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Relationships between executive functions tasks in late childhood

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Abstract

Executive functions (EF) is a general term that refers to cognitive processes designed to organize and adapt human behavior in situations that require planning and decision making, problem solving, initiation and inhibition of actions, and adapting to changes. Among the main components of executive processes, we can emphasize the ability to inhibit and to present cognitive flexibility due to changes. Understanding the relationships among the various components of EF in adults and children has been a focus in the literature. However, these processes are complex and multiple. The present study sought to determine whether correlations exist among performances measured by different tools used to evaluate EF in school-age children. The sample comprised 59 children aged 8 to 12 years attending public schools. Participants were assessed using verbal fluency tasks and narrative discourse with the Montreal Battery of Evaluation of Communication–MAC Battery, random-number generation, the Hayling Test, the Bells Test, and the n-back test. Correlation analyses were performed using Pearson's correlation coefficient. The results suggested a closer relationship among some components of the evaluation of EF, especially among tasks that assess inhibition and cognitive flexibility. **Keywords:** executive functions, inhibition, cognitive flexibility, working memory.

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Introduction

The term executive functions (EF) refers to a complex set of neurocognitive processes that involve the conscious control of thoughts and actions (Kerr & Zelazo, 2004) designed to organize the conduct of an individual to meet goals in situations that demand planning and decision making, problem solving, initiation and inhibition of actions, and responses to new or more difficult situations (Hughes & Graham, 2008). Executive functions comprise the participation of different components such as the central executive of working memory, inhibition, cognitive flexibility, and self-monitoring, among others (Chan, Shum, Toulopoulou, & Chen, 2008; Marcovitch & Zelazo, 2009). Previous studies focused on understanding how these executive components are related in children (Huizinga, Dolan, & Van Der Molen, 2006; Kerr & Zelazo, 2004), but this knowledge is still controversial and has not been sufficiently studied (Rosselli & Ardila, 2003).

Increasingly, more standardized instruments are available for assessing the components of EF (Lezak, Howieson, & Loring, 2004; Strauss, Sherman, & Spreen, 2006). Unclear, however, are what each test or assessment task precisely assesses and the components that are part of a well-accepted and well-known model of executive processing. In general, the neuropsychological assessment of EF tends to be complex and is evaluated by a range of cognitive components, making the differentiation of the various processes included in the performance of the same task difficult (Abusamra, Miranda, & Fererres, 2007; Strauss et al., 2006).

To better understand this relationship between executive components and the clinical paradigms developed for their assessment, exploratory correlational studies have become important for initial discussions of the interface among the different executive subprocesses involved in the different steps of the execution of a neuropsychological task (Ciesielski, Lesnik, Savoy, Grant, & Ahlfors, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Hughes & Graham, 2008; Kray, Kipp, & Karbach, 2009; Kristensen, 2006; Mazzocco & Klover, 2007; McAuley & White, 2010; Vuontela, Steenari, Carlson,

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Koivisto, Fjallberg, & Aronen, 2003). Some studies highlighted an important relationship among executive components, such as between inhibition and the central executive of working memory. The relevance of the role of age in executive development and determining the possible maturation phases of EF during childhood have been the focus of previous studies (Brocki & Bohlin, 2004; Brocki, Eninger, & Thorell, & Bohlin, 2010; Brocki, Randal, Bohlin, & Kerns, 2008). Brocki & Bohlin (2004) demonstrated the progressive evolution of executive processes, suggesting three maturational phases of cognitive ability: (1) 6-8 years of age, (2) 9-12 years of age, and (3) adolescence. These phases emphasize inhibition and working memory, with an important peak of development that occurs at the beginning of late childhood.

This knowledge becomes important to the field of clinical neuropsychology because many neurological and psychiatric disorders are associated with dysfunctional EF, including attention deficit/hyperactivity disorder (ADHD), pervasive developmental disorders, and schizophrenia (Brocki et al., 2008; Rizzutti, 2008; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009; Wilson, Christensen, King, Li, & Zelazo, 2008). Although many disorders include in their characterization deficits in EF, unknown are which executive components are impaired or spared in each pathology. In this context, the present study investigated the possible relationships among executive components measured using different tools that are used to evaluate EF in 8- to 12-year-old children.

