Pontifícia Universidade Católica do Rio de Janeiro

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Cognitive development profiles: relationship between measures of executive function, memory and attention in 7-14 years old students.

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-graduação em Psicologia (Psicologia Clínica) of the Departamento de Psicologia, PUC-Rio, as partial fulfillment of the requirements for the degree of Mestre em Psicologia.

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Rio de Janeiro
February 2016

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do Rio de Janeiro

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Bibliographic data

Gabrig, Iasmin Andrade

Cognitive development profiles: relationship between measures of executive function, memory, and attention in 7-14 years old students./ Iasmin Andrade Gabrig; advisor: Helenice Charchat Fichman. – 2016.

91f. : il. (color.) ; 30 cm

Dissertação (Mestrado) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2016.

Inclui bibliografia

1. Psicologia – Dissertation. 2. Desenvolvimento infantil. 3. Neuropsicologia. 4. funções Executivas. 5. Memória.6. perfis cognitivos. I . Charchat-Fichman, Helenice. II. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Psicologia. III. Título

CDD: 150

Acknowledgments

I dedicate this work to my Advisor Helenice Charchat Fichman and co-advisor Rosinda Oliveira Martins, who made this project viable. I am immensely grateful for the opportunity and encouragement offered to me to continue coursing my academic trajectory.

A number of people from PUC-Rio and UFRJ were instrumental in getting this work into its final shape. I am particularly grateful to the handful of people – colleagues and professors – who took time out of their immensely busy schedules to help me in all the logistical aspects of collect, correct and analyzing these data. I thank them all for their generosity with their time and expertise.

I am also especially grateful for the tremendous emotional support that I received from my partner and friends during these times. You all made my trajectory so much lighter and relaxed. You are and will always be a source of wonderful inspiration. I thank you sincerely, and look forward to working with you in the future.

And finally, I thank Capes and PUC-Rio for the granted aid, without which this work could not have been done.

Abstract

Gabrig, Iasmin Andrade; Charchat-Fichman, Helenice (Advisor). **Cognitive development profiles: relationship between measures of executive function, memory and attention in 7-14 years old students.** Rio de Janeiro, 2016. 91p. MSc. Dissertation – Departamento de Psicologia, Pontifícia Universidade Católica do Rio de Janeiro.

Despite the significant heterogeneity among the Brazilian population, few national studies exist that investigate the trajectories of different cognitive functions throughout healthy development. In order to explore the relationship between executive functioning (EF), memory, and attention in children and adolescents, this project condenses information from two studies of the characterization of cognitive development. Both studies were based on the results of four classical neuropsychological paradigms (verbal fluency, Rey complex figure, Rey auditory- verbal learning, and Stroop test) applied to the same sample of 365 low-income students aged 7 to 14 in Rio de Janeiro. The first study investigated the patterns of interaction between EF and memory and their subdomains. An illustrated scheme of interactions between neuropsychological variables is proposed. The second study aimed to identify similar cognitive functioning profiles among the age group studied. A classification model based on performance levels in organization, memory, and attention is presented. Cluster analyses were employed in both studies. In the first study, cluster analysis was used to examine a model of interaction between variables. In the second, it was used to create a classification method to group individuals who function at similar levels. The results of this dissertation suggest that, although EF domains play an important role in the processes of acquisition and retention, they are clearly distinguishable from memory domains. Additionally, the most significant distinguishing factor between different cognitive profiles throughout childhood is executive performance. At the same time, the memory and attention variables appear to cause subtler and less relevant changes to overall functioning. These results are consistent with neuropsychological literature, which indicates a non-homogeneous cognitive profile during development.

Keywords

Child development; **N**europsychology; Executive functions; Memory; Cognitive profiles.

Resumo

Iasmin Andrade Gabrig; Charchat-Fichman, Helenice. **Perfis de desenvolvimento cognitivo: relação entre medidas de funções executivas, memória e atenção em estudantes de 7 a 14 anos**. Rio de Janeiro, 2016. 91p. Dissertação de Mestrado – Departamento de Psicologia, Pontifícia Universidade Católica do Rio de Janeiro.

A despeito da grande heterogeneidade populacional brasileira, poucos estudos nacionais investigam as trajetórias de diferentes funções cognitivas ao longo do desenvolvimento saudável. A caracterização do perfil de desenvolvimento infantil brasileiro pode contribuir com informações relevantes para identificar padrões de normalidade e patologias ao longo da maturação neural na infância. Possibilita também o diagnóstico precoce e o planejamento interventivo adequado, evitando assim o surgimento ou agravamento de déficits posteriores. Com o objetivo de explorar as relações entre funcionamento executivo (FE), memória e atenção em crianças e adolescentes, o presente trabalho condensa informações obtidas em dois estudos de caracterização do desenvolvimento cognitivo infantojuvenil. Ambos estudos se basearam nos resultados de quatro paradigmas neuropsicológicos clássicos (Fluência Verbal, Figura de Rey, Aprendizagem Auditivo-Verbal de Rey e Stroop), aplicados em uma mesma amostra de 365 estudantes de 7 a 14 anos das camadas socioeconômicas C, D e E do Rio de Janeiro. Análises de conglomerados constituíram a base pré-classificatória em ambos estudos, como modelo de interação entre variáveis no primeiro e como técnica de agrupamento de casos no segundo. O primeiro estudo investigou o padrão de interação entre FE, memória e seus respectivos subdomínios. Um esquema de associação entre variáveis neuropsicológicas é proposto. Os resultados sugerem que, embora os domínios de FE desempenhem importantes papeis nos processos de aquisição e retenção, eles são claramente distinguíveis dos domínios de memória. O segundo estudo objetivou identificar perfis de funcionamento cognitivo similares dentre as faixas etárias estudadas. A hipótese de 4 agrupamentos identificados na análise exploratória foi replicada na análise confirmatória. A análise de agrupamento não-hierárquico, por ser um método interativo, permite que os casos se desloquem de grupo a grupo durante a análise, em função de sua similaridade ou dissimilaridade com outros casos, num limite de até 10 interações. Com base nessa subdivisão de casos, um modelo de classificatório foi apresentado, discriminando os sujeitos de acordo com suas performance em organização, memória e atenção. Os 4 grupos se desmembram em (1) duas classificações generalistas (sujeitos de alta ou baixa performance global), (2) duas classificações intermediárias (sujeitos com desempenho homogêneo ou sujeitos com baixo funcionamento executivo acentuado) e, (3) mais duas classificações específicas (sujeitos de alto ou baixo controle atencional). A ampla maioria dos sujeitos se enquadra na classificação de baixa performance global, de perfil homogêneo. A característica que melhor determina o grupo de maior desempenho global são as variáveis de funcionamento executivo. O maior fator de distinção entre os diferentes perfis cognitivos ao longo da infância também é a performance executiva, enquanto as variáveis de memória e de atenção demonstram mudanças mais sutis e menos determinantes para o funcionamento global. Os resultados de ambos projetos estão em concordância com os padrões descritos em estudos sobre Desenvolvimento Cognitivo Diferencial, tais quais apontam a existência de uma curva de desenvolvimento não-linear e não-homogênea ao longo da trajetória de desenvolvimento infantil.

Palavras-chave

Desenvolvimento infantil; Neuropsicologia; Funções Executivas; Memória; Perfis cognitivos.

Summary

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1
Introduction

1.1 Different concepts about cognitive changes in development

Changes in the structure of intelligence through the lifespan are a central topic in neuropsychological research (CRAIK; BIALYSTOK, 2006; JUAN-ESPINOSA et al., 2002), but this topic is not new in the field. The interest in understanding how the transition of cognitive functioning from infancy to the mature adulthood happens has been a focus of scientific research since the beginning of the 20th century. Binet and Simon's (1916) studies led to the creation of the first system of classification for the performance of children and adolescents in different tasks related to high cognitive functions, such as verbal, spatial, and analytical abilities. After recognizing the apparent linear growth pattern of cognitive skills in children, Binet introduced the concept of mental age, which is determined based on performance characteristics expected to occur at a given chronological stage (BOAKE, 2002).

Spearman (1904) was a pioneer in the analysis of cognitive batteries; he sought to identify which factors influence the growth of mental abilities in human development. Because of the numerous positive correlations that he identified in intelligence tests, he proposed the existence of a unique co-factor that explains the overall incremental changes in mental abilities This co-factor is known as general intelligence, or the g-factor. Since the discovery that the g-factor increases at a linear rate from childhood until early adulthood, several researchers have come to regard the organization of intelligence as a static process. These researchers assume that this underlying general intelligence heavily influences the performance of all cognitive tasks (LI et al., 2004).

Despite the wide dissemination of this theory and its subsequent impact on cognitive studies, many critics argue against the assumption that a unique factor explains intelligence levels. The most common criticism is the fact that this theory ignores possible developmental transformations in the organization of intellectual skills during the course of life. Most studies of cognitive development tend to analyze only the growth of isolated functions over time, without taking into account the interaction between these functions during the lifespan. As Li et al. (2004) articulate, “comparative analyses of the relations between changes in multiple cognitive domains are almost absent from the developmental literature.”

