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Is it a Small World After All? Investigating the Theoretical Structure of Working Memory Cross-Nationally

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Abstract

To our knowledge, this is one of the first studies to test different theoretical models of working memory in childhood based on a computerized assessment. We tested this across several countries: Argentina, Brazil, Canada, Italy, and UK. The present study addressed the wider macro-cultural context and how this impacts working memory. We used two economic indices (GDP and PPP) to characterize the participating countries and ranked the countries based on the Global Index of Cognitive Skills and Educational Attainment. Children between 5 and 10 years completed the same set of short-term and working memory tests. There were two main findings. First, there was a similar pattern in verbal working memory across countries, which suggests that this skill may be relatively consistent across different cultural groups. In contrast, the pattern for visuo-spatial working memory was different across countries, which may explained by cultural differences and educational rankings of the countries. The second

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main finding was that both a domain-general model (3-factor) and a domain-specific model (4-factor) provided a reasonably good fit with the data, there was the high relationship between the verbal and visuo-spatial working memory constructs across the countries in the latter model. Thus, it may be a more parsimonious choice to rely on a three-factor model. The data also suggest culture-similar patterns in a computerized assessment of working memory.

Keywords

working memory – cross-national – income distribution – educational rankings – culture

Highlights

- The aim was to investigate whether the theoretical model of working memory is consistent across different countries: Argentina, Brazil, Canada, Italy, and UK.
- We used macro-factors to characterize the participating countries such as economic indices (GDP and PPP) and the Global Index of Cognitive Skills and Educational Attainment.
- Children from some countries outperformed those from other countries in measures of short-term memory, but not verbal working memory.
- The better fitting model across all countries was one comprised of domain-specific working memory constructs for verbal and visuo-spatial tests (4-factor model), rather than a model with a shared construct for both verbal and visuo-spatial working memory tests (3-factor model).

Working memory is our ability to process and remember information for a brief period. However, there is a debate regarding the theoretical structure of working memory. An early view, based on Daneman and Carpenter's (1980) finding that a reading span task predicted Scholastic Aptitude Test (SAT) scores, is that working memory is a domain-specific skill, as both the reading span task and the SAT require reading (see Conway & Kovacs, 2013). Indeed, this domain-specific view of working memory has been supported in different ages: in childhood (Alloway, Gathercole, & Pickering, 2006); in young adults (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001); and across the lifespan (Alloway & Alloway, 2013).

However, there is an alternative model of working memory based on Turner and Engle (1989)'s finding that a complex span task that did not require reading (operation span task) predicted SAT scores just as strongly as reading span. Their results suggest that working memory could be represented as a domain-general skill. This view fits with an early model of working memory that suggests that a single factor — the central executive — is responsible for controlling resources and monitoring information processing across informational domains (Baddeley & Hitch, 1974; see Engle, Kane, & Tulhoski, 1999, for a review). This long-standing model also includes separable components for short-term memory, which is used for storing information: the phonological loop for verbal information, and the visuo-spatial sketchpad, for visual and spatial representations (see Baddeley & Logie, 1999, for a review). While this model of working memory has been supported by evidence from studies of children (e.g., Alloway, Gathercole, Willis, & Adams, 2004), adult participants, neuropsychological patients (see Baddeley, 1996), as well as neuroimaging investigations (Vallar & Papagno, 2003), the tasks used to measure working memory have primarily been verbal in nature, and have not included visuo-spatial measures (though see Kane et al., 2004).

There are other theoretical models of working memory that include contributing factors, such as processing speed, processing efficiency, time, and controlled attention. For example, when Bayliss et al. (2003) included processing efficiency, they found that complex span performance was independently affected by the domain-general processing efficiency, as well as the domain-specific storage capacity in their tasks. Likewise, Barrouillet et al., (2008) suggested a time-based resource-sharing model of working memory and the processing-storage trade-off. Unsworth and Engle (2007) suggest that working memory requires not only active maintenance of information, but also attentional mechanisms to search long-term knowledge stores for relevant information.

Despite this rich source of knowledge regarding the theoretical framework of working memory, the majority of this research has been confined to first-world Western populations. Thus, the aim of the present study was to investigate the theoretical model of working memory across different countries. We were interested in two country-specific influences that can influence working memory development — income distribution and education rankings. The majority of research on cross-national differences has targeted the micro-context or proximal factors (e.g, the immediate and direct environment), focusing primarily on socioeconomic status (SES) or maternal education. The pattern of findings suggests that an age-based effect where young children appear relatively unaffected by SES background, while older children seem more affected. These studies have been conducted in different countries, for example in UK with 4–5 year olds, using maternal education (Alloway, Gathercole, Willis, & Adams, 2004) and zipcode data as indices of SES (Alloway, Alloway, & Wootan, 2014); in Brazil with 6–7 year-olds using household income, maternal education, and occupation as SES indices (Engel, Santos, & Gathercole, 2008); and with Dutch 4 year olds with maternal education as an SES indicator (Messer, Leseman, Mayo, & Boom 2010). In contrast, studies of older children found differences in spatial and working memory, as a function of SES (Evans & Shamberg; 2009, with American 17-year-olds). The disparity in the effect of income on the micro level between age groups may be explained by the chronic stress hypothesis, which states that prolonged exposure to poverty results in chronic stress, which in turn impacts areas of the brain associated with working memory, the prefrontal cortex (Lupien et al., 2006; Lupien, Maheu, Tu, Fiocco, & Shrmaek 2007).