Methods

Participants

The initial sample consisted of 72 children from public schools in Porto Alegre, Brazil and its metropolitan area. Participants ranged in age from 8 to 12 years (2nd to 6th school grade). Inclusion criteria were the following: self-reported health and education conditions, absence of history of school failure, no general complaints concerning learning or oral language, no uncorrected sensory difficulties, or current or previous history of neurological or psychiatric disorders. Of the initial sample, 13 children were excluded for not meeting one or more of the criteria including (a) 10 children who presented a history of oral language complaints (for example, changes in speech, language delay, etc.), school failure, psychological disorders, neurological or sensory uncorrected in a sociodemographic questionnaire, cultural and health aspects of self-reporting by those responsible, (b) one child who had a score that suggested intellectual difficulty in the Raven Colored Progressive Matrices Test (Angelini, Alves, Custódio, Duarte, & Duarte, 1999) with a cutoff grade III classification and average 26th percentile, and (c) two children who showed signs that suggested ADHD on the Conners Abbreviated Questionnaire-Teacher version (Barbosa & Gouveia, 1993; Conners, 1969) with cutoff points established for each age group (Brito, 1987; Brito & Pinto, 1991) in Brazilian children. The final sample included 59 children (M = 10.69, SD = 1.44) with a mean education of 3.92 years (SD = 1.44 years). The final sample consisted of 25 boys and 34 girls (8 years old, $n = 12$; 9 years old, $n = 10$; 10 years old, $n = 10$; 11 years old, $n = 15$; 12 years old, $n = 12$) with no differences in the sample distribution among the different ages ($p = .319$). After the parents or guardians answered a sociodemographic questionnaire regarding cultural and health aspects (M = 26.52, SD = 5.39), the Colored Progressive Matrices Test (M = 79.35, SD = 16.56) and Conners Abbreviated Questionnaire–Teacher version (M = 1.77, SD = 2.82) were applied.

Procedures and instruments

This study was approved by the Ethics Committee in Research of the Pontifical Catholic University of Rio Grande do Sul (no. 09/04864). Childrens' participation in the study was voluntary and anonymous, and a consent form was signed by parents or guardians. Children were assessed individually at school under positive conditions for evaluation, and each session lasted ~1 h. First, a brief rapport was established with each child. The children were then assessed using a battery of neuropsychological tests that were administered in two alternate orders to control for the effect of order and possible interference between similar subtests.

1) Unconstrained, phonemic, and semantic verbal fluency subtests of the Montreal Battery of Evaluation of Communication (MAC; Fonseca, Parente, Coté, Ska, & Joanette, 2008), children's version. In this task, components of planning, verbal and initiation inhibition, lexical memory, working memory, and cognitive flexibility were evaluated. In the unconstrained modality, the child evokes all of the words to remember for 2.5 min and cannot say names or numbers. In the phonemic and semantic fluency modality, the child should evoke words that begin with the letter "p" and are clothes, respectively, both in 2 min. The total score of correct words was calculated for each modality.

2) Random-Number Generation (adapted version of the original task of Towse & Neil, 1998; Towse and McLachlan, 1999). The executive components of inhibition, cognitive flexibility, and self-monitoring were evaluated. This task is characterized by the production of random numbers within a short period of time. The child is asked to verbalize numbers between 1 and 10 every time the child hears a sound stimulus prerecorded on audio equipment. The child is instructed not to say

consecutive numbers and not to repeat the numbers too closely to each other, considering as perseverations those numbers repeated up to three ranges of evocations. The task is performed in two parts: the first part is performed at a speed of 2 s, and the second part is performed at a speed of 1 s. Each part lasts 90 s. We calculated the total number of hits for each speed (maximum score of 45 for 2 s; maximum score of 90 for 1 s).

3) Bells Test (adapted version of Gauthier, Dehaut, & Joanette, 1989; Vannier, Chevignard, Pradat-Diehl, Abada, & De Agostini, 2006). This task mainly assesses selective attention and processing speed and is characterized by the cancellation of targets (i.e., handle and clapper bells) among distractors (i.e., bells with handles only or clapper and other objects). The child is instructed to cancel all of the bells he/she sees as soon as possible. In this study, the time to perform the task was measured and reflected processing speed.

4) n-back Test (Ciesielski et al., 2006; Vuontela et al., 2003). This task examines the central executive component of working memory and was adapted for children from Dobbs & Rule (1989). In this study we used the visual and auditory n-back versions. In the visual n-back test, the child is shown a sequence of pictures of animals and is instructed to name them. The child then must repeat the name of the animal presented prior to the last animal (n = 1) until the child verbalizes the names of two and three animals (n = 2, n = 3) before the animal was presented. In the auditory n-back test, the child hears a sequence of numbers in which a number is displayed every second. After the child is told to repeat each number verbalized, then he/she needs to evoke the number presented before the last digit and so on, until the child repeats the previous three numbers before the verbalized number (n = 1, n = 2, and n = 3). In this study we calculated the span of the sequence of 10 digits for each level of complexity.