This approach can lead to several precipitate conclusions, such as the notion that inhibitory control only emerges at the age of four (as mentioned by Williams et al., 1999). When researchers analyzed different cognitive functions at the same time, results suggested an alternative explanation for the lack of inhibitory performance before that age: perhaps inhibitory control is not a unified ability (DIAMOND, 2013). Additionally, it is possible that not all inhibitory domains emerge at the same time (MIYAKE et al., 2000) and that perhaps when one inhibitory ability is absent it is often replaced by another executive capacity. However, as mentioned by Friedman and Miyake (2004), this replacement may not have the same level of efficiency.

Another methodological problem that promotes biased impressions of development is that studies are frequently based only on total scores of intelligence, such as IQ measures. In fact, the use of a unique global measure to quantify cognitive functioning led researches to believe that cognitive abilities develop in a homogeneous and linear progression over time. This static notion of developmental changes suggests a uniform growth in performance, despite the possibility that not every cognitive domain improves at the same rate (LI et al., 2004).

A second problem with this static notion of development is that it assumes that the occurrence of intellectual changes is highly dependent on chronological age. Seeing age as a fundamental factor in cognitive improvement tends to cause researchers to overestimate the influence of neurobiological maturation on intelligence. At the same time, it motivates some studies to overlook another important underlying factor: the contribution of experience. As established by Garrett (1946) , “it seems highly probable that neural maturation has much to do with this differentiating process [in cognitive development], but increasing experience and diverging interests must also contribute heavily."

In opposition to the static notion of intellectual development, Cattell's (1987) investment theory was one of the first theories to account for changes in the structure of intelligence over time. Cattell postulated that in the first stages of life, a person has only a single and general mental ability. Considering the power of experience, though, such general ability is viewed as capital to be invested in other sub-skills, such as memory, learning, verbal, or manual capacities (SCHWEIZER; KOCH, 2001). As an individual grows, more sub-skills are obtained, though with different levels of specialization. This process of structural changes in intelligence cited by Cattell (1987) is commonly referred to in scientific literature as the differentiation hypothesis. Some empirical evidence provides positive results that are in accordance with this theory (DE FRIAS et al., 2007; JUAN-ESPINOSA et al., 2006).

Since the first appearance of the differentiation hypothesis in scientific papers, many efforts have been undertaken to identify how neuropsychological functions progress or interact throughout development. Recent findings generally corroborate the notion of the differentiation hypothesis among healthy populations. According to this hypothesis, cognitive functioning begins at a more general point in infancy, and then it assumes gradual levels of specialization as a person ages (BRONFENBRENNER; MORRIS, 2006; SHING; DIAMOND; DAVIDSON, 2010).

This hypothesis is supported by the interpretation of neuroimaging studies that suggest that similar brain circuits are recruited both in children and in adults but that the magnitude of the activation of these circuits is typically larger and more diffuse in infants than in older subjects (CARLSON; MOSES; BRETON, 2002; GIEDD et al., 1999). The hypothesis also arises from longitudinal neuropsychological evaluations that indicate a gradual decrease in the interdependence of different neuropsychological functions during the transition from childhood to adolescence (CRAIK; BIALYSTOK, 2006; DIAMOND, 2002; SHING et al., 2010). According to these studies, the fact that numerous neuropsychological functions are interrelated in younger subjects suggests that a considerable overlap exists between cognitive domains in the first stages of life.

1.2 Inter-individual differences in cognitive functions

In other words, classical theories of intellectual changes tend to characterize development as a linear and homogeneous process related to specific chronological periods (SIEGLER, 1994). This assumption has had multiple consequences in clinical practices over years. For instance, an infant evaluation that reveals a gap between the performance of a specific child and the expected performance patterns of their age group was usually characterized as a developmental delay. However, since the emergence of the differentiation hypothesis, recent studies have placed less emphasis on the linear and chronological aspects of development. This hypothesis also takes into account a range of cognitive variability in healthy children, even when they are compared to the age group (CARLSON; MOSES, 2001; SIEGLER, 1994).

Although measures of global functioning as IQ follow a typical bell curve and suggest that a clear line separates subjects with normal and abnormal levels of functioning, intellectual development is not completely homogeneous. Cognitive patterns, especially in children, are not uniform. Neuropsychological styles assume numerous forms, depending on the specific biological and environmental characteristics of each individual. Certain deviations from the classical profile of development that is illustrated by the bell curve may be explained not as cognitive impartments but as the result of unique external factors.

Cognitive heterogeneity refers to the observation of severe subgroups of individuals who share key socio-demographic characteristics but present very different functional profiles. Heterogeneity is an expected factor in studies that focus on pathological conditions in development, such as ADHD and dyslexia (DE GRAAF et al., 2008; HEIM et al., 2008). These studies usually report the existence of multiple subgroups of individuals with specific profiles but who share the same general diagnosis. However, despite evidence that points to a vast range of neuropsychological profiles present in typical development (FAIR et al., 2012), cognitive heterogeneity is rarely investigated in healthy children. For example, even if two healthy children are the same age, gender, and nationality and they attend the same school, it is highly possible that both will not express the same levels of cognitive functioning over the course of their lives. Such differences occur because several factors exist beyond the mainstream socio-demographic factors that can influence intellectual development and consequently create subgroups with special neuropsychological patterns.

Several features that can influence development have been well established in empirical research; such factors include the socioeconomic status of people's parents, their levels of environmental stimulation, the type of education offered to them, and cultural traits that provide greater specialization in specific skills and not in others (CASEY; GIEDD; THOMAS, 2000; NOBLE; NORMAN; FARAH, 2005; ROGOFF; CHAVAJAY, 1995; TAMIS-LEMONDA et al., 2004). Because factors influencing infant development are so diversified across populations and several cognitive functions are highly dependent on these factors, researcher can expect to find significant variation in the cognitive profiles that manifest in childhood. An illustrative example of this hypothesis is evidence from developing countries. Juric et al. (2013) documented more variation in cognitive profiles within low-income populations. Theoretically, regions with higher levels of social inequality should tend to experience more heterogeneous neuropsychological performance.

1.3 Intra-individual differences in cognitive functions

In addition to variation between individuals, the performance of different functions by the same individual is often not uniform (DAVIDSON et al., 2006; SHING et al., 2010). These differences in distinct cognitive performances by some individuals are often called cognitive profiles (LETTERI, 1980). The term "cognitive profile" refers to a common pattern of neuropsychological functioning typically found in a certain population. These patterns provide clues for understanding details about the particular ways that each individual within a subgroup thinks, memorizes, or solves complex problems, even when the members of the group are similar in other aspects, such as age or gender, or when they present the same average intelligence. For example, two individuals who have the same average level of global functioning (such as the IQ measure) may have specific impairments or advantages in each of the domains that constitute that global measure of intelligence. One of the individuals may succeed more easily in verbal aspects, and the other may excel in executive functioning. However, both may have similar levels of functioning from a global perspective.

Looking only at global measures can minimize perceptions of individual differences. For example, it is common to find children who perform poorly in terms of memory span but who easily compensate for this obstacle using idiosyncratic strategies supported by their language and executive skills. These particular cognitive styles, such as memorizing information by using a conventional repetition approach or using mnemonics, tend to look very similar in terms of final results in a neuropsychological assessment. Some of these styles are presumably more advantageous than others in real life situations (DIAMOND, 2013; LETTERI, 1980).

In other words, not every cognitive function influences global functioning in the same way. Some abilities are more useful for achieving better neuropsychological performance than others and especially for accomplishing tasks that simulate real-life conditions (LETTERI, 1980). To elaborate, some studies suggest that a child’s performance on classical tests of executive functioning, memory, and attention control may be more accurate predictors of their future academic achievement than their performance of other more complex skills such as reading and arithmetic or measures of their global intelligence (CARRETTI et al., 2009; ST CLAIR-THOMPSON; GATHERCOLE, 2006). These data emphasize the importance of mapping the developmental trajectories of and the common relationships between these functions in order to establish more favorable conditions for development.

The hypothesis of a non-uniform relationship between has encouraged the development of numerous theories about how certain cognitive features cause different functions to develop. Based on Baddeley and Hitch’s (1974) model, many studies have already analyzed the factors that explain increases in three of the most important domains of learning: executive, memory, and attentional processes (HUIZINGA; DOLAN; VAN DER MOLEN, 2006; JURIC et al., 2013; SIEGLER, 2013). Currently, a consensus exists that these three skill sets develop interdependently. For example, it is well known that a person's memory capacities are highly dependent on executive abilities. The enlargement of retention capacity alone cannot explain improvements in the performance of complex span tasks. Currently, the most accepted explanation is that improvements in processing speed and, consequently, the ability to release more attentional resources supports the storage of larger amounts of information (FRY; HALE, 1996; KAIL, 1991).

