# Working Memory and Fluid Intelligence: The Role of Executive Processes, Age and School Type in Children*

## Memoria de trabajo e inteligencia fluida: el papel de los procesos ejecutivos, según edad, tipo de escuela en niños

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Abstract

The aim of this study was to verify which components of the working memory (WM) model (phonological, visuospatial and central executive) predict the performance in fluid intelligence (FI), considering age, schooling and school type. The participants were 419 children aged between six and 12 years old, from the first year to the sixth grade of Primary School from public and private schools of Rio Grande do Sul, Brazil. The WM subtests of the NEUPSILIN-Inf – Brazilian Brief Neuropsychological Assessment Battery – for children – were administered, and Raven's Colored Progressive Matrices Test served as FI measure. In the linear regression analysis, the executive component primarily explained the relationship between WM and FI in children, rather than phonological component. When sociodemographic variables were included, age, school type and the executive component explained 47% of FI variance, but the predictive power of the executive component was reduced. The results reinforce the primary relationship between executive processing of WM and FI, as well as the importance of taking into account sociodemographic variables, so the relationship between these constructs are not overestimated.

**Keywords**
working memory; intelligence; neuropsychology

Resumen

El objetivo de este estudio fue constatar qué componentes del modelo de memoria de trabajo (MT): fonológico, visuoespacial y ejecutivo central, predicen el rendimiento en la inteligencia fluida (IF), teniendo en cuenta edad, nivel de educación y tipo de escuela. Participaron 419 niños, entre seis y 12 años, del primero al sexto grado de primaria de escuelas públicas y privadas de Río Grande del Sur (Brasil). Se aplicaron los subtests de MT del Instrumento de Evaluación Neuropsicológica Breve Infantil (NEUPSILIN-Inf) y el Test de Matrices Progresivas de Colores de Raven como medida de IF. En el análisis de regresión lineal, el componente ejecutivo explicó principalmente la relación entre MT y IF en la infancia, en lugar del componente fonológico. Cuando se incluyeron variables sociodemográficas, edad, tipo de escuela y el componente ejecutivo explicaron 47 % de la varianza de la IF, pero hubo una reducción en el poder predictivo del componente ejecutivo. Los resultados refuerzan la relación entre el procesamiento ejecutivo y la FI, así como la importancia de tener en cuenta las variables sociodemográficas, de modo que la magnitud de la relación entre estos constructos no se sobrevalore.

**Palabras clave**
memoria operativa; inteligencia; neuropsicología

* Artículo de investigación

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Evidence suggests that working memory (WM) and general intelligence are related constructs (Barbey, Colom, Paul, & Grafman, 2013; Friedman et al., 2006; Roca et al., 2009). More specifically, a relationship between the central executive of WM and fluid intelligence (FI) has been confirmed in studies with adults (e.g. Colom & Flores-Mendoza, 2006; Fukuda, Vogel, Mayr, & Awh, 2010; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). In the last years, findings of that relationship were also found in childhood (Belacchi, Carretti, & Cornoldi, 2010; Cornoldi, Giofrè, Calgaro, & Stupiggia, 2013; Engel de Abreu, Conway, & Gathercole, 2010; Hornung, Brunner, Reuter, & Martin, 2011; Tilman, Nyberg, & Bohlin, 2008). However, one limitation of these investigations is that sociodemographic factors that may interfere in that relationship have not been controlled or manipulated. In the present study the relationship between WM and FI is investigated in children, taking into account some sociodemographic factors that may also contribute to cognitive performance, such as schooling, socioeconomic status and school type (Ardila, Rosselli, Matute, & Guajardo, 2005; Villaseñor, Martín, Díaz, Rosselli, & Ardila, 2009).

FI has been defined by Cattell (1971) as the cognitive capacity of adaptive and flexible thinking when there are no resources already classified in memory to respond to complex tasks. Such capacity includes mental operations like the recognition and formation of concepts, problem resolution, extrapolation and transformation of information. In other words, FI is the capacity to reason under new conditions, which is opposite to the performance based on learned knowledge, i.e., crystallized intelligence (Horn & Cattell, 1966). In order to investigate FI, non-verbal tasks and tests are usually employed, as they are less dependent on culture and language (Engel de Abreu et al., 2010; Fonseca, Salles, & Parente, 2007). Raven's Progressive Matrices Test is among the most used ones (Cornoldi et al., 2013; Engel de Abreu et al., 2010; Hornung et al., 2011; Tilman et al., 2008).

