWM- to four age groups (4-6 years, 7-8 years, and 9-11 years). Seven models were compared using Confirmatory Factor Analysis. One of these models comprised three factors, and proposed that the storage factors included both storage tests as well as processing tests, and that the processing tests were also included in a third processing factor. Results showed that this model had better fit indexes for the two oldest groups as well as for the whole sample. For the 4-6 years old group there were no significant differences between this new model and the classical three factors model which represented Baddeley and Hitch's classic model.

So then, WM seems to acquire a more complex structure along childhood, but the evidence is scarce and presents mixed results, such as whether it conforms to the classic Baddeley and Hitch's model. The aim of this study is to contribute to the debate of WM structure in children, assessing if WM structure changes across childhood and if it does, to explore how it changes. Following the different theoretic approaches mentioned above, four models were tested using confirmatory factor analysis: 1) WM as an unitary model, with no subcomponents (Model 1); 2) WM composed by two subsystems, one verbal and one visuo-spatial (Model 2); 3) WM divided in three factors, a verbal low executive demand subsystem, a visuo-spatial low executive demand subsystem, and domain-unspecific high executive demand subsystem (Model 3); and 4) WM com-

posed by four factors, two modality specific storage systems, one verbal and one visuo-spatial, and two processing factors, one verbal and one visuo-spatial (Model 4).

Method

Participants

One-hundred and eighty monolingual Spanish-speaking children (103 female -57.2%, and 77 male) within a purposive sample participated on the study. They belonged to three age groups ($n = 60$ ss. each): 6-, 8-, and 11-years old. The younger group had a mean age of 80.04 months ($SD = 3.26$). The 8-years old group had a mean age of 102.12 months ($SD = 3.24$). The older group had a mean age of 140.07 months ($SD = 2.89$). Distribution of gender by group is shown in Table 1.

Table 1
Age and gender distribution

	Age							
	6		8		11		All	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>N</i>	%
Female	25	41.7	35	58.3	43	71.7	103	57.22
Male	35	58.3	25	41.7	17	28.3	77	42.78
Total	60	100	60	100	60	100	180	100

The participants represent a sample of convenience. Children attended, and were tested at, two middle-class public elementary-level schools in the city of Buenos Aires.

Parents were invited to an informative meeting about the study, after which informed consent was solicited in order to allow their children to participate. A written devolution was provided for each child's parents.

Possible participants with a diagnosed psychiatric or neurological condition, language or hearing impairment, or a history of academic failure (repeating course) were excluded from the study. This information was provided by the school registers.

Materials

Automated Working Memory Assessment battery test (AWMA; Alloway, 2007; Injoque-Ricle *et al.*, 2011). This battery is composed by twelve WM tasks and allows to assess all aspects of this memory system. The battery is fully automated, computer-administered. Instructions, as well as verbal stimuli are presented aurally, thereby excluding reading requirements. It includes three low executive demand verbal storage tasks (*Digit recall*, *Word recall*, and *Nonword recall*), three low executive demand visuo-spatial storage tasks: (*Dot Matrix*, *Block recall*, and *Mazes Memory*), three high executive demand verbal processing tasks (*Listening recall*, *Counting recall*, and *Backward digit recall*), and three high executive demand visuo-spatial processing ones (*Odd one out*, *Mister X*, and *Spatial Span*). In *Digit recall*, *Word recall*, and *Nonword recall*, the child has to recall a sequence of numbers, words or non-words, respectively, in the correct order. In *Dot matrix*, a sequence of red dots appears on a white matrix and the child has to point