Another common relationship that researchers examine is the connection between memory and attention control domains. Kane et al. (2003) hypothesized that individual variability in short-term memory span usually reflects differences in inhibitory capacity. In order for a person to absorb and store information in the short-term memory, it is necessary to prevent environmental distraction and interference from other events already encoded in the long-term memory (ENGLE et al., 1999; KANE; ENGLE, 2000). In turn, the development of executive functions results in better management of the strategies needed both to maintain and manipulate information involved in memory tasks (ENGLE et al., 1999). For these reasons, many authors consider the inhibitory control, an ability that involves both executive and attentional domains, as the most relevant factor for neuropsychological development (DIAMOND; GILBERT, 1989; RIDDERINKHOF et al., 1997).

1.4 General goals of this investigation

With the aim of analyzing the relationship between executive functioning, memory, and attention in children and adolescents, this study summarizes information obtained in two studies of heterogeneity in cognitive development. One of the goals of this dissertation is to describe the patterns of interaction found between cognitive domains during typical development and establish whether certain abilities constitute unified or multiple functions. The second goal of this dissertation is to characterize the heterogeneity found in the cognitive profiles of Brazilian infants and to group these infants into categories.

Both of the studies examined were based on the results of four classic neuropsychological paradigms applied to the same subjects: (1) Rey-Osterrieth complex figure; (2) verbal fluency test; (3) Rey Auditory Verbal Learning test; and (4) Stroop paradigm.

The copy of Rey-Osterrieth complex figure (ROCF) is extensively used in clinical practice to investigate visuospatial constructional functions and some aspects of planning and executive function (STRAUSS; SHERMAN; SPREEN, 2006; WABER; HOLMES, 1985). In this test, a complex geometric figure is presented to the subject, followed by the instruction to copy this figure in the best way he can.

Verbal fluency is commonly used in clinical and research settings as a measure of vocabulary and also executive functions (DANEMAN, 1991; STRAUSS; SHERMAN; SPREEN, 2006). In the former, the subject produces, within a limited time interval, as many words as possible within a given semantic category, while in the latter the words to be produced must begin with a given letter.

Rey Auditory Verbal Learning test (RAVLT) is the most widely used learning and memory assessment (STRAUSS; SHERMAN; SPREEN, 2006). It consists of a word list with few simple nouns. The subject listen to the list and then is asked to try to recall all words he is able to remember. The list is repeated several times, and after each repetition the subject try to recall again. The test also included a second list, with different nouns, in order to interfere in the learning of the first list.

The Stroop paradigm evaluates selective attention and cognitive flexibility measuring the shifting ability to suppress a usual response in favor of an unusual response (STRAUSS; SHERMAN; SPREEN, 2006). The word color Stroop task includes trials with minimal and maximal interference. In the minimal interference trials the subject has to name colors of dots or read words. In the maximal interference trials color names are printed in an incongruent color, and it is required that the subject name the color in which color names are printed.

The sample consisted of children aged 7 to 14 years old, with no history of neurological or neuropsychiatric disturbances, from families with monthly income between one and five times the national minimum wage (socio-economic classes c,d and e, as ascertained by an interview with their parents).

Cluster analyses were performed in both studies. It is an exploratory technique that has been used effectively to identify subjects with similar patterns of cognitive functioning. This method makes it possible to determine classification schemes based on neuropsychological performance and, in turn, it provides the basis for taxonomic interpretations of different subgroups of cases or variables (CLATWORTHY et al., 2005).

The two studies that informed this dissertation present several advantages. First, the investigation of multiple cognitive functions allows for amplified descriptions of how different cognitive factors interact during development. Additionally, the advantage of using data from the same sample is that it facilitates the construction of a unified hypothesis. Both studies explore the same set of data using similar statistical analyses but from two distinct perspectives. Finally, the sample studied covers the period of time from childhood to the intermediate phase of adolescence, thus providing an overview of cognitive functioning over a significant developmental period.

The second chapter presents the study titled “Development Patterns of Executive Functions and Memory in Brazilian Students: Relationships Between Domains,” which aimed to investigate how the different subdomains of executive and memory functions are related throughout infant development. An illustrated scheme of interactions between these domains is presented.

The third chapter reviews the study titled “Subgroups in Cognitive Development: Distribution of Brazilian Students Aged 7-14.” Taking into account the wide neuropsychological variability found in Brazilian children and adolescents, this study explored subgroups with similar patterns of cognitive functioning throughout development. In the study, a classification model was proposed based on performance levels in organization, memory, and attention scores. The study also examined which factors contribute to the peculiarities found in each cognitive profile. Finally, the “Final Considerations” section of this paper presents a brief discussion of both chapters.

2. STUDY I - Development patterns of executive functions and memory in Brazilian students: relationships between domains

2.1 Introduction

Executive functions (EF) are described as high-level cognitive functions that are recruited when conscious control is required (ALVAREZ; EMORY, 2006). The term "Executive Functions" is often used to describe cognitive domains such as interference inhibition, planning, set-shifting, and verbal fluency (JURADO; ROSSELLI, 2007). EF mediate the capacity to organize thoughts in a goal-directed manner and have been described as essential for academic success and learning (BERG, 2008; BLAIR; RAZZA, 2007a; BULL; ESPY; WIEBE, 2008; DURAND et al., 2005; SUBOTNIK, 2012). Studies have suggested that storage capacity in short-term memory and EF operate in a counterbalanced system (CASE; KURLAND; GOLDBERG, 1982; PASCUAL-LEONE, 1970). When storage demands in certain tasks exceed the storage capacity available, the processing capacity takes over to prevent information decay and vice-versa.

According to some authors (CASE; KURLAND; GOLDBERG, 1982; CHI, 1977; DEMPSTER, 1981), when processing demands are controlled, storage capacity in short-term memory reaches a ceiling effect at approximately 5 years of age and remains relatively constant after that point. However, the efficiency with which data are processed (due to the growing executive abilities in adolescence) releases storage capacity, thereby enabling increased information handling. In other words, increasing demands of storage are not met by increments in memory storage itself; these demands are instead accommodated by the upgrading of EF processing capacity, which frees resources for extra storage space in short-term memory (CASE; KURLAND; GOLDBERG, 1982; CHI, 1977; GATHERCOLE, 1999; PASCUAL-LEONE, 1970; SHING; DIAMOND; DAVIDSON, 2010).

The most prominent model of the relationship between EF and the memory systems was proposed by Baddeley and Hitch (1974). In their original working memory system model, the central executive system in a supervisory role to regulate the information flow in its slave's systems (the phonological loop and the visuospatial sketchpad). The phonological loop stores verbal content, whereas the visuospatial sketchpad manages visuospatial data. The central executive system controls the amount of information manipulated in these systems and thus plays a prominent role in selecting, inhibiting and retaining information in short-term memory centers. However, empirical data have also demonstrated the importance of EF components in preventing decaying, intrusions or total forgetting in long-term memory (CARRETTI et al., 2005; COMOLDI et al., 1999; TROYER; GRAVES; CULLUM, 1994).

In 2000, Baddeley added a third slave system to his model (the episodic buffer) to establish a working memory theory that also includes an interface with long-term storage. The episodic buffer appears to be in both hemispheres with activations in the frontal and temporal lobes and in the left portion of the hippocampus (RUDNER et al., 2007). Following the popularity of this model, episodic memory development has been primarily studied from the traditional perspective in which long-term recall is facilitated by an increase in four executive components: (1) working memory capacity, (2) the ability to connect semantic and experiential knowledge, (3) metamemory processes, and, finally, (4) correct strategy implementation (SIEGLER, 2013).

The episodic buffer is responsible for the use of mnemonic strategies in complex tasks, such as when simultaneous verbal and visuospatial components are required to elevate the chance of future recall. Due to this multiprocessing ability, the episodic buffer is thoroughly affected by individual differences in attention span, especially in attentional disorders. For example, in a study with 6th to 8th graders diagnosed with ADHD, the participants showed less recall capacity and a higher number of intrusions in a simple 4-trial free recall task compared with the control group. However, when the ADHD children were assisted in the use of appropriate strategies, they performed as well as the controls (COMOLDI et al., 1999).

On the other hand, some other authors proposed a different relationship between strategies and recall ability. According to Miller (1990), children (aged 3 to 12) have an initial step in which they fail to produce strategies. After that, they have a phase in which a strategy is used only partially and then, finally, the strategies are well used but yield little or no extra benefits in posterior recall. This evidence raises questions specific to the true relationship between long-term memory and strategic executive processing in childhood (COYLE; BJORKLUND, 1996).