FI is closely associated with WM (Belacchi et al., 2010; Colom & Flores-Mendoza, 2006), defined by Baddeley (Baddeley, 2007, 2012; Baddeley & Hitch, 1974), in his multi-component model, as a limited capacity system that temporarily stores information and also processes it, making it possible for the individual to perform complex activities, such as reasoning, learning and understanding. The multi-component model assumes that WM is divided in four components: the phonological component (*phonological loop*), the visuospatial component (*visuospatial sketchpad*), the central executive and the episodic buffer. The phonological component is responsible for the storage and temporary maintenance of sequences of acoustic elements or elements based on discourse. The visuospatial component is specialized in the temporary maintenance of visuospatial element information. The central executive is an attentional system with limited capacity that selects and manipulates the material coming from previous components, acting like a WM global system controller. Finally, the episodic buffer is a multimodal code mechanism that allows the interaction among various WM subcomponents and long-term memory. In this study, the last component will not be directly assessed.

Phonological and visuospatial components, considered as storage subsystems in the multi-component model, are assessed through simple span tasks that simultaneously require the retention and additional processing of the stimulus (Conway, Jarrold, Kane, Miyake, & Towse, 2008; Engel de Abreu et al., 2010). Simple span tasks (e.g. forward digit span, pseudowords and/or nonword span, Corsi blocks forward) assess the storage capacity for short periods of time in situations that do not impose other cognitive demands (Gathercole, Alloway, Willis, & Adams, 2006). Complex span tasks require a double task (e.g. word span in sentences, backward digit span, Corsi blocks backward) and thus evaluate the executive capacity of simultaneously storing and processing the information, that is, central executive component (Alloway, Gathercole, Willis, & Adams, 2004). Even though it is possible to establish a differentiation among WM components and assess them in separate tasks, it is important to emphasize that no task is a pure measure of those capacities (Conway et al., 2008). Some studies have indicated that simple and complex span tasks likely require both storage capacity and central executive, but in different degrees. Complex span tasks may primarily involve central executive and secondary storage capacity, while simple span tasks may require more storage capacity and less central executive component (Conway, Macnamara, Getz, & Engel de Abreu, in press; Kane et al., 2004; Unsworth & Engle, 2007). Studies testing structural models have strongly supported the view that storage (simple tasks) and executive (complex tasks) components are already distinguishable, although related, in children (e.g. Alloway et al., 2004; Engel de Abreu et al., 2010; Hornung et al., 2011). These findings are consistent with the Baddeley`s model for adults (Baddeley, 2012).

Throughout the last years, researchers have been trying to understand how and why WM and FI are related (e.g. Belacchi et al., 2010; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Cornoldi et al., 2013; Dang, Braeken, Ferrer, & Liu, 2012; Engel de Abreu et al., 2010; Engle, Kane, & Tuholski 1999; Hornung et al., 2011; Oberauer, Süß, Wilhelm, & Wittmann, 2008; Redick, Unsworth, Kelly, & Engle, 2012; Tilman et al., 2008; Unsworth & Engle, 2007). The results of studies with both adults and children are controversial in what concerns the role of WM components in the explanation of the performance in FI tests (Belacchi et al., 2010; Colom, Rebollo, Abad, & Shih, 2006; Dang et al., 2012; Engle et al., 1999; Engel de Abreu et al., 2010; Hornung et al., 2011; Tilman et al., 2008). In studies with adults, there is evidence that when the common variance between the storage (simple tasks) and executive (complex tasks) components is removed, only the executive component is associated with FI (Engle et al., 1999). Although the association between FI and executive component has been also found in other studies (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Dang et al., 2012; Kane et al., 2004), FI was significantly associated as well with both storage and executive components (Colom et al., 2006; Conway et al., 2008). In addition, storage was a better predictor of FI in some of these studies (Colom et al., 2008; Colom et al., 2006).

These inconsistent findings are also observed among the few studies with children (Belacchi et al., 2010; Cornoldi et al., 2013; Engel de Abreu et al., 2010; Hornung et al., 2011; Tilman et al., 2008). Engel de Abreu et al. (2010)'s study with 119 children aged between 5 and 9 years indicated that, after the control of shared variance between phonological storage and executive component, only the executive component assessed through complex tasks was predictor of FI. This relation between executive component and FI was also found in other studies (Cornoldi et al., 2013; Swanson, 2008). However, Tilman et al. (2008), in a study with 196 children aged between 6 and 13 years, have verified that both components contributed in the prediction of FI and, thus, they had considered that the executive component does not necessarily have a primary role in the relationship with FI. Hornung et al. (2011)'s study indicated that short-term storage capacity (composed of the shared variance of simple and complex span tasks – general-domain) primarily explicated the relationship between WM and fluid intelligence. Therefore, more investigations are needed to clarify that question.