the squares of the matrix on which each dot appeared, in the exact same order. *Block recall* has the same procedure than *Dot Matrix*; the child sees on the computer screen a board with nine cubes, located randomly, then some of the cubes are touched by an examiner, and the child has to reproduce the touches in correct order. In *Mazes memory*, the child sees a two-dimensional maze with a path drawn on it, and immediately has to reproduce the path, tracing it with his or her finger. In *Listening recall*, the child listens to a series of short sentences and has to decide whether they are true or false, and then has to recall the last word of each sentence on the exact order. *Counting recall* shows a series of dots and arrows appears on the computer screen and the child has to count aloud one by one all the dots, and finally, recall the total number of dots that appear on each trial, in correct order. *Backward digit recall* presents sequences of numbers and the child has to recall them in reverse order. *Odd one out*, shows sets of three shapes on the computer screen, two are the same and the third one is different. The child has to indicate which one is the odd one out, and after a certain amount of sets are presented, they have to point to the place in which the odd figure was presented, in the exact order. In *Mister X*, sets of two stick people figures are presented, one with a yellow hat and the other with a blue one, and both with a red dot in one of their hands. The figure with the blue hat can appear rotated in six possible positions. The child has to say whether they have the dot in the same hand or in a different one, and then, in a picture with six compass points, has to point the location of the red dot in sequence. *Spatial span* shows sets of two arbitrary shapes, one with a red dot on top of it, and one of them can be rotated in three possible positions. First, child has to say if the shape with the red dot is the same or the opposite than the one without the dot, and then, has to point in sequence the location of the dot in a three compass points. Each AWMA task has increasing difficulty levels, with six items each. When the child fails at least in three items of the same level, the task is discontinued and the next one is administered.

Procedure

Children completed the AWMA in an individual session lasting approximately 40 minutes, in a quiet office at their school. The order of the tasks was the standard postulated by the authors of the test: *Digit recall*, *Dot matrix*, *Listening recall*, *Odd one out*, *Word recall*, *Mazes memory*, *Counting recall*, *Mister x*, *Nonword recall*, *Block recall*, *Backward digit recall*, and *Spatial recall*.

Data analysis

In order to assess the structural organization of WM in the three group ages a confirmatory factor analysis (CFA) was conducted using the AMOS c.5.0 software (Arbuckle, 2003). CFA is a statistical method used to test the goodness of fit of a theoretical model to the empirical data (Arbuckle, 2003; Hair, Anderson, Tatham, & Black, 1998). Analyses were carried out

using the maximum likelihood estimation, focusing on the factor score weights, reliability and model fit indexes for each one of the tested models (Arbuckle, 2003; Harrington, 2008).

The model fit indexes used were: *Chi Squared* (χ^2), *Comparative Fix Index (CFI)*, *Tucker-Lewis Index (TLI)* and *Root Mean Squared Error of Approximation (RMSEA)* (Bollen, 1990; Kline, 1998). *Chi Squared* is a goodness-of-fit measure base on the comparison between the covariance matrix of a proposed model and the covariance matrix of the data. It shouldn't be significant if there is a good model fit (Hu & Bentler, 1999). *CFI* compares the fit of the existing with the fit of a null model which assumes the latent variables in the model are uncorrelated. Its value has to be at least .90 (Schumacker & Lomax, 1996). *TLI* is one of the goodness-of-fit measures less affected by the sample size because it doesn't include the degrees of freedom of none of the models in its equation. By convention, values equal or over to .90 indicate a good fit of the model (Hair *et al.*, 1998). *RMSEA* is a measure of approximate fit with an attempt to remove the effects produced by the degrees of freedom and the sample size. The cutoff of a good model fit is suggested to be equal or lower to .06 (Hu & Bentler, 1999).

Even if the number of subjects by age group of this study ($n:p$) might be considered small, according to Cattell (1978), a ratio of $n:p$ between 3 to 6 is accepted, and following Gorsuch (1983), if $n:p = 5$ this analysis can be conducted.

Pearson's correlation analysis among all AWMA subtests was conducted on the complete sample and within each age group to assess the relationships between the tasks.

Results

Table 2 showed the descriptive statistics for all the AWMA tasks. When normality wasn't reached the scores were transformed to its natural logarithm. For the 6-year old group the transformed variables were: *Counting recall*, *Backward digit recall*, and *Odd one out*. For the 8-years-old group: *Listening recall* and *Mister X*. For the 11-years old group, *Digit recall*, *Word recall*, *Mazes memory*, *Listening recall*, and *Backward digit recall* were transformed. And in the general sample, *Digit recall*, *Mazes memory*, *Listening recall*, *Backward digit recall*, and *Mister X* required normalization.