Larger strategic resources may be necessary in pathological conditions (such as ADHD and general learning disabilities) but not primarily essential to successful long-term recall over typical development. As demonstrated by some authors (MASTROPIERI; SCRUGGS; FULK, 1990; MCKEOWN et al., 1983) children could achieve better long-term recall and reading comprehension with simple specific vocabulary training and without instructions related to strategy. Semantic facilitation can speed up access to memory traces and liberates attention resources to process increasing information rates. Another important argument is that some age groups have more benefits from strategy use than others, such as the example that older children achieve better recall performance after strategy training than younger children (BJORKLUND et al., 1997).

Beyond the episodic buffer, a wide range of other EF components show moderate correlations with each other (MIYAKE et al., 2000) and with memory components (ENGLE et al., 1999; JURADO; ROSSELLI, 2007; MIYAKE et al., 2000). Additionally, several studies report specific interactions that could more thoroughly explain the performance variations in general executive or memory tasks (BULL; SCERIF, 2001; CONWAY et al., 2002; JURIC et al., 2013; MIYAKE et al., 2001; PASSOLUNGHI; SIEGEL, 2001). In this line, EF and working memory tests share a common underlying executive attention component (inhibitory control), which could be the best performance predictor in tasks that require these abilities. These results indicate a fractionation of the executive factors that accounts for the variance of memory spans in children and adults.

The components of EF and the memory systems show a large improvement with age during childhood and adolescence (GATHERCOLE, 1998; JURADO; ROSSELLI, 2007); however, the progression of their domains appears to be dissonant. Short-term memory span in early pubescence tends to be similar to adult levels (GATHERCOLE, 1998). Different executive abilities have been shown to have distinct developmental trajectories (HUIZINGA; DOLAN; VAN DER MOLEN, 2006; KLIMKEIT et al., 2004), and certain executive components do not achieve completely mature levels until later in adolescence. For example, the ability to resist distraction is the first executive skill acquired (age six), and stabilizing impulse control capacity is acquired at approximately 10 years of age. The last ability to appear is verbal fluency, which stabilizes at around age 15 (JURADO; ROSSELLI, 2007). Other abilities tend to be very stable throughout development, such as the capacity to hold two pieces of information in mind (played by working memory), which occurs at approximately 4 years of age but remains relatively difficult across all ages and does not substantially change (DAVIDSON et al., 2006).

Even with different development patterns, the range of commonality in the EF (including its distinct domains) and memory systems suggests that there are some basic components underlying cognitive outcomes during childhood. The progress of these two cognitive aspects coincides with frontal lobes maturation (ALVAREZ; EMORY, 2006; DIAMOND, 2002; JURADO; ROSSELLI, 2007; SMITH; JONIDES, 1999), which could be taken as evidence of functional similarity. Notably, Shing and col. (2010) found that memory maintenance and inhibitory control were not separable in children at 4–7 or 7–9.5 years but were differentiated in an older group (9.5–14.5 years). A strong hypothesis is that an inhibitory mechanism and goal maintenance (both components located in frontal lobes) enable other EF components and the memory system to upgrade (BLAIR; RAZZA, 2007a; CARLSON; MOSES; BRETON, 2002; FRIEDMAN; MIYAKE, 2004; SHING; DIAMOND; DAVIDSON, 2010).

In line with the studies showing a non-linear cognitive trajectory in development, the present study investigated the relationship between different EF components (such as attentional control, interference inhibition, organization and verbal fluency) and memory domains during childhood and adolescence in Brazilian students.

2.2 Method

2.2.1 Participants

The participants included 354 children and adolescents aged 7 to 14 years old (M=10.11; SD=2.16) of both genders with no history of neurological or neuropsychiatric disturbances. The sample was made up of 52% girls and 48% boys with no significant differences in gender distribution ($\chi 2$ (3) = 1.09, p = .778). The children were students of private schools that serve families with monthly incomes between one- and fivefold the national minimum wage (socio-economic classes c, d and e, as ascertained by an interview with their parents) in Rio de Janeiro (NERI, 2008).

The project was approved by a local Research Ethics Committee (16/2010 – Ethics Committee of the Psychology Department of the Pontifícia Universidade Católica do Rio de Janeiro). Informed consent was obtained from all parents prior to the testing session.

2.2.2 Measures

The present study used four classical neuropsychological paradigms of memory and EF for children. All four paradigms are regularly employed in neuropsychological assessments and widely known in terms of their psychometric characteristics (STRAUSS; SHERMAN; SPREEN, 2006). Table 1 shows all measures, scores and valued functions.

Rey-Osterrieth Complex Figure (ROCF)

The accuracy score for a copy of a copy of the Rey complex figure (REYcopy) was used as a measure of organization (STRAUSS; SHERMAN; SPREEN, 2006).

Stroop test (ST)

The Victoria version of the ST was used (CHARCHAT-FICHMAN; OLIVEIRA, 2009a). The first [color naming (T1)] and last [interference (T3)] trials were included as scores for the speed of processing and inhibitory control, respectively (STRAUSS; SHERMAN; SPREEN, 2006).

Verbal fluency (VF)

VF included letter and semantic fluency tested with one-minute trials (STRAUSS; SHERMAN; SPREEN, 2006). This study used the total number of words produced in phonetic (VF-P) and semantic (VF-S) trials. The phonetic fluency included F, A and M letters, and the semantic fluency included animals, fruits and clothing categories (CHARCHAT-FICHMAN; OLIVEIRA; DA SILVA, 2011). Strategic scores for letter fluency were used, including the number of phonological clusters (PVF-Cluster) and cluster size (PVF-size) as measures of strategic searching, in addition to switching across clusters/single-words (PVF-switch) as a measure of cognitive flexibility.

Rey auditory-verbal learning test (RAVLT)

A version of the RAVLT (SCHMIDT, 1996) was used to assess episodic memory capacity and learning. This version has 4 learning trials (A1, 2, 3, and 4), followed by an interference trial (B1), free recall after interference (A5), and delayed recall (A6) (OLIVEIRA; CHARCHAT-FICHMAN, 2008a). In addition to the simple scores, the following compound inhibitory scores were included: total learning (proactive interference (B1/A1), retroactive interference (A5/A4) and forgetting (A6/A5).

Table 1 – *Measures, scores and functions valued*

Executive function scores		
Measure	**Score**	**Function valued**
Rey Complex Figure	*REY-c*	*organization*
Stroop	*T1*	*processing speed*
	T3	*inhibitory control*
Verbal Fluency	*VF-P*	*phonological verbal production*
	VF-S	*semantic verbal production*
	PVF-clust	*strategic searching*
	PVF-size	
	PVF-switch	*cognitive flexibility*
Memory scores		
Measure	**Score**	**Function valued**
Rey auditory-verbal learning test	*A1*	*short term memory span*
	A5	*free recall after interference*
	A6	*delayed recall*
	B1	*working memory span*
	learning $\sum(A1\text{-}A4)/4$	*learning ratio*
	proactive B1/A1	*proactive interference*
	retroactive A5/A4	*retroactive interference*
	forgetting A6/A5	*forgetting*

2.2.3 Procedures:

Tests were administered to each subject individually by a trained professional. All subjects were submitted to the four paradigms in a fixed order in two testing sessions. The first session included the ROCF and RAVLT, and the second included the VF and ST paradigms. The pause period demanded by the RAVLT was interspersed with non-verbal activities (as in the copy of the Rey Figure).

2.2.4 Statistical analysis

A cluster analysis was performed to map the relationships between EF variables and memory using the Pearson Correlation as a similarity measure. Values were standardized with Z-scores. Additionally, a principal component analysis (PCA) was performed using the Varimax rotation method to investigate the number of factors that could better explain the variability between the distinct domains studied. IBM SPSS© Statistical Software 20 was used to execute all analyses.

2.3 Results

Table 2 shows the descriptive analysis of each variable and age included in this study.