In addition to the controversial findings, the available studies rarely take sociodemographic variables into account to explore the relationship between WM and FI. For example, in some studies reported earlier, children had come from families of different socioeconomic levels and this factor was not considered in the analysis (Hornung et al., 2011; Tilman et al., 2008). In some studies, socioeconomic information is not even mentioned (e.g. Cornoldi et al., 2013). Ignoring these aspect can lead to an overestimation of the relationship between WM and IF. There is evidence that age, schooling and socioeconomic level (measure correlated with school type) interfere in cognitive performance (Foss, Vale, & Speciali, 2005; Villaseñor et al., 2009). In Brazilian studies, it is especially relevant to consider school type, having in mind that national examinations have revealed a superior school performance from private school students (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira [Inep], 2006). The difference in performance may be explained by qualitative aspects in the schooling process, such as teaching methods and level of stimulation, quality of the relations maintained in the school context with colleagues and teachers, among others (Gardinal & Marturano, 2007). Based upon those considerations, the relationship between WM and FI in children was investigated. More specifically, the aim was to verify which components of WM best explain FI, taking sociodemographic factors into account.

## Method

### *Participants*

The data analyzed in this study originate from the research "Development of a Brazilian Brief Neuropsychological Assessment Battery – for children". The participants were 419 children (54.4% girls) aged between six and 12 years ($M$ = 8.99; $SD$ = 1.98) from the first year to the sixth grade of Primary School, going to seven public state (50.8%) and nine private (49.2%) schools in the city of Porto Alegre, state of Rio Grande do Sul, Brazil. The criteria for inclusion in the sample were: absence of a history of neurological or psychiatric disorders (epilepsy, traumas, meningitis, convulsive episode, use of medication and sleep disturbances), of uncorrected visual or hearing difficulties, of a history of school failure, of suggestive signs of ADHD or intellectual deficit.

The distribution of age of the participants was as follows: six years – 13.6%, seven years - 14.6%, eight years - 15%, nine years - 14.8%, 10 years - 14.3%, 11 years - 13.8% and 12 years - 13.9%. The distribution of education of the participants was as follows: kindergarten - 13.6%, first grade – 17.2%, second grade – 15.3%, third grade - 16.9%, fourth grade - 14.3%, fifth grade – 19.3% and sixth grade - 3.4%.

Type of school and socioeconomic status are correlated (Villaseñor et al., 2009). In this study, socioeconomic status (SES) was obtained through the Economic Classification Criterion Brazil (2008) (http://www.viverbem.fmb.unesp.br/docs/classificacaobrasil.pdf), which scores ranging from 34-0 points, distributed as follows: A1 = 30 to 34, A2 = 25 to 29; 21-24 = B1, B2 = 17-20, C = 11-16, D = 6 to 10, E = 0 to 5. A frequency analysis indicated that only 6.3% children belonged to the socioeconomic class A in public school. In contrast, 54.7% of the children belonged to that socioeconomic level in private school. The correlation between school type and SES was 0.63 ($p < 0.01$). School type was utilized in the statistical analyzes.

### *Instruments*

The NEUPSILIN-Inf – Brazilian Brief Neuropsychological Assessment Battery – for children (Salles et al., 2011; Salles et al., in press) was administered. The instrument assesses cognitive functions such as attention, memory, language, executive functions and perception. For this study, the performance of children in WM was analyzed through the tasks: digit repetition forward (digit span) and pseudoword repetition (pseudoword span), which assess the phonological storage component of WM, and digit repetition backward and visuospatial WM (a task similar to Corsi's blocks backward, in which the examiner points out progressively longer sequences of stimuli and the child is asked to repeat pointing out the stimuli in the inverted presentation order). This type of task involves, besides visuospatial information storage, the processing/manipulation of this information by the central executive (see Rossi-Arnaud, Pieroni, Spataro, & Baddeley, 2012; Vandierendonck, Kemps, Fastame, & Szmalec, 2004).

Raven's Colored Matrices Test - Special Scale (Angelini, Alves, Custódio, Duarte, & Duarte, 1999; Raven, Court, & Raven, 1986) was employed to assess non-verbal intelligence.

### *Procedures*

The research project was approved by the Ethics Committee of the Psychology Institute of the Federal University of Rio Grande do Sul – UFRGS, protocol nº. 2008/067. A Free and Informed Consent was obtained from parents or guardians. The assessment happened in collective sessions (20 minutes) with eight students at most, in which the Raven test was administered, and in an individual session (60 minutes) in which the administration of the NEUPSILIN-Inf took place.