Pearson's correlation analysis with the complete sample ($N = 180$) shows that all tasks have a positive significant correlation between each other (Table 3).

At 6-years old, the following correlations were observed. When analyzing verbal low executive demand tasks (*Digit recall*, *Word recall*, and *Nonword recall*), significant correlation is only observed between *Digit recall* and *Nonword recall* ($r = .27, p < .05$), and between *Digit recall* and some of the rest of the AWMA tasks (see Table 3). When analyzing correlations within the low executive demand tasks (*Dot matrix*, *Block recall*, and *Mazes memory*), a high significant correlation between *Dot matrix* and *Block recall* ($r = .77, p < .01$), was observed, and a significant but low correlation was found

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Table 2
Descriptive statistics for AWMA subtests

	6-years old				8-years old				11-years old				All			
	<i>M</i>	<i>SD</i>	<i>Sk</i>	<i>K</i>	<i>M</i>	<i>SD</i>	<i>Sk</i>	<i>K</i>	<i>M</i>	<i>SD</i>	<i>Sk</i>	<i>K</i>	<i>M</i>	<i>SD</i>	<i>Sk</i>	<i>K</i>
Digit Recall	19.87	3.36	0.298	-0.524	23.33	3.12	0.232	-0.503	26.87	4.17	0.664	0.471	23.36	4.568	.452	.419
Word Recall	14.78	3.74	0.039	-0.507	17.87	4.15	-0.193	-0.770	19.25	4.85	-0.969	3.209	17.30	4.639	-.218	.299
Nonword Recall	8.15	2.87	-0.107	-0.860	8.87	3.16	-0.074	0.005	11.22	3.66	0.176	-0.134	9.41	3.485	.254	.099
Dot Matrix	15.83	4.34	0.193	0.560	20.77	4.63	0.171	0.106	24.95	4.70	0.128	-0.035	20.52	5.874	.121	-.230
Block Recall	14.45	4.91	0.278	-0.202	19.93	4.46	0.156	0.185	25.47	4.16	0.029	0.817	19.95	6.370	-.082	-.444
Mazes Memory	10.38	6.51	-0.071	-1.012	20.02	4.66	-0.183	-0.353	25.55	4.30	-1.305	5.271	18.65	8.166	-.584	-.370
Listening Recall	3.48	3.22	0.281	-0.968	8.10	3.70	0.815	0.375	11.83	4.06	0.686	0.626	7.81	5.011	.412	.058
Counting Recall	11.27	4.21	0.863	1.041	15.55	3.99	0.137	0.053	19.77	4.53	-0.289	0.075	15.53	5.476	.160	-.597
Back. D. Recall	6.63	3.04	0.306	1.870	9.28	2.82	0.369	0.085	14.03	4.07	0.818	1.982	9.98	4.532	.681	1.186
Odd One Out	10.80	4.74	0.950	1.457	14.07	4.31	0.009	-0.081	18.95	4.38	-0.279	1.439	14.61	5.580	.128	-.433
Mister X	4.57	3.02	0.409	0.514	7.05	3.40	1.594	4.310	11.27	4.62	0.291	-0.051	7.63	4.644	.827	.686
Spatial Span	9.05	4.96	0.618	-0.008	12.48	5.57	-0.422	-0.582	18.50	4.30	-0.360	0.700	13.34	6.306	-.104	-.799

Note. *M*: Mean; *SD*: Standard Deviation; *Sk*: Skewness; *K*: Kurtosis

between *Dot matrix* and *Mazes memory* ($r = .25, p < .05$). With the rest of the tasks correlations were also found (see Table 3). Within verbal high executive demand tasks (*Listening recall*, *Counting recall*, and *Backward digit recall*), only a correlation between *Counting recall* and *Backward digit recall* was found ($r = .30, p < .05$). Regarding the rest of the other AWMA tasks, some correlations were also found (see Table 3). Finally, within the visuo-spatial high executive demand tasks (*Odd one out*, *Mr. X*, and *Spatial span*), significant correlations were observed between *Odd one out* and *Spatial span* ($r = .38, p < .01$) and between *Mr. X* and *Spatial span* ($r = .27, p < .05$) (Table 3).