Furthermore, there is a link between a lack of a stimulating environment and poorer cognitive skills. A low-stimulating environment is typically defined as less exposure to the arts, such as music, dance, and drama (Bracey, 2006), to museums, theaters, libraries, and culturally enriching experiences (Bradley & Corwyn, 2002), and smaller and fewer designated play areas in the home (Evans, 2004). Conversely, children who are raised in a highly stimulating environment develop skills that increase their likelihood for academic success, such as attentional skills (Posner, Rothbart, Sheese, & Kieras, 2008), processing skills that facilitate sequential and procedural learning (Jonides, 2008), and reading (Wandell, Dougherty, Ben-Schachar, & Deutsch, 2008). Thus, it is possible that the lack of environmental resources characteristic of a low-SES environment, and not just the stress experienced, is a significant factor that contributes to lower academic performance.

While we have an emerging picture of working memory and SES across different cultures, there are few cross-national comparisons. The present study extends this research to address the wider macro-cultural context (distal factors) and how this may impact working memory performance. In order to characterized the participating countries on a similar scale, we used two economic indices. The first index was based on the rankings of countries sorted by their gross domestic product (GDP), derived from purchasing power parity (PPP) calculations. The theory behind PPP is that identical goods should have only one price in an efficient market. For example, a Big Mac should cost the same in the UK as in Italy or Singapore or South Africa. Using PPP is thought to provide a more useful comparison of differences in living standards as it accounts for the relative cost of living and the inflation rates of the countries.

The second country-specific influence that we were interested in is education rankings as discrepancies between different global environments can influence academic achievement (Barber, 2005). School performance has often been seen as an indicator of a nation's development and performance relative to other countries. Working memory is a key cognitive skill associated with learning (see Cowan & Alloway, 2008, for a review). For math outcomes, low working memory scores were closely related to poor performance on arithmetic word problems (Passolunghi & Mammarella, 2010; Swanson & Sachse-Lee, 2001) and poor computational skills (Bull & Scerif, 2001; Geary, Hoard, & Hamson, 1999). Working memory scores also predicted achievement growth in mathematics over a five-year period in typically developing grade-schoolers (Geary, 2011). Cross-cultural research in math skills in Italian children fits this overall trend that working memory is a unique predictor of mathematical concepts (Alloway & Passolonghi, 2011). With respect to the role of working memory in science achievement, research with high schoolers has indicated that there were strong links between working memory and science curriculum (Alloway, Banner, & Smith, 2010; Gathercole, Pickering, Knight, & Stegmann, 2004a).

The present study adds to the existing literature on the theoretical structure of working memory by extending the investigation to different national groups. To our knowledge, no other studies have conducted multiple developmental comparisons (>2) of working memory across different countries. In contrast, other fields have benefited from a long tradition of exploring the contribution of culture to memory performance. This knowledge is important because it can shed light on how nuances in cultural differences may result is differential allocation of cognitive resources.

We had a unique opportunity to investigate different theoretical models of working memory in a cross-national context in the following countries: Argentina, Brazil, Canada, Italy, and UK. We specifically tested two competing models of working memory — domain-specific or domain-general — based on a current and long-standing debate on this particular aspect (see Conway and Kovacs, 2013). All participating children completed the *same* set of working memory and short-term memory tests taken from the Automated Working Memory Assessment (Alloway, 2007). There were several distinctive elements about the tests used to measure working memory in the present study. First, verbal and visuo-spatial working memory was measured using complex span tasks involving processing and recall of information (see Conway et al., 2005, for a review of such tasks). In contrast, tasks involving only the recall of information were used to measure verbal and visuo-spatial short-term memory. While other models included processing efficiency (Bayliss et al., 2003) and attentional components, it was beyond the scope of the present study to include these as well. Second, the interval between the presentation of items was fixed to control for the effect of time-based forgetting (see Towse et al.; 1998). The automatization of stimuli presentation also minimized administrator error, which is an important factor as data were gathered across such large international populations. Third, there were multiple indicators for each memory factor, which leads to a more robust analysis of different theoretical models.