## Results

Descriptive statistics of all measures were calculated. Tasks showed approximately normal distribution with skewness values ranging from - 0.01 to 1.29, and kurtosis values ranging from - 0.27 to 1.28. All variables were correlated with age (range from 0.4 to 0.57; $p < 0.01$), schooling (range from 0.4 to 0.55; $p < 0.01$) and school type (range from 0.16 to 0.27; $p < 0.01$). In order to identify specific differences related to age bands, the sample was divided in two age groups – 5-8 years and 9-12 years. Older children performed better on all tasks: digit repetition forward ($t$ (417) = 10.11; $p < 0.01$; $d$ = 1), pseudoword span ($t$ (412) = 7.46; $p < 0.01$; $d$ = 0.73), digit repetition backward ($t$ (417) = 9.4; $p < 0.01$; $d$ = 0.92), visuospatial WM ($t$ (416) = 7.88; $p < 0.01$; $d$ = 0.77), WM total ($t$ (411) = 12.99; $p < 0.01$; $d$ = 1.28) and Raven ($t$ (410) = 8.33; $p < 0.01$; $d$ = 1.14). The sample was also divided by levels of schooling – 1-3 grades and 4-6 grades. Children of the 4-6 grades performed better on all tasks: digit repetition forward ($t$ (417) = 11.31; $p < 0.01$; $d$ = 1.1), pseudoword span ($t$ (412) = 8; $p < 0.01$; $d$ = 0.78), digit repetition backward ($t$ (417) = 9.74; $p < 0.01$; $d$ = 0.95), visuospatial WM ($t$ (416) = 8.25; $p < 0.01$; $d$ = 0.8), WM total ($t$ (411) = 13.73; $p < 0.01$; $d$ = 1.35) and the Raven ($t$ (410) = 10.5; $p < 0.01$; $d$ = 1.03). It is observed through the $d$ values that the a magnitude of differences between age groups was moderate in the pseudoword span and visuospatial WM and high in the other tasks, while in schooling groups the differences were high (except in the pseudoword span), taking as reference values defined by Cohen to effect size (1988). A possible difference related to sex was also investigated but it was not found. The differences regarding school type are presented in Table 1, which describes the means, standard deviations, the significance of the Student's test $t$ and effect size ($d$). In this case, the differences related to school type were small, except in the Raven, which was moderate. From these analyzes, it is observed that the three sociodemographic variables seems to influence cognitive tasks performance. Thus, these variables were controlled in subsequent analyzes. To investigate the relationship between WM and FI were performed Pearson correlations between WM sub-tests of the NEUPSILIN-Inf and the total score of the children in the Raven test. The shared variance with age, schooling and school type has been eliminated from the correlation to avoid that the relationship between the two constructs (WM and FI) could be overestimated (Table 1).

**Table 1**

*Means, Standard deviations of the Measures of WM and Non-verbal Intelligence by School Type and Intercorrelations, Controlling the Shared Variance with Age, Schooling and School Type (N = 419)*

| | Max. | Public Mean (*SD*) | Private Mean (*SD*) | *t* | *d* | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phonological component | | | | | | | | | | | |
| 1 Digit repetition (forward) | 24 | 18.64(4.23) | 19.77(3.98) | 2.80* | 0.27 | - | 0.31* | 0.23* | 0.09* | 0.28* | 0.09 |
| 2 Pseudoword repetition | 20 | 12.27(3.43) | 13.43(3.46) | 3.42* | 0.34 | | - | 0.17* | 0.05 | 0.45* | **0.17*** |
| Executive component | | | | | | | | | | | |
| 3 Digit repetition (backward) | 28 | 17.89(5.29) | 19.25(4.89) | 2.72* | 0.27 | | | - | 0.31* | 0.75* | **0.22*** |
| 4 Visuospatial WM | 28 | 20.57(6.49) | 22.67(5.9) | 3.45* | 0.34 | | | | - | 0.76* | **0.3*** |
| 5 WM Total | 76 | 50.74(12.11) | 55.4(10.39) | 4.2* | 0.42 | | | | | - | **0.36*** |
| 6 FI (Raven) | 36 | 27.25(5.43) | 30(4.51) | 5.57* | 0.55 | | | | | | - |

*Note.* *$p < 0.001$.
Source: own work

In Table 1, the correlations between all pairs of variables indicated that the tasks of WM were related with FI as measured by Raven Test, with the exception of pseudoword repetition task (phonological loop, simple task). The executive component of WM (complex tasks) showed higher correlation with FI, and the visuospatial task presented the stronger relation ($r = 0.3$; $p < 0.01$).