At the 8-years old group, within the verbal low executive demand tasks only a significant correlation between *Digit recall* and *Nonword recall* was observed ($r = .43, p < .01$). Significant correlations with other AWMA tasks were also found (see Table 4). When analyzing the associations between the visuo-spatial low executive demand tasks, *Dot matrix* had significant correlations with *Block recall* ($r = .69, p < .01$), and with *Mazes memory* ($r = .36, p < .01$), and *Block recall* with *Mazes memory* ($r = .36, p < .01$). This tasks also have significant correlations with other tasks of the WM battery (see Table 4). Regarding the verbal high executive demand tasks, *Counting recall* showed

Table 3
Pearson's correlations among AWMA subtests for the complete sample and for the 6-years old group

	1	2	3	4	5	6	7	8	9	10	11	12
1. Digit Recall	.	.31**	.49**	.51**	.57**	.48**	.42**	.59**	.57**	.50**	.39**	.47**
2. Word Recall	-.05	.	.28**	.29**	.32**	.31**	.15*	.34**	.24**	.35**	.26**	.30**
3. Nonword Recall	.27*	.16	.	.31**	.41**	.22**	.28**	.38**	.32**	.41**	.27**	.35**
4. Dot Matrix	.21	-.13	.10	.	.81**	.54**	.46**	.66**	.55**	.70**	.50**	.60**
5. Block Recall	.20	-.13	.01	.77**	.	.57**	.50**	.76**	.60**	.73**	.58**	.67**
6. Mazes Memory	.14	.02	.04	.25*	.23	.	.27**	.55**	.49**	.51**	.49**	.52**
7. Listening Recall	-.02	-.10	-.23	.14	.04	.14	.	.54**	.49**	.48**	.41**	.47**
8. Counting Recall	.27*	.02	.10	.53**	.51**	.30*	.21	.	.64**	.72**	.53**	.63**
9. Backward Digit Recall	.34**	-.18	.08	.21	.14	.13	.17	.30*	.	.57**	.47**	.61**
10. Odd One Out	.29*	.06	.16	.53**	.49**	.21	.14	.50**	.11	.	.54**	.64**
11. Mr. X	.03	.03	-.25	.20	.24	.26*	.11	.30*	.15	.12	.	.55**
12. Spatial Span	.08	-.09	.12	.36**	.51**	.29*	.07	.34**	.31*	.38**	.27*	.

Note. *N* = 180; 6-years old *n* = 60

Complete sample correlations are shown above the diagonal. 6-years old group correlation are shown below the diagonal.

** $p < .01$; * $p < .05$

Table 4
Pearson's correlations among AWMA subtests for the 8-years old group and the 11-years old group

	1	2	3	4	5	6	7	8	9	10	11	12
1. Digit Recall	.	.10	.43**	.08	.20	.06	.20	.26*	.11	-.04	.11	.22
2. Word Recall	.18	.	.20	.22	.18	.19	.01	.13	.07	.25	.12	.12
3. Nonword Recall	.44**	.18	.	.13	.37**	.07	.28*	.31*	.05	.23	.22	.18
4. Dot Matrix	.25	.04	.12	.	.69**	.36**	.30*	.64**	.23	.53**	.34**	.34**
5. Block Recall	.28*	.13	.32*	.54**	.	.36**	.41**	.70**	.24	.54**	.49**	.32*
6. Mazes Memory	.24	.15	-.07	.25	.24	.	.05	.36**	.37**	.47**	.44**	.44**
7. Listening Recall	.35**	-.10	.36**	.15	.28*	.10	.	.45**	.20	.35**	.24	.38**
8. Counting Recall	.40**	.20	.23	.18	.50**	.29*	.37**	.	.39**	.61**	.35**	.45**
9. Backward Digit Recall	.34**	.08	.23	.32*	.50**	.16	.43**	.52**	.	.33*	.19	.34**
10. Odd One Out	.30*	.19	.36**	.54**	.61**	.26*	.28*	.55**	.56**	.	.41**	.29*
11. Mr. X	.15	.10	.33*	.23	.33*	.20	.22	.27*	.28*	.50**	.	.41**
12. Spatial Span	.14	.12	.18	.34**	.48**	.13	.23	.44**	.47**	.65**	.36**	.