Method

Income Distribution

The participating countries represent a range of income distribution and educational ranking. Out of 180 countries, these are the GDP (PPP) rankings for the participating countries (World Bank, 2012): Argentina=73; Brazil=74; Canada=14; Italy=24; UK=21. The second economic index was the percentage of population living below the poverty line. The poverty line is defined as the minimum level of income identified as adequate in a given country. The current figure is $1.25 per day identified by the World Bank in 2008 (Ravallion, Chen, & Sangraula, 2009). Here is the percentage of the population living below the poverty line for the participating countries: Argentina=36%; Brazil=21%; Canada=9% (approximately); Italy=(not available); UK=14% (approximately).

Educational Rankings

These rankings were based on the Global Index of Cognitive Skills and Educational Attainment (Economist Intelligence Unit, 2012), which compares the performance of 39 countries in cognitive skills based on three internationally comparable education data: Programme for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS), and Progress in International Reading Literacy Study (PIRLS) scores in Reading, Math, and Science; and educational attainment (based on literacy and graduation rates). The scores are weighted (two-thirds cognitive skills and one-third educational attainment) and then normalized based on the sample to enable comparison across countries. The countries are ranked (out of 39) and allocated into one of five groups based on their z-scores and how far above or below the mean they fall. The UK is ranked 6 and Canada is tenth, and they both fall into Group 2 (*z*-scores between 0.5 and 1 above the mean). Italy is ranked 24 and is in Group 3 (*z*-score is between -0.5 and 0.5 from the mean). Argentina and Brazil are ranked 35 and 39 respectively, and fall into the lowest group (5; *z*-scores less than 1 below the mean).

Argentina

Bilingual-speaking (L1=Spanish, L2=Portuguese/English) children from Buenos Aires city were recruited from middle-class public schools and all lived in an urban area (*n*=119; *M* age=7.60 yrs; *SD*=11.52 mo; 50.4% boys). The duration of compulsory education is thirteen years and the mandatory age for starting school is around five years old (kindergarten). Children with a diagnosed psychiatric or neurological condition, language or hearing impairment, or had a history of academic failure (repeating course) were excluded from the study.

This information was provided by school reports. Some of these data were reported in Injoque-Ricle, Barreyro, and Burin (2012).

Brazil

We recruited 84 bilingual Portuguese/Spanish speakers from public (government) schools mainly at Assis city, a municipality in the state of São Paulo in Brazil (n=84, M age=8.55 yrs; SD=21.21 mo; 45.2% boys). The mandatory age for starting school is at six years old, and it is compulsory to complete three years of high school (the equivalent of completing the junior year in a North American high school). No children with visual or auditory problems participated of the study; children with neurological, psychiatric disorders or with learning disabilities were also not included in the sample. The primary caregiver of the participating children provided their highest educational level. A third of the Brazilian sample had completed 11 years of education (34.5%), while a further 25% had some college education. None of the primary caregivers were illiterate.

Canada

Students were recruited from mainstream schools in Western Ontario (n=183, M age=7.63 yrs; SD=16.41 mo; 44.8% boys). All students were monolingual English speakers and were from a variety of socioeconomic backgrounds. The duration of compulsory education that a child must be enrolled in school is 11 years, and the mandatory age for starting school is around six years old (kindergarten). In a survey given to the main caregiver, only 4% had no educational qualifications, while 52% had a college degree or vocational training.

Italy

Children were recruited from four mainstream schools located in the northwest of Italy (n=206, M age=8.00 yrs; SD=8.43 mo; 47.1% boys). The duration of compulsory education that a child must be enrolled in school is nine years, and the mandatory age for starting school is around six years old (kindergarten). Italy suffers from inequality in the distribution of wealth and resources with a gap between the wealthy north and impoverished south (over 65 percent of impoverished families live in southern regions; UNDP, 2006). However, the children in the present study were living in the north and the majority of parents came from professional homes that were predominantly middle class; though there were families from across the social spectrum. None of the participating children were receiving special education services or had behavioral problems.

UK

Children were recruited from both rural and urban schools in England (*n*=645, *M* age=7.78 yrs; *SD*=21.77 mo; 47.9% boys). The duration of compulsory education that a child must be enrolled in school is 12 years, and the mandatory age for starting school is around five years old (kindergarten). Schools included in the present study represent a range of low, middle, and high performance in the combined score of the national assessments in English, mathematics, and science that students sit in the final year of elementary education at the age of 10 or 11 (Department for Education and Skills, 2006). Based on information provided by the child's main caregiver, the average age at which the mother left school was 17 years, 46% had a college degree or vocational training, and only 6% had no educational qualifications. Some of these data were reported in Alloway et al., (2006).

Working Memory Tests

Verbal Memory

Twelve tests from the Automated Working Memory Assessment (AWMA; Alloway, 2007), a standardized computer-based battery, were administered. The three verbal short-term memory measures were digit recall, word recall, and nonword recall. In each test, the child hears a sequence of verbal items (digits, one-syllable words, and one-syllable nonwords, respectively), and recalls each sequence in the correct order.