Table 2 − Descriptive analyses (means and standard deviation)

Age group	7		8		9		10		11		12		13		14		Total	
Number	n=48		n=53		n=49		n=48		n=48		n=39		n=40		n=29		n=354	
Gender distribution	(23 M; 25 F)		(27 M; 26 F)		(22 M; 27 F)		(23 M; 25 F)		(27 M; 21 F)		(16 M; 23 F)		(19 M; 21 F)		(14 M, 15 F)		(171 M; 183 F)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
T1	26,42	9,11	22,21	4,89	19,95	5,57	20,33	4,88	17,64	4,42	16,33	3,57	14,79	3,29	15,05	3,43	19,74	6,56
T3	46,86	15,09	43,46	12,96	37,65	8,62	36,84	10,31	33,63	8,16	31,54	8,77	25,10	6,35	26,27	8,03	36,53	12,88
A1	5,00	1,69	5,43	1,31	5,82	1,29	6,15	1,59	6,52	1,47	6,45	0,98	6,50	1,26	6,36	1,62	5,93	1,51
B1	4,54	1,43	4,62	1,33	4,86	1,40	5,15	1,25	5,58	1,50	5,71	1,39	5,25	1,21	5,77	1,63	5,08	1,43
A5	6,92	2,47	7,00	1,82	7,94	1,98	8,04	1,97	8,75	1,85	8,84	1,76	9,33	1,73	8,59	1,82	8,10	2,10
A6	7,31	2,36	7,43	2,26	7,76	2,12	8,28	2,06	8,81	1,86	9,00	1,72	9,53	1,63	9,05	1,73	8,28	2,11
Learning	28,19	7,05	30,30	5,47	31,61	4,44	33,06	4,37	34,38	4,70	36,05	4,35	35,98	3,71	34,95	4,73	32,54	5,66
Proactive	1,08	0,75	0,91	0,40	0,88	0,34	0,90	0,34	0,88	0,24	0,89	0,20	0,83	0,21	0,92	0,20	0,91	0,39
Retroactive	0,86	0,50	0,81	0,23	0,85	0,19	1,04	1,49	0,87	0,15	0,85	0,15	0,88	0,14	0,84	0,13	0,88	0,56
Forgetting	1,10	0,29	1,06	0,21	0,99	0,19	1,05	0,19	1,02	0,16	1,04	0,22	1,03	0,15	1,06	0,12	1,04	0,23
Rey-c	10,54	6,21	12,32	5,88	15,50	6,66	16,88	8,52	21,12	6,83	22,31	7,22	25,84	8,18	26,03	7,63	18,42	8,99
VF-S	25,06	5,92	29,11	8,40	33,12	7,18	32,56	6,68	37,15	8,57	37,56	6,89	39,03	8,79	40,36	8,28	33,04	9,40
VF-P	14,48	5,18	16,81	6,47	23,43	7,54	22,15	5,17	24,25	7,05	26,10	7,24	26,28	7,30	30,77	8,50	21,81	8,54
PVF-cluster	3,23	1,31	3,96	1,97	5,10	2,55	5,00	1,89	5,27	2,22	5,51	2,21	6,08	2,67	6,59	3,45	4,89	2,45
PVF-size	8,79	3,93	10,25	5,37	12,37	6,16	12,50	4,75	12,63	5,27	13,31	5,15	14,60	5,83	15,95	7,99	12,09	5,82
PVF-switch	6,96	4,02	8,72	4,40	14,29	5,68	12,65	4,34	15,10	5,56	16,08	6,14	15,68	6,18	19,55	6,54	12,91	6,45

2.3.1 Hierarchical cluster analysis:

A hierarchical cluster analysis dendrogram (Figure 1) shows only three small groups in the first hierarchical level (distance of five). The first group is a ‘VF-clustering formation’ group (VF cluster number and size), the second is a ‘VF production’ cluster (VFF-total and switches) and the third is a ‘long-term retrieval’ cluster (A5 and A6). Only the two VF clusters present very high internal homogeneity (i.e., were grouped in a lower level than at a distance of 3).

In the second hierarchical level (lower level than distance 10), the ‘VF-clustering formation’ group is also connected to VF-total, and the ‘VF production’ cluster includes the semantic VF. Together, these groups form a larger VF group with all measures of this task connected at this level. Additionally, the Learning score appears to be connected to A1, which emerges as a ‘memory acquisition’ group. This last cluster also now includes the A1 score, thereby forming a large ‘memory retrieval’ group.

At the third level (lower level than distance 15), the Rey-c is united to the VF measures, B1 is added to the ‘memory retrieval’ group and a relationship between Stroop-T1 and Stroop-T3 emerges, thereby forming an ‘attentional’ group.

The RAVLT interference scores only group at levels 4 and 5 (greater than distance 15), wherein Forgetting and Retroactive scores are added to the memory group and Proactive is added to the attentional group. The latter grouping of these variables implies high heterogeneity and distance from the other cognitive measure in this study.

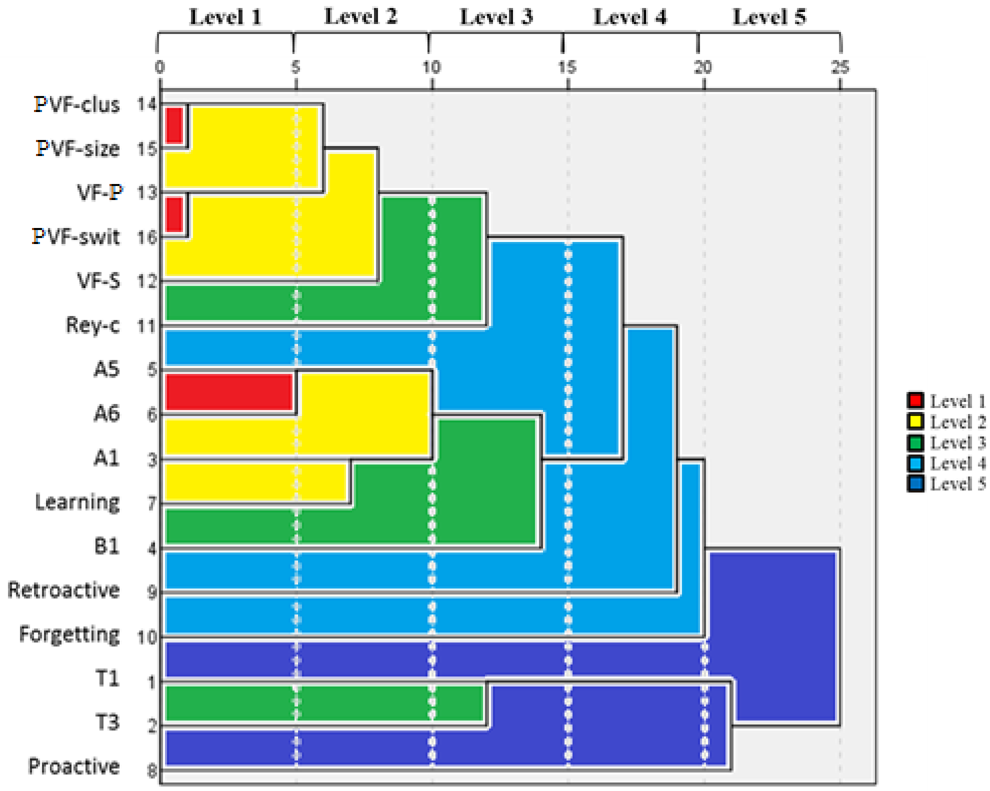


Figure 1 – *Hierarchical Cluster Dendrogram*

2.3.2 Principal Component Analysis (PCA):

A preview PCA exploratory analysis showed a 6-factor model (with eigenvalues greater than 1) that together explained 80.56% of the variance in this database. This model had 4 well-structured components and two others with only isolated variables (retroactive and forgetting scores). Based on this first model, a four-factor extraction was performed, excluding the last two weak factors from the preview six-factor model to avoid these isolated components. The four new components extracted (with eigenvalues greater than 1) maintained the exact initial configuration of the first four factors found in the exploratory analysis. These four components together explain 66.39% of the total variance in these data. Table 3 shows which variables belong to each component, and Table 4 shows the *eigenvalues* and cumulative percentage of variance that each component explains.Table 3 – *PCA: Description of each component*

	Components			
	1	2	3	4
VF-P	.933*	.164	.111	.037
PVF-Cluster	.877*	.123	-.100	.130
PVF-Size	.842*	.116	-.126	.140
PVF-Switch	.812*	.149	.186	-.024
VF-S	.679*	.325	.206	.059
A1	.163	.825*	-.131	-.108
A5	.211	.691*	.205	.543
A6	.128	.755*	.234	.161
learning	.273	.830*	.159	.014
B1	.056	.279	.749*	.041
proactive	-.124	-.559	.709*	.108
retroactive	-.053	.080	.017	.675*
forgetting	-.169	.060	.050	-.610*
REY-c	.382	.354	.354	-.219
T1	-.409	-.432	-.300	.206
T3	-.404	-.249	-.436	.242

**values greater than 0.6*

Table 4 – *PCA: eigenvalue and cumulative percentage of variance for each component*

Components	***eigenvalue***	***% of variance***	***Cumulative %***
1	5.815	36.345	36.345
2	1.945	12.158	48.502
3	1.547	9.669	58.171
4	1.315	8.220	66.392