Note. 8-years old group: $n = 60$; 11-years old group: $n = 60$

8-years old group correlations are shown above the diagonal. 11-years old group correlations are shown below the diagonal.

** $p < .01$; * $p < .05$

significant correlations with *Listening recall* ($r = .45, p < .01$) and *Backward digit recall* ($r = .39, p < .01$). Significant correlations with the rest of the tasks are shown in Table 4. Finally, within the visuo-spatial high executive demand tasks, all tasks showed significant correlations with each other, and also with other tasks from the battery (Table 4).

At 11-years old, within the verbal low executive demand tasks, only a significant correlation between *Digit recall* and *Nonword recall* ($r = .44, p < .01$) was found, with the exception of the correlations found with the rest of the AWMA tasks (see Table 4). Regarding the visuo-spatial low executive demand tasks, also one significant correlation was found

within this task group, and was between *Dot matrix* and *Block recall* ($r = .54, p < .01$). For the significant correlations found with the other AWMA tasks see Table 4. When observing the associations within the verbal high executive demand tasks, *Listening recall* showed a significant correlation with *Counting recall* ($r = .37, p < .01$), and *Backward digit recall* ($r = .43, p < .01$), and *Counting recall* with *Backward digit recall* ($r = .52, p < .01$). Significant correlations with the rest of the WM tasks were also found and are shown in Table 4. Regarding the visuo-spatial high executive demand tasks, all have significant correlations between each other, and with other WM tasks (Table 4).

Table 5
Goodness-of-Fit statistics for the different models for each group

	Age	χ^2	<i>d.f.</i>	<i>Sig.</i>	<i>CFI</i>	<i>TLI</i>	<i>RMSEA</i>
Model 1	6	85.564	54	.004	.786	.738	.100
	8	71.234	54	.058	.914	.895	.074
	11	68.162	54	.093	.926	.909	.067
	All	101.860	54	.000	.959	.950	.070
Model 2	6	71.290	53	.048	.876	.845	.076
	8	69.221	53	.067	.919	.899	.072
	11	58.103	53	.293	.973	.967	.040
	All	86.740	53	.002	.971	.964	.060
Model 3	6	73.297	51	.022	.849	.804	.086
	8	61.186	51	.155	.949	.934	.058
	11	56.728	51	.270	.970	.961	.044
	All	67.413	51	.062	.986	.982	.042
Model 4	6	66.265	48	.041	.876	.829	.080
	8	60.253	48	.110	.939	.916	.066
	11	46.786	48	.523	1.000	1.000	.000
	All	60.815	48	.101	.989	.985	.039
Model 5	6	82.769	53	.006	.796	.748	.098
	8	62.926	53	.165	.951	.938	.056
	11	60.746	53	.217	.959	.949	.050
	All	85.113	53	.003	.973	.966	.058

At 6-years old CFA showed that none of the proposed model adjusted to the data. Table 5 shows the models fit indexes for this age group.

In the 8 years old subsample, the model that had the best fit indexes was the three factor model ($\chi^2 = 61.186, p = .155; CFI = .949; TLI = .934; RMSEA = .058$). Despite the absence of significant differences between the three and four factor model, ($\Delta \chi^2 = 0.993, p = .80$), the model fit indexes for latter ($\chi^2 = 60.253, p = .110; CFI = .939; TLI = .916; RMSEA = .066$) weren't as good as those for the three factor. Table 3 shows the model fit indexes for this age group. The factor score weight values found are shown in Figure 1a. Regarding correlations among factors, significant and positive correlations were only found between Factor 2 and Factor 3 ($r = .935, p = .003$). Due to the high correlation between Factor 2 and 3, a new model was tested in which both factors were turned into one (Figure 1b). On this new two factor model, one factor grouped the three verbal storage tests and the other the visuo-spatial storage tasks and all the concurrent processing tasks. This model (Model 5) had slightly better fit indexes than Model 3 and it showed not significant differences ($\Delta \chi^2 = 1.743, p = .42$).