To examine the aim of this study were performed hierarchical linear regression analyses to investigate the specific contribution of WM components (phonological, visuospatial and central executive components) and also of the sociodemographic variables (age, schooling and school type) in the explanation of FI. In the regression, however, a composite score of the phonological storage tasks (phonological component - PC) and a composite score of tasks involving executive processes (executive components - EC) were employed. Prior to summing the scores, the tasks were converted in *z* scores. Such procedure has been carried out in most of the studies that have assessed the specific contribution of WM for the performance in the Raven test (e.g.: Engel de Abreu et al., 2010; Tilman et al., 2008). The correlation between the phonological component - PC and executive component - EC was 0.43 ($p < 0.01$).

First, the roles of PC and EC in the prediction of FI were analyzed, with PC entering in the first block and EC in the second one (Table 2). PC explained 17% of FI variance while EC, controlling the variance explained by PC, added 16% of explanation, in a total of 33% ($R^2_{adjusted} = 0.33$, $F(1, 419) = 102.26$, $p < 0.01$). After that, the analysis was conducted with EC entering in the first block and PC in the second. EC explained 30% of FI variance and PC, with the explanation of EC being controlled, added only 3% of explanation, reaching the total of 33% ($R^2_{adjusted} = 0.33$, $F(1, 419) = 102.25$, $p < 0.01$). Therefore, the EC contributed more to the explanation of FI.

In the second hierarchical regression analyses, age, schooling and school type entered sequentially in the first three blocks and EC was included in the fourth block in order to investigate the FI variance explained by executive processing after controlling for shared variance with sociodemographic variables. Table 3 shows the variance added for each variable in the prediction of FI in each block of the regression. Age explained 33% of variance, followed by school type with 9% and EC, with 5%. There was no schooling residual variance explaining FI. Importantly, after controlling for sociodemographic variables, EC had its explained variance reduced from 30% (Table 2) to 5% (Table 3). The model was able to explain 47% ($R^2_{adjusted} = 0.47$, $F(1, 419) = 90.42$, $p < 0.01$).

## Discussion

The aim of this study was to investigate which WM components predict FI performance. The results suggest that the executive component primarily explains the relationship between WM and FI in childhood, rather than phonological component.

**Table 2**
*Linear Regression Analysis with PC and EC Composites Predicting FI (N = 419)*

| Block | Predictor | B | *T* | $R^2_{adjusted}$ |
|---|---|---|---|---|
| 1 | PC | 0.41* | 9.25 | 0.17 |
| 2 | EC | 0.45* | 9.91 | 0.16 |
| $R^2_{adjusted} = 0.33$ Durbin-Watson=1.56 | | | | |
| 1 | EC | 0.54* | 9.91 | 0.3 |
| 2 | PC | 0.22 | 4.97 | 0.03 |
| $R^2_{adjusted} = 0.33$ Durbin-Watson= 1.86 | | | | |

Note. PC: phonological component; EC: executive component
* significant correlation $p < 0.01$
Source: own work

**Table 3**
*Linear Regression Analysis with WM and Sociodemographic Variables Predicting FI (N = 419)*

| Block | Predictor | β | T | $R^2_{adjusted}$ |
|---|---|---|---|---|
| 1 | Age | 0.57* | 14.13 | 0.33 |
| 2 | Age | 0.46* | 3.35 | 0.33 |
| | Schooling | 0.11 | 0.81 | 0.01 |
| 3 | Age | 0.55* | 4.23 | 0.33 |
| | Schooling | 0.04 | 0.33 | 0.01 |
| | School Type | 0.3* | 7.83 | 0.09 |
| 4 | Age | 0.46* | 3.67 | 0.33 |
| | Schooling | 0 | 0.04 | 0.01 |
| | School Type | 0.24* | 6.7 | 0.09 |
| | EC | 0.27* | 6.43 | 0.05 |
| $R^2_{adjusted}$ = 0.47 Durbin-Watson= 1.86 | | | | |

Note: PC: phonological component; EC: executive component
* significant correlation $p < 0.01$
Source: own work

Sociodemographic aspects also seem to contribute for fluid non-verbal intellectual processing and should be considered in the analysis to encompass individual differences arising from general development (age) and contextual factors (socioeconomic status, type of school).

Initially, the correlational analyzes suggest that, although related, the constructs of WM and FI – in their total scores – are distinguishable in childhood, since their relationship was just next to moderate. Regarding the link between specific components WM and FI, the positive correlations found in this study (ranging between 0.17 and 0.3) are of comparable magnitude those observed by Engel de Abreu et al. (2010). They also considered age and schooling in the analysis and found correlations ranging between 0.19 and 0.34, and executive component showed also a higher relation with FI (the PC showed only a weak positive correlation with FI in the second grade). Specifically, the visuospatial task (which also involves executive processing) showed greater relation with FI in the present study, which was also observed in adults (Dang et al., 2012). The PC assessed by pseudoword span task was not related and the digit repetition forward presented only a very weak relation with FI.