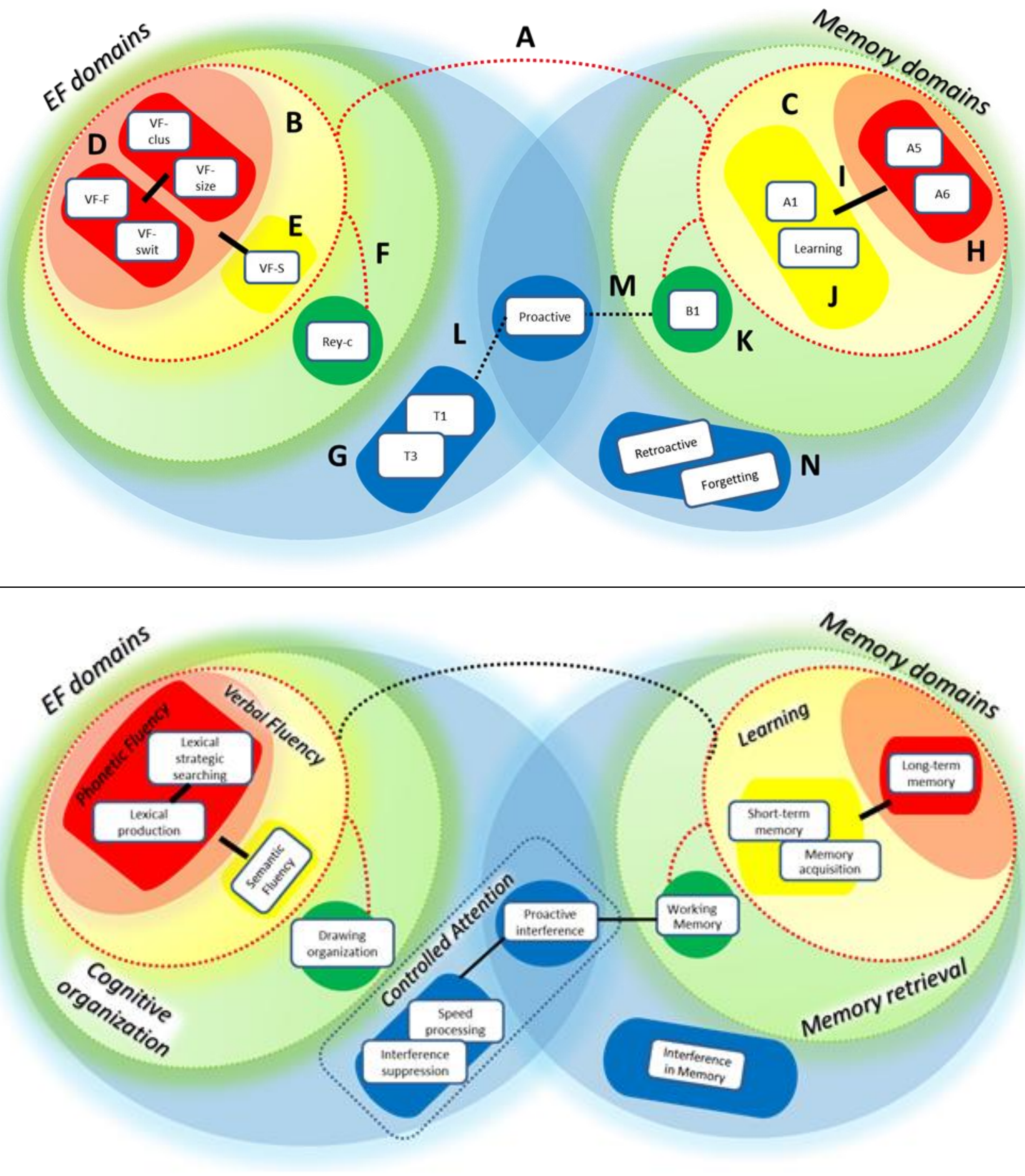
2.4 Discussion

The present study used hierarchical cluster and factorial analysis to investigate the relationship between EF and memory in various domains in children between the ages of 7 and 14. A hierarchical cluster analysis showed three large and heterogeneous variable groups: (1) VF variables plus the Rey-c formed the 'cognitive organization' group; (2) the simple scores and learning score of RAVLT formed the 'memory retrieval' group with retroactive and forgetting showing distant association with the other variables inside this group; and (3) the Stroop scores formed the 'controlled attention' group with the RAVLT proactive interference, which was also very distant from the Stroop scores. Within those three largest heterogeneous groups found in a hierarchical cluster analysis, only three small groups show relatively high intragroup homogeneity: (1) the number and size of VF clustering, (2) the switch and total letter fluency and (3) the RAVLT long-term memory variables (A5 and A6).

Such a configuration has been shown in a confirmatory factorial analysis. Based on the preview exploratory analysis, a four-factor model was extracted. According to the highest values (greater than 0.60) in each component, it was possible to identify (1) the first as a 'verbal fluency' component, including the letter and semantic fluency plus the clustering and switching of strategic scores; (2) the second as a 'memory retrieval' component with the A-list simple scores and learning variable from RAVLT playing a major role; (3) the third as a 'proactive interference' component, including only B1 and the proactive variable from RAVLT; and (4) the forth component appears to be more independent and distant from the other cognitive variables studied and was formed by the retroactive and forgetting variables of RAVLT, respectively.

The high intergroup heterogeneity suggests a fractionation in the cognitive domains during childhood and adolescence. This conclusion draws on numerous points of evidence (BLAIR; RAZZA, 2007b; GATHERCOLE et al., 2004; HUIZINGA; DOLAN; VAN DER MOLEN, 2006; KLIMKEIT et al., 2004; MIYAKE et al., 2000; SHING et al., 2010; TIDEMAN; GUSTAFSSON, 2004) indicating non-linear and non-homogeneous cognitive profiles across development. These findings also corroborate those related to the fractionation of EF in independent subdomains. The analyses presented similar patterns (summarized in Figure 2).

Figure 2 – ***Summary of interactions found between each component***



A: far distance between executive functions and memory variables; B: highly homogeneous group with all phonetic VF variables; C: highly homogeneous group with all A-list memory variables; D: close relationship between phonetic production and strategic searching; E: close but different phonetic and semantic fluency; F: relationship between verbal and visual strategic organization; G: weak and dissolved relationship between Stroop/Rey-copy variables and other scores; H: similarity between long-term retrieval variables; I: relationship between long- and short-term retrieval; J: relationship between short-term memory and total learning; K: relationship between working memory and learning group; L: relationship between proactive interference in memory and attentional variables; M: relationship between working memory and proactive interference susceptibility; N: distant nature between interference variables and other memory scores.

2.4.1 EF domains versus Memory domains

In both analyses, all fluency variables and four specific RAVLT scores (A1, A5, A6 and Learning) demonstrated clearly distinct natures indicating two well-defined and relatively independent cognitive domains regarding the EF and Memory components (A-point, Figure 2). Both analyses also suggest high intra-group homogeneity in the Fluency group (B-point, Figure 2) and the Memory group (C-point, Figure 2). These results indicate relationships between cognitive domains that appear to be more constant across development regardless of the age group. For example, the close proximity between fluency variables is consistent in several studies (HUGHES; HUGHES, 2002; KOSMIDIS et al., 2004; SAUZÉON et al., 2004) that found that letter fluency is possibly a strategically dependent task at multiple ages.

The traditional view includes interfaces between semantic memory and verbal fluency (BRUCKI; ROCHA, 2004; CHARCHAT-FICHMAN; OLIVEIRA; DA SILVA, 2011; TROYER; MOSCOVITCH; WINOCUR, 1997); however, this study provided only a very distant connection between fluency and verbal memory variables (A-point, Figure 2). Likewise, strategic resources (required by fluency and Rey-c) demonstrated no strong connections to memory variables. The relationship between strategy use and memory only occurs in specific age groups not examined here.

2.4.2 Phonetic fluency and different strategic scores

In the Fluency group, all strategic scores appear to be good explanations for overall verbal fluency performance; however, the hierarchical cluster analysis especially indicated a switched score with the closest relationship to total letter fluency (D-point, Figure 2). This is in line with a previous study that indicated clustering and switching as close but dissociable fluency components (TROYER; MOSCOVITCH; WINOCUR, 1997) and switching capacity as the best predictor of verbal fluency abilities (KAVÉ; KIGEL; KOCHVA, 2008; KOSMIDIS et al., 2004; TROYER; MOSCOVITCH; WINOCUR, 1997).

2.4.3 Phonetic versus Semantic fluency subtypes

Both phonetic and semantic fluency are indicated by factorial analysis as the best explanations of variance in performance for the tests used in this study. This could be due to strong EF underlying multiple cognitive domains (BOLLA et al., 1990; BRYAN; LUSZCZ; CRAWFORD, 1997; DANEMAN, 1991).

The fluency subtypes are near each other; however, the semantic task demonstrates evident borders distinguishing the essence of each trial (E-point, Figure 2). Some studies also suggested that measurements of the VF developmental pattern are task-dependent. Children at 10 to 12 years of age reach an adult level in semantic fluency but not letter fluency tasks. This could be explained by a major dependency of letter fluency on EF, whereas the semantic task depends more on the size and quality of organization in lexical-semantic networks (KAVÉ; KIGEL; KOCHVA, 2008; SAUZÉON et al., 2004).

2.4.4 Cognitive organization and controlled attention domains

According to the hierarchical cluster analysis, the proximity between VF variables and the copy of a complex figure (F-point, Figure 2) show a potential interaction between verbal and visuospatial organizational abilities, suggesting a common component underlining both skills. This makes hypothetical sense because visual organization depends on verbal regulation (KLICPERA, 1983; VYGOTSKY; HANFMANN; VAKAR, 2012). However, this proximity appears to be diluted in factorial analysis. The Rey-copy plus the Stroop variables showed weak relationships with all four factors, which could be interpreted as evidence that these tasks recruit basal abilities (such as speed processing and inhibitory control for Stroop and organization and planning capacity for Rey-copy) demanded by various other cognitive tests (G-point, Figure 2).