Model 5 was also tested in the 6-years old subsample and didn't had good fit indexes (see Table 3).

Figure 1
Factor loading and factor covariance for the three-factor model (A) and Model 5 (B) for the data for 8-years old groups

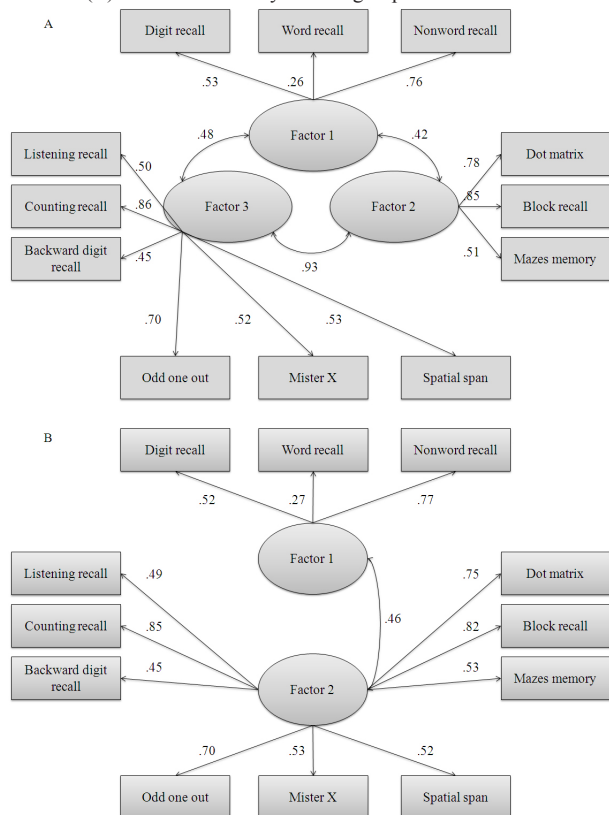


Figure 2
Factor loading and factor covariance for the four-factor model for the data for 11-years old groups

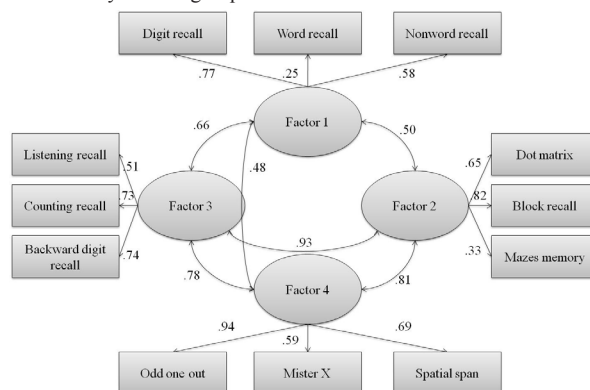
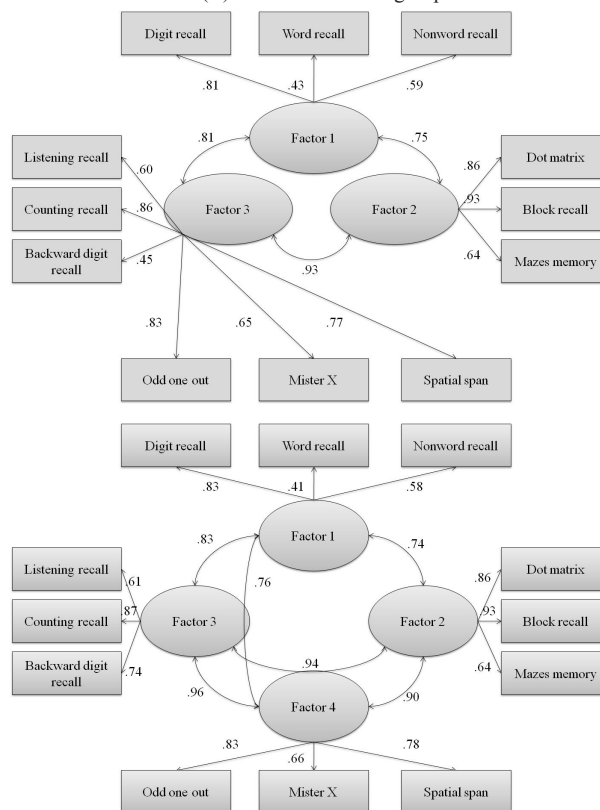


Figure 3
Factor loadings and factor covariances for the three-factor model (A) and four-factor model (B) for the data for all groups.