The regression analysis suggests that the PC would not be the main responsible ones for the relationship between WM and FI. It was observed that when the PC variance is controlled, EC has a unique variance that is predictive of FI. This residual variance has been considered representative of "cognitive control" (Engle et al., 1999). This result reinforces the findings of Engel de Abreu et al. (2010) and several studies (Conway et al., 2002; Dang et al., 2012; Kane et al., 2004; Swanson, 2008; Unsworth & Engle, 2007) in which the EC explain better the relationship between the two constructs. Unsworth and Engle (2007) have explained this findings in adults by a dual-component framework that combine an active maintenance component (primary memory) with controlled cue-dependent search and retrieval process of information that cannot be maintained (secondary memory). In complex span tasks, the items to be recalled are quickly shifted from initial short term storage (primary memory) to secondary memory. Attention is necessary to cause involvement in the search of the representation stored in secondary memory and to confront potential problems such as proactive interference in order to successfully retrieve shifted items. Raven tasks probably depend on the same mechanisms, since the requirement for an item to be completed is that a series of intermediate results must be stored during the period in which an item is being solved. Those intermediate results must be briefly ensured in primary memory, but as a consequence of having to manipulate other aspects of the problem, they may be quickly shifted to secondary memory (Unsworth & Engle, 2007). This way, the relationship between the executive components of WM and FI would occur because both the more complex span tasks and Raven tasks involve the ability to effectively control attention in order to keep relevant information for the task goal while facing interference.

Based upon that hypothesis, it is possible that children with low scores in complex span tasks and FI tests present more difficulty in engaging in the search of elements in secondary memory and must be more prone to consider unnecessary information and alternative interpretations of the material, which might decrease their performance (Engle, 2010; Unsworth & Engle, 2007). The use of attention to actively retrieve representations from secondary memory in the presence of proactive interference must hence underlie the correlation between the tasks observed in this study. Other than attentional control processes, it is important to consider that the visuospatial WM task, which showed a higher correlation with FI, and the Raven test also have in common the employment of visuospatial stimuli. Therefore, the use of tasks with similar characteristics in the assessment of WM and FI contributes to the relationship found empirically (Salthouse & Pink, 2008). Nevertheless, the scores of visuospatial WM task and the index of Raven are dissociable, since the correlation between them was low.

It is important to highlight that Hornung et al. (2011) found that a short-term storage component (shared variance between simple and complex span tasks) primarily explained the relationship between WM and FI. However, it should be noted that the "pseudoword recall" task, considered by authors as a simple task of phonological storage, appears to be more complex (it is necessary to recall sequences of pseudowords) than the "pseudoword repetition" task (used in this study) and probably requires more executive processing. This would explain, for example, the correlation ($r$ = 0.27) between "pseudoword recall" score and the total score on Raven in Hornung et al. (2011), while there was no relation between simply repeat pseudowords and Raven scores in the present study and the study by Engel de Abreu et al. (2010). Thus, it is possible that simple span tasks explain little to the relationship between MT and FI.

The association of PC with FI, when considered in isolation (without controlling EC variance), it is explained by overlapping of some factors between simple and complex tasks' performance. In some situations, simple tasks may involve some degree of cognitive control if they require the retrieval of elements in secondary memory under overload conditions in short-term memory (Unsworth & Engle, 2006, 2007), as when the sequence of digits is longer on simple tasks of forward recall of digits. Importantly, simple tasks of PC showed no specific variance in explaining FI after controlling for EC, which reinforces the primary importance of executive processes in the link between WM and FI (Conway et al., 2002; Engle et al., 1999).

In this study, three sociodemographic variables were taken into account. In the correlation their effect was controlled and in the predictive analysis it was verified that age and school type, with the elimination of shared variance with WM components, were important in the explanation of FI performance. When sociodemographic variables were included in the model of FI, the predictive power of EC was reduced, and school type (equivalent to the socioeconomic status) was also an important factor while age had a primary role. This result is similar to that found by Swanson (2008), when age, phonological store and executive components were considered together and the residual variance of executive component was significant FI predictor in children with a similar explained amount of variance. Thus, it is emphasized that without considering the influence of sociodemographic factors, the magnitude of the relationship of EC with FI might have been overestimated.