2.4.5 Learning domain

In the Memory group, the measures of long-term retrieval after interference (A5 and A6) are very similar to each other (H-point, Figure 2) and, although not distant, also show clear distinctions from the short-term memory domain. The connection between A1, A5 and A6 suggests only a moderate relationship between short-term memory span and long-term retrieval after interference (I-point, Figure 2). This indicates that the short-term memory span is not especially helpful in remembering things following a distraction. Hypothetically, executive factors (such as selection and inhibition) could be more effective in preventing interference in long-term memory (DEMPSTER, 1981); however, there is no strong evidence for this in this study.

The short-term retrieval measure (A1) is the most closely related to learning score (J-point, Figure 2), indicating the importance of episodic short-term memory retrieval in the learning process. According to the factorial analysis, these domains together play a major role in explaining the performance variability in the memory component. Some studies showed similar results (BADDELEY; PAPAGNO; VALLAR, 1988; PAPAGNO; VALENTINE; BADDELEY, 1991), demonstrating that the short-term phonological span plays an important role in long-term vocabulary learning in children. The opposite effect was described in another study (HULME; MAUGHAN; BROWN, 1991), indicating that long-term memory contributes to short-term memory span in adults, thereby suggesting a two-way interaction between short-term memory span and episodic memory. However, another study (BADDELEY; PAPAGNO; VALLAR, 1988) only found interactions between short-term phonological storage and learning for unfamiliar verbal material but not for meaningful items that are already known, suggesting that this memory-learning effect could be more accentuated during development (when the semantic networks are formed).

2.4.6 Short-term memory, working memory and controlled attention

The A1 and B1 scores from RAVLT also appear to have varying natures (K-point, figure 2). Other studies reported the same difference in children (FORRESTER; GEFFEN, 1991; VAKIL; GREENSTEIN; BLACHSTEIN, 2010). B1 was a measure of short-term retrieval; however, the B1 score was distinguishable from the A1 score, likely due the proactive interference played by preview learning of the first word list (STRAUSS; SHERMAN; SPREEN, 2006). Using a hierarchical cluster analysis, it is possible to identify a weak connection between a proactive interference score and the Stroop task variables (L-point, Figure 2), indicating a possible interaction between the ability to prevent proactive interference on memory and the type of interference control demanded by the Stroop test. This item in addition to evidence from a factorial analysis demonstrating B1 and the proactive interference to be the same component suggests that proactive interference could be a common component among the EF and memory domains (M-point, Figure 2). This is in concordance with other studies that link working memory with the ability to prevent proactive interference (KANE; ENGLE, 2000) and working memory capacity as predictors of Stroop test performance (KANE; ENGLE, 2003).

2.4.7 Interference in memory

The combined scores of interference in long-term memory (retroactive and forgetting) appear to be more distant and independent from the memory variables (N-point, Figure 2). This suggests a clear dissociation between the 'interference' and 'memory' scores during cognitive development, like reported by Vakil et al. (2010).

2.4.8 Final conclusions

EF plays a central role in memory and learning processes; however, the EF and Memory domains are clearly distinguishable during cognitive development. These findings could be very useful in determining which neuropsychological measures would be included in short cognitive assessment batteries or as a neuropsychological map for planning the best rehabilitation approach in accordance with cognitive development trajectory.

A limitation to the current study is that the non-executive processes were unrelated to each task used. Studies often face assessment issues regarding the relationships between cognitive domains. Many widely used measures of executive functioning are complex and involve a wide range of skills, thereby complicating efforts to identify specific processes. Another aspect worth noting is that the present study investigated cognitive interactions in a large scope of ages without separate age groups. However, some cognitive interactions only emerge in specific age spans across development, as shown in some studies (HUIZINGA; DOLAN; VAN DER MOLEN, 2006; JURIC et al., 2013; SHING; DIAMOND; DAVIDSON, 2010). This hypothesis will guide future investigations.

3
STUDY II − Subgroups in cognitive development: Distribution of Brazilian students aged 7-14

3.1 Introduction

The vast majority of development theories acknowledge a basic concept: the key factor in the changes in cognitive performance during the transition from childhood to adulthood is a systematic increase in the capacity of several neuropsychological functions (BALTES, 1987; DIAMOND, 2002; ØSTBY et al., 2009; SIEGLER, 1994). While it is known that several chronological milestones occur as part of cognitive development, these changes tend not to appear in a uniform way in all subjects (SHING et al., 2010; TURIEL; DAVIDSON, 1986). Thus, it is expected greater variability levels in infant than in adult populations, as a result of the heterogeneity between transitional phases (DIAMOND, 2002), also observed in elderly (ARDILA, 2007). Some factors, such as the transition pattern between developmental phases, the interaction among functions, and the general composition of individual cognitive profiles may contribute to the understanding of not only increases in capacity but also the architecture of cognitive changes. Such contributions are essential for the systematization of development theories and interventions aimed at intervening in the development process.

Scientific literature suggests that children's cognitive performance varies primarily by virtue of demographic variables such as age (CASEY; GIEDD; THOMAS, 2000; GIEDD et al., 1999; SOWELL et al., 2001), education level, education quality, and socioeconomic status (MCLOYD, 1998; NOBLE; NORMAN; FARAH, 2005); environmental variables such as the parental stimulation offered to a child (ANDRADE et al., 2005; TAMIS-LEMONDA et al., 2004); and, relevant cultural factors (ROGOFF; CHAVAJAY, 1995) which may favor certain functions over others; and biological variables such as genetic factors (DIAMOND et al., 2014), neurological maturation (CASEY; GIEDD; THOMAS, 2000; GIEDD et al., 1999; SOWELL et al., 2001), and nutritional quality throughout gestation and childhood (BRYAN et al., 2004; GLEWWE; KING, 2001).

Biological and environmental variation are the primary explanation for individual differences in the cognitive performance of children and adolescents Both biological and environmental factors can cause significant variation in infant populations; these factors also seem to cause similar variation in cognitive functioning throughout development.

The heterogeneous factors influencing neurological maturation suggest the existence of different neuropsychological profiles throughout childhood and adolescence. This variation in neuropsychological profiles falls within the expected scope of variation in healthy populations (GEVINS; SMITH, 2000; HAPPÉ, 1999; LETTERI, 1980).

Some studies have investigated the cognitive heterogeneity of children in order to develop a classification system. However, the focus of these studies has been exclusively on samples of children with specific disorders such as ADHD, autism and dyslexia (FAIR et al., 2012; FEIN et al., 1985; HEIM et al., 2008; SUK-HAN HO et al., 2004). These studies have often used multivariate statistical models, such as analysis of hierarchical clustering. This is an exploratory analysis technique that has proven highly effective in identifying the subgroup of cognitive profiles into which an individual falls. This type of analysis supports classification schemes based exclusively on cognitive performance.

Despite the high heterogeneity of the Brazilian population, especially in terms of socioeconomic distribution and education quality, few studies have investigated the neuropsychological variability among healthy students (BROOKING et al., 2012; CHARCHAT-FICHMAN; OLIVEIRA; DA SILVA, 2011; CHARCHAT-FICHMAN; OLIVEIRA, 2009b; OLIVEIRA; CHARCHAT-FICHMAN, 2008b). Additionally, studies that use multivariate analyses to explore neuropsychological heterogeneity in development are still rare in Brazil.

Among the existing studies, some limitations exist in sample size and the number of cognitive functions evaluated. These limitations can restrict or hide possible interactions between neuropsychological domains. In general, the current research includes few models that use information processing theory to examine the developmental trajectory of different cognitive functions. This scope restriction limits the understanding of human development as a non-homogeneous and non-linear process, despite the fact that extensive evidence suggests that this is true in the process of human development (DAVIDSON et al., 2006; DEMPSTER, 1981; KLIMKEIT et al., 2004; SHING et al., 2010).

Certain lifespan and neuroimaging studies propose that the transitions between neuropsychological stages do not occur in proportional and simultaneous increases for all functions. Instead, empirical evidence suggests unequal development rates for different cognitive attributes and the discontinuity of interactions between some factors (LI, 2003; LI et al., 2004; SHING et al., 2010). To elaborate, while all functions are relatively interrelated and interdependent in young children (TIDEMAN; GUSTAFSSON, 2004), it is already possible to observe the autonomy and separation of several functions in the early stages of adolescence. For instance, although processing speed and short-term memory capacities are interrelated up to 7 years of age, they are largely segregated in 12-year-olds (FRY; HALE, 1996; KAIL, 1991). Additionally, neither of these abilities is more crucial to global performance in adolescence as they were in the first developmental phases (HUIZINGA; DOLAN; VAN DER MOLEN, 2006).