5) Hayling Test (Burgess & Shalice, 1997; Fonseca, Oliveira, Gindri, Zimmermann, & Rappold, 2010 [Brazilian version]. The components of inhibition of initiation of a verbal response were analyzed. The objective of the test is to complete 30 sentences, divided into two parts (A and B) with 15 sentences in each part. In part A, a sentence is completed with a word that fits the requirements generated by the syntactic-semantic context as soon as possible. In part B, the child must complete the sentence with a word that is inconsistent with the general meaning of the sentence as soon as possible. In this task, the variables measured are total reaction time, error score (/15 on part A and /45 on part B, with each error being scored between 1 and 3 in part B), and a complementary relationship score between the run times of parts A and B (B/A).

Data analysis

Data were analyzed with SPSS software, version 15.0, with a significance level of $p \leq .05$. Correlations were verified using Pearson's correlation coefficient after verifying whether the data were parametric using the one-sample Kolmogorov-Smirnov test.

Results

We analyzed the possible correlations between span scores, hits, errors, and time in the executive component tasks investigated in this study. Table 1 shows all of the variables of executive performance (mean and standard deviations) examined in the children.

In general, by observing the maximum score for each task versus the average score for every test in Table 1, the children's scores were 30-70% correct. The most difficult paradigms were the n-back test in their third most complex level of difficulty *(n* = 3) and part B of the Hayling Test.

Table 2 shows the correlation coefficients and significance levels between the correct answer scores on the random-number generation test, time and score errors on the Hayling Test, time score on the Bells Test, span score on the visual and auditory n-back tests, and hit score on the verbal fluency test.

Among the most significant correlations ($p \leq .01$), hit scores on the random-number generation test were

Table 1. Descriptive data of performance on tests of verbal fluency, executive function, random-number generation, the Hayling Test, the n-back Test, and the Bells Test

EF score (maximum score)	Average	(SD)
VF unconstrained (hits)	44.51	(21.51)
RNG 2 s (hits/45)	37.21	(5.03)
RNG 1 s (hits/90)	56.24	(12.85)
VF phonemic (hits)	14.42	(6.03)
VF semantic (hits)	17.25	(4.92)
Bells (time)	113.56	(36.42)
N-back visual 1 - span (/10)	8.85	(2.26)
N-back visual 2 - span (/10)	4.42	(3.15)
N-back visual 3 - span (/10)	2.66	(3.24)
N-back auditory 1 - span (/10)	8.46	(2.47)
N-back auditory 2 - span (/10)	4.05	(2.75)
N-back auditory 3 - span (/10)	2.53	(2.94)
Hayling (part A time)	33.49	(25.57)
Hayling (part A errors/15)	.68	(.86)
Hayling (part B time)	59.92	(32.05)
Hayling (errors/45)	16.53	(9.75)
Hayling (part B time–part A time)	25.86	(34.80)

A, average; SD, standard deviation; EF, executive function; VF, verbal fluency; RNG, random-number generation.

Table 2. Correlations between accuracy and time scores on the verbal fluency tasks, Bells Test, random-number generation test, Hayling Test, and n-back test

		VF Un-constrained	VF Phonemic	VF Semantic	Bells Test	RNG 2 s	RNG 1 s
RNG	2 s	.280*					
	1 s		.359**				-
Hayling	Part A time	-.339**	-.265*			-.266*	
	Part A errors/15		-.409**	-.257*			
	Part B time	-.549**	-.267*	-.418**	.276*		
	Part B errors/45	-.381**		-.351**			
	Part B time - Part A time	-.266*					
N-back visual	1 - Span					.341**	
	2 - Span			.266*		.356**	
	3 - Span					.438**	
N-back auditory	1 - Span					.294*	
	2 - Span		.303*			.362**	.380**
	3 - Span			.257*		.352**	.360**

*$p \leq .05$, **$p \leq .01$.
RNG, random-number generation; VF, verbal fluency.

positively correlated with the variable numbers of correct spelling and verbal fluency scores on the visual and auditory n-back tests. With regard to the Hayling Test, all scores were negatively correlated with the hit scores on the verbal fluency test with the exception of the errors score/15 on part A. This, in turn, showed a negative correlation with correct spelling scores on the verbal fluency test.