At 11-years old, the second, third, fourth, and fifth model showed good fit indexes. Among those models, the one that presented the best indexes was the four factors model ($\chi^2 = 46.786, p = .523; CFI = 1.000; TLI = 1.000; RMSEA = .000$). This model was significant different from Model 2 ($\Delta \chi^2 = 11.317, p = .045$), Model 3 ($\Delta \chi^2 = 9.942, p = .019$), and Model 5 ($\Delta \chi^2 = 13.960, p = .016$). Table 3 shows the resulting fit indexes for the 11-years old group. The factor score weight values found are

shown in Figure 2. Regarding the correlations among factors, the following significant and positive correlations were found: Factor 1 and Factor 2 ($r = .502, p = .014$), Factor 1 and Factor 3 ($r = .663, p = .003$), Factor 1 and Factor 4 ($r = .482, p = .020$), Factor 2 and Factor 3 ($r = .739, p = .001$), Factor 2 and Factor 4 ($r = .815, p = .001$), and Factor 3 and Factor 4 ($r = .778, p = .002$).

The same analyses were conducted with the complete sample. Both Model 3 and Model 4 had good fit indexes (three-factor model: $\chi^2 = 67.413, p = .06$; $CFI = .986$; $TLI = .982$; $RMSEA = .042$; four-factor model: $\chi^2 = 60.815, p = .10$; $CFI = .989$; $TLI = .985$; $RMSEA = .039$) (see Table 3), and significant difference between them weren't found ($\Delta \chi^2 = 6.598, p = .085$). Figure 3 shows the resulting models.

Discussion

The aim of this study was to provide evidence regarding WM structure in children of different ages (6-, 8-, and 11-years old) and explore whether this system has a changing structure across childhood. For this purpose four models were originally tested. The first proposed model was a unitary and non-specific model. The second one was based on the idea of dissociation between the modality of the information being stored or processed by WM, resulting in a two factor model, verbal and visuo-spatial. The third model that was proposed included two low executive demand storage systems -a verbal and a visuo-spatial one- and a high executive demand system that includes both verbal and visuo-spatial processing tasks, inspired in Baddeley and Hitch's original model (1974). The last of the models proposed a division between storage and processing resources within each modality, which implies fractioning WM in four factors: a verbal short term memory factor, a verbal working memory factor, a visuo-spatial short term memory factor, and a visuo-spatial working memory factor (e.g. Alloway, Gathercole, Willis *et al.*, 2004; Baddeley, Thomson, & Buchanan, 1975; Baddeley & Wilson, 1985; Conway *et al.*, 2002; Gathercole & Baddeley, 1989; Gathercole & Hitch, 1993; Papagno, Valentine & Baddeley, 1991; Papagno & Vallar, 1992; Swanson, 1994; Unsworth & Engle, 2007).

Correlation analysis supports the idea of a WM with a changing structure across childhood. At 6-years old the few significant associations that were found were low. The verbal low executive demand tasks didn't have an association with almost any task. *Digit recall* was the only one that showed associations with one verbal low executive demand task (*Nonword recall*), and two verbal high executive demand tasks (*Counting recall* and *Backward digit recall*). Furthermore, *Listening recall* didn't show any association with any other verbal task of the battery. On the other hand, *Counting recall* showed more associations with the visuo-spatial tasks than with the verbal ones. At 8-years old even if the correlations are slightly stronger than at 6-years-old, and more significant correlations were found (e.g. *Listening recall* and *Counting recall*), verbal low execu-

tive demand tasks still didn't show associations with the rest of the tasks, and the verbal high executive demand tasks showed associations with both visuo-spatial low and high executive demand tasks rather than with the verbal low executive demand ones. Finally, at 11-years old, verbal low and high executive demand tasks are starting to show significant associations and the strength of the associations between the verbal high executive demand tasks and the visuo-spatial high executive demand tasks are becoming weaker.