Overall, the relationship between WM and FI was found in this study, stressing the role of executive components and sociodemographic variables. The results should be considered as the specific tasks used in this study, since the degree of participation of storage and executive processing depends on the specific cognitive demands of each task. In this way, it is important to carefully define which tasks can represent simple and complex processing. The criteria used often vary among studies. This methodological heterogeneity limits a direct comparison of the findings. In this study, we note that even using a limited number of tasks, the overall results were consistent with other studies using similar classical WM tasks (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Engel de Abreu et al., 2010; Swanson, 2008).

Looking forward to reduce theoretical and consequent methodological variety as well as to better compare results among studies, we suggested that different complex WM tasks continue to be investigated in order to ascertain which other aspects of executive processing/ attentional control may be more related to FI. Similarly, it is recommended to use more than one FI test seeking to increase the validity of the results. It is possible that other non-verbal intelligence tasks recruit different degrees of attencional demands than Raven and elucidate others aspects of the relation between WM and FI. In these analyzes, age and socioeconomic status should be considered towards a more comprehensive view of the relationship between these two individual and sociocultural variables.

## References


Ardila, A., Rosselli, M., Matute, E., & Guajardo, S. (2005). The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology, 28*(1), 539-560.

Alloway, T., Gathercole, S., Willis, C., & Adams, A. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology, 87*(2), 85-106.

Angelini, A., Alves, I., Custódio, E., Duarte, W., & Duarte, J. (1999). *Matrizes Progressivas Coloridas de Raven. Manual*. São Paulo, SP: Centro Editor de Testes e Pesquisa em Psicologia.

Baddeley, A., & Hitch, G. (1974). Working memory. In G. Bower (Ed.), *Recent advances in learning and motivation* (pp. 48-79). New York: Academic Press.

Baddeley, A. D. (2007). *Working memory, thought, and action*. Oxford University Press.

Baddeley, A. D. (2012). Working memory, theories models and controversy. *The Annual Review of Psychology, 63*(1), 1-29.

Barbey, A. K., Colom, R., Paul, E., & Grafman, J. (2013). Architecture of fluid intelligence and working memory revealed by lesion mapping. *Brain, 135*(4), 1154-1164.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M., & Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology, 41*(4), 579-597.

Belacchi, C., Carretti, B., & Cornoldi, C. (2010). The role of working memory and updating in Coloured Raven Matrices performance in typically developing children. *European Journal of Cognitive Psychology, 22*(7), 1010-1020.

Cattell, R. (1971). *Abilities: Their structure, growth, and action*. New York: Houghton Mifflin.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Colom, R., & Flores-Mendoza, C. (2006). Armazenamento de curto prazo e velocidade de processamento explicam a relação entre memória de trabalho e o fator *g* de inteligência. *Psicologia: Teoria e Pesquisa, 22*(1), 113-122.

Colom, R., Rebollo, I., Abad, F. J., & Shih, P. C. (2006). Complex span tasks, simple span tasks, and cognitive abilities: A reanalysis of key studies. *Memory & Cognition, 34*(1), 158-171.

Colom, R., Abad, F. J., Quiroga, M. A., Shih, P. C., & Flores-Mendoza, C. (2008). Working memory and intelligence are highly related constructs, but why? *Intelligence, 36*(6), 584-606.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*(2), 163-183.

Conway, A., Jarrold, C., Kane, M., Miyake, A., & Towse, J. (2008). Variation in working memory: An introduction. In A. Conway, C. Jarrold, M. Kane, A. Miyake & J. Towse (Eds.), *Variation in working memory* (pp. 227-249). New York: Oxford University Press.

Conway, A. R. A., Macnamara, B., Getz, S., & Engel de Abreu, P. M. J. (in press). Working memory and fluid intelligence: A multi-mechanism view. In R. Sternberg & S. B. Kaufman (Eds.), *The Cambridge handbook of intelligence*. New York: Cambridge University Press.

Cornoldi, C., Giofre, D., Calgaro, G., & Stupiggia, C. (2013). Attentional WM is not necessarily specifically related with fluid intelligence: The case of smart children with ADHD symptoms. *Psychological Research, 77*(4), 508-515.

Dang, C., Braeken, J., Ferrer, E., & Liu, C. (2012). Unitary or non-unitary nature of working memory? Evidence from its relation to general fluid and crystallized Intelligence. *Intelligence, 40*(5), 499-508.

Engel de Abreu, P. de, Conway, A., & Gathercole, S. (2010). Working memory and fluid intelligence in young children. *Intelligence, 38*(6), 552-561.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102-134). New York: Cambridge University Press.

Engle, R. W. (2010). Role of working memory capacity in cognitive control. *Current Anthropology, 51,* S1.