Overall, mild to moderate correlations were found between some measures of verbal fluency, random-number generation, and test and runtime on the Hayling Test and on the Bells Test, showing that the correlations between the executive components such as inhibition and cognitive flexibility occurred with different levels of intensity. The findings suggest a relationship between the cognitive flexibility and inhibition components and between cognitive flexibility and the central executive of working memory. Table 3 shows the correlations between performance on the n-back test and Hayling Test. Notably, some correlations were absent, such as between the scores of unconstrained verbal fluency, which requires more executive strategies of initiation and working memory or sustained attention measures.

As shown in Table 3, among the most significant correlations ($p \leq .01$), the scores on part B of the Hayling Test were negatively correlated with the scores on the visual n-back test and second level of difficulty in auditory n-back *(n* = 2). The time variable in parts A and B of the Hayling Test showed a negative correlation, scoring 1 on the visual n-back test and 2 and 3 on the visual n-back test, respectively. Table 3 also presents the absence of correlations between attention scores and working memory scores, indicating associations between the central executive of working memory, processing speed, and verbal inhibition.

Table 3. Correlations between accuracy and time scores on the n-back and Hayling Tests

		N-back visual 1 - span	N-back visual 2 - span	N-back visual 3 - span	N-back auditory 1 - span	N-back auditory 2 - span	N-back auditory 3 - span
	Part A time	-.302*					
	Part A errors/15						
Hayling	Part B time		-.312*	-.297*			-.357**
	Part B errors /45		-.376**	-.320*		-.301*	-.519**
	Part B time– Part A time						-.295*

*$p \leq .05$, **$p \leq .01$

Discussion

The aim of the present study was to explore the relationships between components of EF assessed by different paradigms in school-age children. The correlations between EF measurements ranged from 30% to 70%, the variability of which was probably related to the inclusion of children who ranged in age from 8 to 12 years (Davidson et al., 2006; Matute, Chamorro, Inozemtseva, Barrios, Rosselli, & Ardilla, 2008). Considering the results observed here, significant correlations were found, both positive (accuracy of correct answers) and negative (accuracy of incorrect answers and time), among several of the components examined in this sample, especially among components of inhibition, cognitive flexibility, and the central executive of working memory.

Considering that verbal fluency tasks are defined as measures of cognitive flexibility and search strategies in the production of words (Nieto, Galtier, Barroso, & Espinosa, 2008) and require linguistic and mnemonic executive processes, we expected that the correlations would be common with the other components examined in this study. The literature supports this hypothesis, indicating a relationship between the development of language processes and EF, such as the central executive of working memory and cognitive flexibility (Sesma, Mahone, Levine, Eason, & Cutting, 2009).

Phonemic verbal fluency was positively correlated with the accurately generated random-number scores (1 s), indicating that a greater number of words produced correctly from a restrictive language criterion was associated with a greater number of hits in the task of generating random numbers. Orthographic verbal fluency has been strongly related to verbal initiation and inhibition, with strong activation of the frontal cortical and subcortical regions (Abbott, Waites, Lilywhite, & Jackson, 2010). The random-number generation test showed a strong demand for inhibitory control and self-monitoring (Towse & MacLachlan, 1999). The correlation suggests a strong relationship between the inhibitory processing of linguistic self-monitoring and switching. Both tasks likely have similar underlying mechanisms. Festman, Rodriguez-Fornells, & Münte (2010) reported a strong association between the language alternation and inhibitory components, which were demanded by both tasks examined in this study. This association was found between random-number generation (2 s) and unconstrained verbal fluency.

These correlations were expected because to produce the answers that the random-number generation task demands, the children can overcome the tendency to produce automatic sequencing. To meet this demand to produce words with spelling criteria, the child must perform groupings or phonetic spelling. When that category is exhausted, the child can utilize a new category. This involves the ability to inhibit responses unrelated to the context and cognitive flexibility to use new strategies (Nieto et al., 2008; Ostrosky-Solis, Gutierres, Flores, & Ardila, 2007), indicating the participation of these components in both tasks. However, as the speed increases in random-number generation, which requires more cognitive flexibility and inhibitory control, correlated only with verbal fluency, the presence of *a priori* search criteria in the recall of words appeared to demand greater verbal inhibition in the children in our sample.

The tasks of unconstrained and phonemic verbal fluency showed a negative correlation with parts A and B of the Hayling Test, indicating the existence of a relationship between the number of words recalled in two modalities of verbal fluency and the time the child needs to verbalize the word to complete each sentence in the Hayling Test. This relationship suggests the demand for the selective attention and processing speed implicit in verbal fluency because the child must recall the words as quickly as possible.