The CFA conducted with the entire sample showed that two models (Model 3 and 4) had good fit indexes and we didn't found significant differences between them, suggesting that in different ages during childhood a different structure of WM could be observed. Regarding developmental variations, a different factorial solution was found for two age groups. For the 6-years old group none of the proposed models had good model fits, suggesting that at this early age WM structure is not clear yet. At the age of 8, initially the model that had better fit indexes was the three factor model, suggesting that WM is composed by a verbal low executive demand storage factor, a visuo-spatial low executive demand storage factor, and a high executive demand processing factor. Nevertheless the high correlation observed between the factor that grouped the processing tasks and the visuo-spatial storage tasks lead to test a new two factor model: one factor included the verbal storage tasks and the second one the visuo-spatial tasks and the verbal and visuo-spatial processing tasks. This resulting model (Model 5) didn't had significant differences with the previous one (Model 3) and had better fit indexes. These results might indicate that at this age the visuo-spatial storage tasks (*Dot matrix*, *Block recall*, and *Mazes memory*) demand some executive resources. This suggest that at this age group we can't discuss a structuring of WM. At 11-years, even if the two, three, and four factor model had good fit indexes, the four factor model had the best fit indexes, which were significant different from the fit indexes of the other two models. According Model 4, WM is composed by a verbal low executive demand storage factor -VSTM-, a visuo-spatial low executive demand storage factor -VSSTM-, a verbal high executive demand processing factor -VWM- and a visuo-spatial high executive demand processing factor -VSWM-. These last two factors suggest a fractioning within the domain-unspecific factor proposed in Models 3 regarding the modality of the information that is being processed, or a further specialization of processing resources according to modality.

Gathercole *et al.* (2004) tested a two factor model that separated VWM of VSWM, and a three factor model inspired on Baddeley and Hitch's original model, in a sample of children and adolescents from 6- to 15-years old. They found that in all group ages WM had a three factor structure. The difference between the findings of the Gathercole *et al.* (2004) study and the present study may obey the fact that in our study visuo-spatial processing tasks were included, while the study conducted

by Gathercole *et al.* (2004) only included verbal processing tasks to represent the CE. The tasks included in our analysis might influence and change the structure of the factors and their correlations.

Alloway *et al.* (2006) conducted a study in which using the same tests tested the three- and four-factor model proposed in the present study, along with a different three-factor model in which each storage factor and the processing factor shared their participation in the processing tests with the same modality as the storage factor. Thus, the factor that represented the CE grouped verbal and visuo-spatial processing tasks, the factor representing the PL grouped the verbal storing tests and the verbal processing ones, and the VSSP representing factor grouped both the visuo-spatial storing tests and the visuo-spatial processing tests. This model, which wasn't tested on the present study due to statistical limitations, is the one which had better fit indexes.

The results from this study suggest that WM structure changes among the tested group ages, showing a progressive differentiation and specialization within WM through childhood. Between the ages of 6 and 8 this memory system would initiate its structuring, since at 6 years-old non structure was found, and at 8 years-old the fact that more than one model had good fit indexes and didn't differentiate statistically from each other indicates an undefined structure. Near adolescence, a clear structure is found and indicates a complex structure within this memory system.

Further research could explore the cognitive processes contributing to structure changes in WM during childhood found on this study. On the other hand, research with adolescents, young adults, and adults could be done to explore whether the structure found at the age of 11 still holds or if it evolves to a different and more complex structure. Regarding WM structure and socioeconomic status, research in different socio-economic status should be conducted, since differences in WM development have been reported (Hackman & Farah, 2009; Lipina, Martelli, Vuelta, Injoque-Ricle & Colombo, 2004).

Even though different authors justified the sample sizes used in this study -*n:p* ratio- (Cattell, 1978; Gorsuch, 1983), this results should be considered as exploratory and future studies with bigger sample size should be conducted to confirm these results. Also, with a bigger sample size, the model that had better fit indexes in the study of Alloway *et al.* (2006) should be tested to establish whether it has better fit indexes than the models resulting from this study.

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