The three verbal working memory measures were listening recall, backward digit recall, and counting recall. In the listening recall task, the child is presented with a series of spoken sentences, has to verify the sentence by stating 'true' or 'false', and recalls the final word of each sentence in sequence. In the backwards digit recall task, the child recalls a sequence of spoken numbers in reverse order. In the counting recall task, the child is presented with a visual array of red circles and blue triangles, counts the number of circles, and then recalls the tallies of circles. Test-retest reliabilities of the British AWMA for digit recall, word recall, nonword recall, listening recall, counting recall and backward digit recall are .89, .88, .69, .88, .83, and .86, respectively (Alloway, 2007).

Visuo-Spatial Memory

Three measures of visuo-spatial short-term memory were administered. In the dot matrix task, the child is shown the position of a red dot in a series of four by four matrices and recalls this position by tapping the squares on the computer screen. In the mazes memory task, the child is shown a maze with a red path drawn through it for three seconds and traces in the same path on a blank maze presented on the computer screen. In the block recall task, the child views a video of a series of blocks being tapped, and reproduces the sequence in the correct order by tapping on a picture of the blocks.

Three measures of visuo-spatial working memory were administered. In the odd-one-out task, the child views three shapes, each in a box presented in a row, and identifies the odd-one-out shape. The child then recalls the location of each odd one out shape, in the correct order, by tapping the correct box on the screen. In the Mr. X task, the child is presented with a picture of two Mr. X figures and identifies whether the blue Mr. X is holding the ball in the same hand as the yellow Mr. X. The blue Mr. X may be rotated. At the end of each trial, the child recalls the location of each ball in the blue Mr. X's hand in sequence, by pointing to an eight-point compass. In the spatial recall task, the child views a picture of two arbitrary shapes where the shape on the right has a red dot on it and identifies whether the shape on the right is the same or opposite of the shape on the left. The shape with the red dot may also be rotated. At the end of each trial, the child recalls the location of each red dot on the shape in sequence, by pointing to a three-point compass. Test-retest reliabilities are .85, .86, .90, 88, .84, and .79 for dot matrix, mazes memory, block recall, odd-one-out, Mr. X, and spatial recall respectively.

Composite scores were also calculated by averaging the raw scores of the three tests associated with each of the four memory components (verbal short term memory, visual short term memory, verbal working memory, visual short term memory). Further details of test reliability and validity for the UK version are reported in Alloway et al. (2006) and Alloway, Gathercole, Kirkwood, and Elliott (2008), respectively.

Translations

The English-language AWMA was presented using a speaker with a British accent for the British children and a speaker with a Canadian accent for the Canadian children. The AWMA was translated into Spanish (Argentina), Portuguese (Brazil), and Italian. These translations were undertaken by a bilingual speaker and then checked for accuracy and comprehension by independent native speakers. In a first phase, the written versions of the English and second language test materials were evaluated for accuracy by two neutral judges, fluent in both languages. In the second phase, only the translated tests were appraised for accuracy and comprehension by native speakers. Further information on the translations and test reliability can be found here: Spanish (Injoque-Ricle, Calero, Alloway, & Burin, 2011); Portuguese (Santos & Engel, 2008); and Italian (Alloway & Passolunghi, 2011).

TABLE 1 *Raw scores for all short-term and working memory tests as a function of country and age group.*

	Argentina n=119			Brazil n=84		
Measure	**Mean (SD)**	**Skew**	**Kur**	**Mean (SD)**	**Skew**	**Kur**
V STM: Digit recall	23.45 (4.42)	.40	.07	21.56 (4.86)	0.62	0.13
V STM: Word recall	17.17 (4.8)	−.27	−.58	17.78 (3.77)	−0.59	0.87
V STM: Nonword recall	9.82 (3.62)	.34	−.16	9.24 (3.39)	−0.33	−0.41
V STM: **Composite**	16.81 (3.48)	.29	−.10	16.20 (2.44)	−0.13	−0.54
V WM: Backward digit recall	9.95 (4.73)	.25	−.01	7.83 (3.75)	0.40	−0.42
V WM: Listening recall	7.75 (4.96)	−.60	−.45	6.20 (4.03)	−0.32	−0.38
V WM: Counting recall	15.88 (5.43)	−.04	−.21	12.51 (3.51)	0.35	−0.22
V WM: **Composite**	11.19 (4.59)	−.14	−.37	8.85 (3.00)	0.32	−0.65
VS STM: Dot matrix	20.65 (5.66)	.46	.24	15.88 (3.36)	0.04	−0.26
VS STM: Mazes memory	18.03 (8.89)	.21	−.43	13.61 (5.63)	−0.02	−0.87
VS STM: Block recall	20.57 (6.88)	.31	−.22	14.05 (3.99)	0.34	0.80
VS STM: **Composite**	19.75 (6.43)	.33	−.13	14.51 (3.32)	0.17	−0.17
VS WM: Odd-one-out	14.73 (5.65)	.20	−.06	11.17 (4.05)	0.11	−1.10
VS WM: Mr X	8.08 (5.37)	1.02	1.20	5.93 (3.58)	0.98	3.14
VS WM: Spatial recall	13.97 (5.85)	−.16	−.94	8.24 (4.40)	0.30	−0.20
VS WM: **Composite**	12.26 (5.04)	.55	.06	8.45 (3.10)	0.41	−0.52