Regarding fluency with the *a priori* criteria for recall (phonemic and semantic), a negative correlation was found with the error scores on part A of the Hayling Test. A greater number of words generated with the recall criteria was associated with a lower number of errors on part A of the Hayling Test (words that are semantically related to the context of the phrase. This result demonstrates the relationship with components of attention, initiation and inhibition, and verbal-semantic linguistic processing. To accomplish the task, the child needs to have access to semantic memory (multiple forms of knowledge related to crystallized intelligence, information systems, linguistic and phonological structure, and syntactic and semantic memory) that is associated with the exe executive abilities discussed above. In addition to the correlation with the unconstrained and phonemic verbal fluency tasks, the time score on part B of the Hayling Test was negatively correlated with semantic verbal fluency accuracy. This finding supports the hypothesis that semantic verbal fluency is linked to executive components, with the strong involvement of frontal and temporal regions (Buchweitz, Mason, Tomicht, & Just, 2009; Houdé, Rossi, Lubin, & Jolie, 2010).

Another interesting finding was the negative correlation between the scores on the random-number generation task and time scores on part A of the Hayling Test. A greater number of hits on the generation task was associated with less time in the recall of words semantically related to phrases. This result suggests the involvement of focused attention, inhibition, verbal processing speed, and self-monitoring.

With regard to the processing speed variable measured with the Bells Test, a positive correlation was found with part B of the Hayling Test, suggesting that the time to cancel the bells was related to the executive processing speed component (Gauthier et al., 1989). Processing speed is a performance variable that has been insufficiently examined in studies with children that used cancellation paradigms (Vannier et al., 2006). Given the importance of this cognitive component in infant neurodevelopment and its strong relationship with accuracy, processing speed should be investigated further.

Moderate correlations were found between some components such as semantic verbal fluency and the visual n-back 2 and auditory n-back 3. This finding further supports the association between inhibition and cognitive flexibility of semantic verbal fluency to the central executive component of working memory measured by n-back (Ciesielski et al., 2006; Davidson et al., 2006; Nieto et al., 2008).

Positive correlations were found between the n-back tests and other EF paradigms, which were stronger than the correlations found among other tasks, with performance in random-number generation in the two-speed versions as well as in two levels of difficulty of the n-back. More specifically, the random-number generation test (1 s) showed a strong correlation with the auditory n-back 2 and 3. This result supports the correlation between the inhibition component and the central executive of working memory. A greater degree of complexity was associated with a greater demand of the inhibitory component and with a greater manageability of the central executive. This relationship is reinforced by studies that found that n-back performance was significantly correlated with performance on tasks that assess inhibitory components such as the FAS, the traditional version of the verbal fluency paradigm (letter-based starting with F, A and S), Stroop test, and Wisconsin Card Sorting Test (Ciesielski et al., 2006; McMillan, Laird, Witt, & Meyerand, 2007). The auditory input that is common among the tasks must have also contributed to such correlations.

Additionally, negative correlations were found between the n-back tests and the error and time scores on the Hayling Test. The visual n-back test and the second and third level of the auditory n-back were negatively correlated with the errors score/45 on part B of the Hayling Test, considered one of the most sensitive instruments in the evaluation of verbal initiation and inhibition (Burgess & Shalice, 1997; Siqueira, Scherer, Reppold, & Fonseca, 2010). This finding suggests that the longer the n-backs 2 and 3 span of the child, the fewer are the errors on part B of the Hayling Test. These modalities of the n-back test and Hayling Test may require greater demands for the components of inhibition.

Overall, the present study may contribute to a growing understanding of more specific relationships among different components of EF. However, the results should be interpreted with caution, considering the limitations of the experimental design, which promotes an exploratory analysis with a relatively small sample. Nonetheless, this study contributes important data that reflect the underlying components of the intersection among different tests. We found evidence that verbal fluency tasks, random-number generation, the Hayling Test, and the n-back test have components in common, especially inhibitory control, cognitive flexibility, processing speed, and the central executive of working memory. These data are consistent with the literature, which generally found relationships only between the central executive of working memory and inhibition. The present results also highlight the importance of examining the maturational stages of each executive component during childhood (Brocki & Bohlin, 2004; Brocki, Eninger, Thorell, & Bohlin, 2010; Brocki et al., 2008).

Future studies should examine larger samples and perform regression analyses, which may confirm the preliminary findings obtained in the present exploratory analysis. It is still highly relevant to clinical child neuropsychology that such relationships are investigated in neurological and psychiatric populations to identify the dissociations between spared and impaired executive abilities.

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