Fonseca, R. P., Salles, J. F., & Parente, M. A. M. P. (2007). Ferramenta útil na pesquisa e clínica de neuropsicologia: Um Compêndio de Testes Neuropsicológicos. *Interamerican Journal of Psychology, 41*(3), 403-406.

Foss, M., Vale, do F., & Speciali, J. (2005). Influência da escolaridade na avaliação neuropsicológica de idosos aplicação e análise dos resultados da Escala de Mattis para Avaliação de Demência (Mattis Dementia Rating Scale - MDRS). *Arquivos de Neuropsiquiatria, 63*(1), 119-126.

Friedman, N., Miyake, A., Corley, R., Young, S., DeFries, J., & Hewitt, J. (2006). Not all executive functions are related to intelligence. *Psychological Science, 17*(2), 172-179.

Fukuda, K., Vogel, E., Mayr, U., & Awh, E. (2010). Quantity, not quality: The relationship between fluid intelligence and working memory capacity. *Psychonomic Bulletin & Review, 17*(5), 673-679.

Gardinal, E. C., & Marturano, E. M. (2007). Meninos e meninas na Educação Infantil: associação entre comportamento e desempenho. *Psicologia em Estudo, 12*(3), 541-551.

Gathercole, S., Alloway, T., Willis, C., & Adams, A. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*(3), 265-281.

Horn, J., & Cattell, R. (1966). Refinement and test of the theory of fluid and crystalized general intelligences. *Journal of Educational Psychology, 57*(5), 253-270.

Hornung, C., Brunner, M., Reuter, R., & Martin, R. (2011). Children's working memory: Its structure and relationship to fluid intelligence. *Intelligence, 39*(4), 210-221.

Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira. (2006). *Resultados do Enem 2005: análise do perfil socioeconômico e do desempenho dos participantes*. Brasilia: Author.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latente variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*(2), 189-217.

Oberauer, K., Süß, H., Wilhelm, O., & Wittmann, W. W. (2008). Which working memory functions predict intelligence? *Intelligence, 36*(6), 641-652.

Raven, J. C., Court, J. H., & Raven, J. (1986). *Coloured progressive matrices*. London: H. K. Lewis.

Redick, T. S., Unsworth, N., Kelly, A., & Engle, R. W. (2012). Faster, smarter? Working memory capacity and perceptual speed in relation to uid intelligence. *Journal of Cognitive Psychology, 24*(7), 844-854.

Roca, M., Parr, A., Thompson, R., Woolgar, A., Torralva, T., Antoun, N., Manes, F., et al. (2009). Executive function and fluid intelligence after frontal lobe lesions. *Brain, 133*(1), 234-247.

Rossi-Arnaud, C., Pieroni, L., Spataro, P., & Baddeley, A. (2012). Working memory and individual differences in the encoding of vertical, horizontal and diagonal symmetry. *Acta Psychologica, 141*(1), 122-132.

Salles, J. F., Fonseca, R. P., Rodrigues, C. C., Mello, C. B., Barbosa, T., & Miranda, M. C. (2011). Desenvolvimento do Instrumento de Avaliação Neuropsicológica Breve Infantil NEUPSILIN-INF. *Psico-USF, 16*(3), 297-305.

Salles, J. F., Fonseca, R. P., Miranda, M. C., Berlin, C., Rodrigues, C. C., & Barbosa, T. (in press). *Instrumento de Avaliação Neuropsicolinguistica Breve Infantil NEUPSILIN-INF.* São Paulo: Editora Vetor.

Salthouse, T. A., & Pink, J. E. (2008). Why is working memory related to fluid intelligence? *Psychonomic Bulletin and Review, 15*(2), 364-371.

Swanson, H. L. (2008). Working memory and intelligence in children: What develops? *Journal of Educational Psychology, 100*(3), 581-602.

Tillman, C., Nyberg, L., & Bohlin, G. (2008). Working memory components and intelligence in children. *Intelligence, 36*(5), 394-402.

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: An examination of simple and complex spans and their relation to higher order abilities. *Psychological Bulletin, 133*(6), 1038-1066.

Unsworth, N., Redick, T., Heitz, R., Broadway, J., & Engle, R. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635-654.

Vandierendonck, A., Kemps, E., Fastame, M. C., & Szmalec, A. (2004). Working memory components of the Corsi blocks task. *British Journal of Psychology, 95*(1), 57-79.

Villaseñor, E., Martín, A., Díaz, E., Rosselli, M., & Ardila, A. (2009). Effects of parents' educational level, school type and gender on the development of attention and memory. *Revista Latinoamericana de Psicología, 41*(2), 257-27.