Note: * V=verbal, VS=visuo-spatial; STM=short-term memory; WM=working memory; Kur=Kurtosis

Results

Cross-National Comparisons

There were no missing data points, as only fully completed tests were recorded. The mean standard scores were calculated for the sample as a whole for each measure as a function of age group (see Table 1). Country-specific patterns were investigated with a MANCOVA performed on four composite memory tests (verbal short-term memory, visuo-spatial short-term memory, verbal working memory, and visuo-spatial working memory), as a function of country (Argentina, Brazil, Canada, Italy, and the UK). Age in months (continuous variable) was entered as a covariate. The overall Hotelling's Trace group term was significant for country: $F(16, 4910)=54.94$, $p<.001$; $\eta 2p=.15$. Bonferroni

Canada n=183			Italy n=206			UK n=645		
Mean (SD)	Skew	Kur	Mean (SD)	Skew	Kur	Mean (SD)	Skew	Kur
26.42 (3.76)	0.11	1.78	23.02 (3.58)	−0.03	−0.15	23.53 (4.25)	0.31	1.15
21.77 (3.79)	−0.89	4.52	18.91 (3.51)	−0.72	0.10	14.34 (3.58)	0.15	0.16
14.37 (3.98)	0.03	−0.03	16.32 (4.55)	−0.15	0.39	9.68 (3.3)	0.05	−0.09
20.86 (3.24)	−0.14	1.01	19.42 (3.00)	−0.16	0.27	15.85 (3.08)	0.26	0.15
8.49 (3.02)	−0.08	1.20	9.69 (2.93)	0.37	0.23	7.56 (3.75)	0.10	−0.48
7.96 (3.52)	−0.18	−0.44	8.57 (2.77)	−0.29	−0.87	6.85 (3.23)	−0.20	−0.58
12.92 (4.37)	−0.06	0.49	15.01 (3.72)	0.03	0.40	12.73 (4.52)	−0.08	−0.17
9.79 (2.82)	−0.24	0.52	11.09 (2.24)	0.23	−0.37	9.05 (3.32)	−0.07	−0.56
18.03 (3.78)	0.30	0.08	17.95 (3.35)	0.28	−0.18	15.52 (3.78)	0.12	0.57
15.71 (5.48)	0.35	0.54	15.98 (4.70)	0.27	−0.34	10.03 (5.88)	0.17	−0.57
16.36 (4.41)	0.06	0.79	17.47 (3.91)	0.91	2.53	14.91 (4.10)	0.26	0.69
16.70 (3.81)	0.19	0.26	17.13 (2.93)	0.50	0.41	13.49 (3.88)	0.12	0.12
15.45 (4.24)	0.12	0.67	13.75 (3.47)	0.22	0.04	11.53 (3.99)	0.41	0.21
8.47 (3.50)	0.24	−0.01	7.47 (3.72)	0.33	−0.44	6.48 (3.56)	0.28	−0.40
11.33 (4.93)	0.15	0.40	11.18 (4.84)	−0.31	−0.29	9.65 (4.55)	−0.05	−0.23
11.76 (3.47)	0.07	0.03	10.80 (3.19)	−0.03	−0.56	9.22 (3.40)	0.14	−0.34

adjustment for multiple comparisons indicated significant country-based differences for each memory composite ($p<.02$). For verbal short-term memory, Canadian children performed better than children from the other countries (Argentina, Brazil, Italy, and UK); children from Italy outperformed children from the other countries, except for those from Canada. For visual short-term memory, the main pattern was that the British children performed worse those from other countries, except the Brazilians. Children from Brazil performed worse than those from Argentina. For verbal working memory, the only significant difference was that the Italian children outperformed those from Brazil. For visual working memory, children from Canada outperformed those from the other countries, while the Brazilian children scored worse than those from all other countries, except Argentina.

Theoretical Structure of Working Memory

The degree to which the data fit alternative models of working memory was tested formally using confirmatory factor analysis (CFA; Bentler, 2001; Bentler & Wu, 1995). This method provides a means of testing the adequacy of competing theoretical accounts of the relationships between measures, with each model specified in terms of paths between observed variables and latent constructs, and between constructs. A commonly used index of goodness of fit for each model is the χ^2 statistic, which compares the degree to which the predicted covariances in the model differ from the observed covariances. A good fit is determined by small and nonsignificant χ^2 values. Because this statistic is sensitive to variances in sample sizes, with very large samples as in the present study even the best-fitting models frequently yield significant χ^2 values (Kline, 1998).

Model adequacy was therefore evaluated using additional global fit indices, such as the Comparative Fit Index (CFI; Bentler, 1990), that are more sensitive to model specification than to sample size (Kline, 1998). Fit indices with values equal to or higher than .90 demonstrate a marginal fit, and values above .95 indicate a good fit. Further assessment of the extent to which the specified model approximates to the true model is the root mean square error of approximation (*RMSEA*). A *RMSEA* value of .08 or lower is acceptable, and a value below .05 indicates a good fit (see McDonald & Ho, 2002).

We tested two models as a function of country, as well as for the whole dataset (n=1237). The input was the partial correlation matrix, with age in months partialed out. In the models tested, paths between latent constructs were left free to co-vary in the absence of justifiable assumptions concerning direction of causality. In each case, the level of significance of the path weights between each observed variable and its associated factor, and the correlations between all pairs of factors, was set at an alpha level of .05. Fit indices and factor loadings for all models as a function of country, and as the sample as a whole, are shown in Table 2.

Model 1 was a three-factor model, based the theoretical framework put forward by Baddeley and Hitch (1974), as well as Engle, Tuholski, Laughlin, and Conway (1999). There were separable latent constructs for verbal short-term memory and visuo-spatial short-term memory, and a common latent construct that captured performance in tests of both verbal and visuo-spatial working memory.

We also tested a four-factor model that distinguished between short-term memory and working memory; as well as between verbal and visuo-spatial stimuli (Model 2). This model was consistent with the theoretical position for domain-specific working memory constructs found in adult data (Shah & Miyake, 1996). In order to compare the model fit across the nested models, we

TABLE 2 *Goodness of fit statistics and path coefficients for latent constructs* (p<.05) *as a function of country*

Model	Country	χ^2 (df)	CFI	RMSEA	STM Verbal-VS F1–F2	WM-Verbal STM	WM-VSSTM
1 (3 fac)	Argentina	84.54 (51)*	.96	.07	.67	.84	.93
1 (3 fac)	Brazil	68.85 (51)*	.96	.06	.98	.10	.85
1 (3 fac)	Canada	77.71 (51)*	.97	.05	.48	.60	.83
1 (3 fac)	Italy	112.36 (51)*	.88	.07	.41	.49	.90
1 (3 fac)	UK	203.78(51)*	.94	.06	.54	.59	.80
1 (3 fac)	ALL	443.16(51)*	.93	.08	.55	.58	.81

Model	Country	χ^2 (df)	CFI	RMSEA	STM Verbal-VS F1–F2	WM Verbal-VS F3–F4	Verbal STM-WM F1–F3	VS STM-WM F2–F4	Verbal STM-VS WM F1–F4	VS STM-Verbal WM F2–F3
2 (4 fac)	Argentina	75.99 (48)*	.97	.06	.67	.93	.85	.94	.78	.90
2 (4 fac)	Brazil	93.47 (48)*	.88	.12	.04	.93	.85	.79	.04	.86
2 (4 fac)	Canada	68.96 (48)*	.97	.05	.49	.97	.70	.86	.54	.77
2 (4 fac)	Italy	90.62 (48)*	.92	.06	.43	.85	.73	.89	.32	.82
2 (4 fac)	UK	163.80(48)*	.96	.06	.54	.90	.67	.77	.47	.78
2 (4 fac)	ALL	399.66(48)*	.94	.07	.55	.90	.61	.81	.55	.76

Note: VS=visuo-spatial; STM=short-term memory; WM=working memory; *$p<.05$

Four Factor

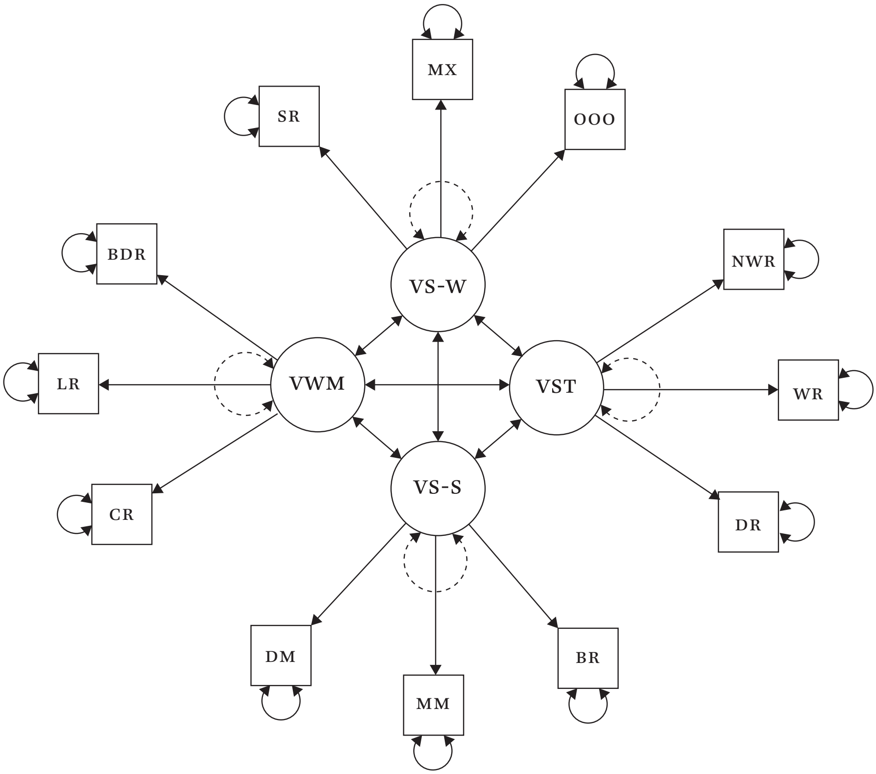

FIGURE 1 *Path model for the four-factor model based on domain-specific working memory constructs (Model).*

looked at both the AIC values and a chi-squared difference test (see Table 3). The four-factor model provided the best fit (Model 2). Although this model provided a good fit to the data across all the countries, there are concerns of multicollinearity as the correlation between visuo-spatial short-term and working memory was high in the majority of the countries (<.90).

Discussion

The purpose of the present study was to investigate whether the structure of working memory, based on a computerized assessment, is consistent across different cultures. To our knowledge, this is one of the first studies to test different theoretical models of working memory in childhood across several coun-

Three Factor

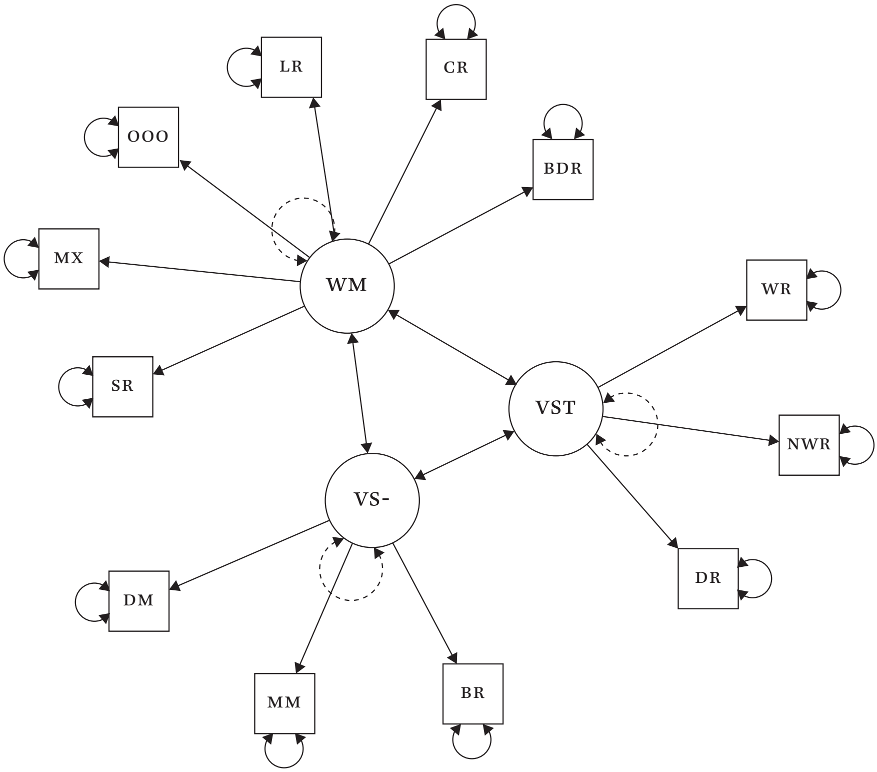

FIGURE 2 *Path model for the three-factor model based on a domain-general working memory construct (Model 3).*

tries. One interesting finding was that there was generally a similar pattern across countries with respect to verbal working memory. This pattern suggests that verbal working memory capacity may be relatively robust across different cultural groups. Similar patterns with respect to performance in verbal working memory were also observed in adult cross-cultural samples between the UK and South Africa (Cockroft, Alloway, Copello, & Milligan, 2014).

However, the pattern for visuo-spatial working memory was different across countries, where children from Canada typically outperformed those from other countries, while those from Brazil underperformed in comparison to the other children. Performance in short-term memory tests were also variable, with the Canadian children performing higher in verbal short-term memory and the Brazilian children performing worse in visuo-spatial short-term memory. One question is why there was a dissociation in working memory

TABLE 3 *Model comparisons as a function of country*

Country	M1 AIC	M2 AIC	M2 — M1 Diff
Argentina	6.54	3.99	8.55 (3); *p*=.04
Canada	−0.29	−3.04	8.75 (3); *p*=.03
Italy	34.36	18.62	21.74 (3); *p*<.001
UK	125.78	91.79	39.99 (3); *p*<.001
ALL	785.50	699.95	43.50 (3); *p*<.001

Note: M=Model

performance as a function of culture where in verbal working memory tests, performance was fairly similar, but not in visuo-spatial working memory tests. One possibility could be linked to the cultural differences. Nell (1999) suggested that individuals from first-world Western countries may have greater exposure to test taking practices and thus may have developed test wiseness (known as acculturation). This could also include the ability to follow directions, pay close attention to the task, and feel confident in their responses.

Another explanation could be related to differences in educational rankings, as Brazil fell in the lowest educational band. A cross-national comparison of nearly thirty countries found that in low-income countries, including Brazil, the predominant influence on academic attainment was the quality of education (Heyneman & Loxley, 1983). Previous research has suggested that the quality of education plays an important role in the cognitive test results of non-westernized groups (i.e. any group not of western middle class origin (Manly, Byrd, Touradji, Sanchez & Stern, 2004; Manly, Jacobs, Touradji, Small & Stern, 2002; Shuttleworth-Edwards et al., 2004). For example, in a comparison of Argentinian and American samples on a standardized IQ test, the Argentinian sample performed worse than the American sample particularly in verbal IQ tests, which was attributed to 'unknown' cultural factors (Insua, 1983, p. 436). However, cultural differences have also arisen in nonverbal IQ tests (see Ostrosky-Solis, Ramirez & Ardila, 2004, Rosselli & Ardila, 2003). These cultural differences may in part be driven by the differences in educational and cognitive values, as well as familiarity with educational materials they can access (Miller-Jones, 1989). This view was supported in a study where white British children and black Zambian children were asked to construct clay models, and complete pen-paper tasks and wire modeling tasks (Serpal, 1994). The white English children performed better on pen-paper tasks, while black Zambian children were more adept on wire modeling tasks. However, they performed similarly on the clay modeling task, a material that was accessible to both groups. In the present study, it is possible that memory tasks may form a greater component of education in Western countries than in Latin countries, which may have given the former group of children a small advantage. In addition, the lack of familiarity with computerized tasks may have played a role as Brazilian children performed within age-expected levels in paper and pencil working memory tasks, such as nonword repetition and block recall (Santos & Bueno, 2003; Santos, Mello, Bueno, & Della, 2005).

In line with recent theoretical research on working memory, we tested both domain-general and domain-specific working memory models. Model 1 represented the domain-general model where there was a common latent construct for tests of both verbal and visuo-spatial working memory (Baddeley & Hitch, 1974). Model 2 was a domain-specific model that included separable latent constructs for verbal and visuo-spatial working memory (see Friedman & Miyake, 2000; Miyake et al., 2001). While both models provided a reasonably good fit with the data, the χ^2 difference test indicated that the better fitting model was one that comprised of domain-specific working memory constructs. However, one concern is the high relationship between the verbal and visuo-spatial working memory constructs across the countries. Thus, it may be a more parsimonious choice to rely on a three-factor model.

Another pattern is that visuo-spatial short-term memory tests seem to share approximately 70–80% of variance with working memory in some of the country-specific models (Argentina, Brazil, and Italy). This pattern may not be due to age differences as age was partialled out in the correlation matrix used in the confirmatory factor analyses. One possibility for this country-specific pattern in working memory could be linked to their language proficiency as the three cultural groups who demonstrated stronger links between visuo-spatial short-term memory and a generalized working memory component were bilingual. Some researchers have suggested that bilingual children have specialized language stores as a result of learning multiple languages (García-Pentón, Fernández, Iturria-Medina, Gillon-Dowens, & Carreiras, 2014). This could explain why verbal short-term and working memory were less strongly related, as the former skill does not need to rely on WM resources. In contrast, visuo-spatial short-term memory may be less specialized, and thus relies on the additional cognitive resources associated with working memory. This close association between visuo-spatial short-term memory and working memory seems to results in a cognitive advantage for bilingual children that was not present for monolingual children (Morales, Calvo, & Bialystok, 2014) or for verbal tasks (Engel de Abreu, 2011).

In summary, the findings from the present study extend existing research on the micro level of cultural contexts such as research focused on socio-economic background or maternal education (Alloway et al., 2013; Engel et al., 2008; Messer et al., 2010) or daycare experience (Alloway et al., 2004), and offers new insight into working memory performance at the macro-cultural level. At the micro level, factors such as socio-economic background and maternal education do not appear to greatly affect working memory performance (at least in younger children), possibly because the within-country population represents a fairly homogeneous cultural group, and thus differences are relatively small. However, at the macro level, when one cultural group is compared with another, such differences are magnified and can be detected even in the early years. The relatively uniformity observed in verbal working memory performance across cultures, as well as the general robustness of a three-factor model of working memory in a cross-national context suggests that this model is not an artifact of a primarily Western or English-speaking sample. However, subtle differences in more specific links, such as between visuo-spatial short-term memory and working memory, suggest larger cultural issues that can affect the interplay between the different memory components.

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