Collecting data about the trajectories of cognitive development can help to determine what skills emerge in different developmental stages and what functions are specifically related to these stages. This data can also highlight the contribution of specific cognitive domains to overall performance throughout childhood. The characterization of development profiles in Brazilian infants may provide relevant information with which to identify normal and pathological patterns in neural maturation. This characterization can also contribute to early diagnosis and appropriate intervention planning, thus preventing the emergence or worsening of deficits.

This study presents measures of the following characteristics in healthy children and adolescents: general executive functions, including verbal fluency, strategic lexical search, and visual organization; memory, including short- and long-term retrieval and learning; and attentional control, including interference control of processing tasks and memory control. All of the scores are based on four classical neuropsychological paradigms commonly utilized in neuropsychological evaluation (STRAUSS; SHERMAN; SPREEN, 2006). The aim of this study is to explore the cognitive profiles of Brazilian students and the specifics of each subgroup throughout development.

3.2 Method

3.2.1 Participants

The participants included 350 children and adolescents aged 7- to 14-years-old (*M* = 10.36, *SD* = 2.84) with no history of neurological or neuropsychiatric disturbances. In the sample, 52% of the children were girls and 48% were boys; no significant differences existed in the gender distribution ($\chi^2(3) = 1.09$, $p = 0.778$). The children were students at private schools that serve families with monthly incomes between one and five times the national minimum wage (socioeconomic classes c, d, and e) in Rio de Janeiro (NERI, 2008).

A research ethics committee formed by the Department of Psychology at Pontifica Universidade Católica do Rio de Janeiro approved the project. Informed consent was obtained from all parents prior to the testing session.

3.2.2 Measures

In this study, the children were tested using four classical neuropsychological paradigms of executive functions (EF), memory, and attention. All four of the paradigms are regularly employed in neuropsychological assessments and widely known in terms of their psychometric characteristics (STRAUSS; SHERMAN; SPREEN, 2006). Table 5 displays all measures and, scores and their evaluated aspects. The paradigms used were as follows:

The Rey-Osterrieth complex figure (ROCF)

The accuracy score of the copy of the Rey complex figure (REYcopy) was used as a measure of organization (STRAUSS; SHERMAN; SPREEN, 2006).

The Stroop test

The Victoria version of the Stroop test (ST) was used (CHARCHAT-FICHMAN; OLIVEIRA, 2009b). The first (color naming - T1) and last (interference - T3) trials were included as scores for the speed of processing and inhibitory control, respectively (STRAUSS; SHERMAN; SPREEN, 2006). Additionally, the ratio of Trial 3 and Trial 1 was computed as an interference score (INT), and the number of errors in trials one and three (ERR1 and ERR3) were included as distractibility scores.

Verbal fluency

Verbal fluency (VF) included phonological and semantic fluency tested in one-minute trials (STRAUSS; SHERMAN; SPREEN, 2006). This study used the total number of words produced in phonological (VF-P) and semantic (VF-S) trials. The phonological fluency trials included letters F, A and M, and the semantic fluency trials included animal, fruit, and clothing categories (CHARCHAT-FICHMAN; OLIVEIRA; DA SILVA, 2011). Strategic scores for phonological fluency were used, including the number of phonological clusters (PVF-cluster) as a measure of strategic searching and switching across clusters and single words (PVF-switch) as a measure of cognitive flexibility. Clusters size (PVF-size) was computed as a measure of access to semantic memory.

The Rey auditory-verbal learning test

A version of the Rey auditory-verbal learning test (RAVLT) was used to assess episodic memory capacity and learning (STRAUSS; SHERMAN; SPREEN, 2006). This version includes four learning trials (A1-4) followed by an interference trial (B1), trials of free recall after interference (A5) and delayed recall (A6), and two recognition lists (REC-A and REC-B) (OLIVEIRA; CHARCHAT-FICHMAN, 2008b). In addition, the following composite scores were included in the test: total learning (∑(A1-A4) as a measure of learning), proactive interference (B1/A1) and retroactive interference (A5/A4) as interference scores, and forgetting (A6/A5).

Synthetic Variables

Four synthetic variables were calculated and the test scores were grouped in four categories of global, organization, memory, and attentional performance, according to the interactions found in the study from the first chapter and neuropsychological literature (STRAUSS; SHERMAN; SPREEN, 2006). To compute these variables, test results were converted to standardized Z scores in order to place all scores in the same metric. Additionally, the standardized scores of trial 1 and trial 3, their numbers of errors, and their proactive and retroactive interference results were adjusted so that higher numbers indicated better attentional performance, as is standard in measurements of test scores. The means of the specific standardized test scores were computed into synthetic variables. All of this information is displayed in Table 6.

Table 5 − Measures and scores and their evaluated aspects

Organization Scores		
Measure	**Variable**	**Evaluated aspects**
Rey–Osterrieth complex figure[1] (ROCF)	*REYcopy*	*visuospatial organization*
Verbal Fluency (VF)	*VF-P*	*phonological verbal production*
	VF-S	*semantic verbal production*
	PVF-clust[2]	*strategic phonological search*
	PVF-switch[2]	*cognitive flexibility*
Memory Scores		
Measure	**Variable**	**Evaluated aspects**
Rey Auditory Verbal Learning Test (RAVLT)	*A1*	*short term memory*
	A5	*free recall after interference*
	A6	*free recall after interval*
	B1	*working memory*
	learning $\sum(A1\text{-}A4)$	*total learning*
	forgetting *A6/A5*	*forgetting rate*
	REC-A	*recognition*
	REC-B	*recognition*
Verbal Fluency (VF)	*VF-size*[2]	*access to semantic memory*[3]
Attentional Scores		
Measure	**Variable**	**Evaluated aspects**
Rey Auditory Verbal Learning Test (RAVLT)	*proactive* *B1/A1*	*proactive interference*
	retroactive *A5/A4*	*retroactive interference*
Stroop Test (ST)	*T1*	*processing speed*
	T3	*inhibitory control*
	INT *(T3/T1)*	*inhibitory control*
	Err1	*Distractibility*
	Err3	

[1]*Quantitative score of the copy trial only (scored according to the Taylor's criteria also presented for Oliveira and Charchat-Fishman, 2008)*
[2]*Strategic scores computed for phonetic trial only (according to the Sauzeon's criteria, 2004)*
[3]**According to Abwender, 2001**

Table 6 − Synthetic variables

Synthetic Variables	
Variable	**Description**
Organization Performance	*Average performance in organization scores* *(REYcopy, VF-P, VF-S, PVF-cluster, PVF-switch)*
Memory Performance	*Average performance in memory scores* *(A1, A5, A6, B1, A1, A4, forgetting, REC-A, REC-B, VF-size)*
Attentional Performance	*Average performance in attentional scores* *(proactive, retroactive, T1, T3, INT, Erro1, Erro3)*
Global Performance	*Average performance in all four synthetic scores*

3.2.3 Procedures

A trained psychology student or professional administered the tests to each subject individually. All subjects were submitted to the four paradigms in a fixed order in two testing sessions. The first session included the ROCF and RAVLT tests in that order, and the second session included the VF test followed by the ST paradigm test. The interval demanded by the RAVLT delayed recall test included nonverbal activities, as in the recall of the Rey figure.

3.2.4 Statistical analysis

Cluster analyses were performed to identify subgroups with similar patterns of cognitive performance. The analyses included two steps:

(1) Exploratory analysis with hierarchical clusters

Cluster analyses involve a pre-established classification system in which all subjects begin in one group. They are then divided continuously and move down a hierarchy based on multiple scores on tests performed recursively. In this exploratory study, the Euclidean distance was used as the dissimilarity metric, and linkage between groups was used as the cluster method.

(2) Confirmatory analysis with nonhierarchical clusters

Because cluster analysis is an interactive method, nonhierarchical analysis allows subjects to move from group to group during the analysis as a function of their similarity or dissimilarity to other cases. A cap of ten possible interactions between subjects was used in this analysis. The number of clusters pre-selected followed the four-group solution found in the exploratory analysis.

The ages and performance levels of the groups identified in the hierarchical and nonhierarchical analyses were compared using ANOVAs. Tukey post-hoc tests illustrated significant intergroup differences. Repeated ANOVAs tests followed by Bonferroni post-hoc tests were used to compare intragroup performances. The age variable was stratified into the following ranges: 7 to 8, 9 to 10, 11 to 12 and 13 to14 years. All analyses were conducted using the statistical software SPSS 20.

3.3 Results

3.3.1 Hierarchical cluster analysis

The hierarchical cluster analysis led to the identification of two groups, Group A and Group B, at distance < 20. Information about these groups can be found in figures Figure 3 and Figure 4. Group A was subdivided into Group 1 and Group 2. Group B was subdivided into Group 3 and Group 4. Four groups existed at distances < 15. At distances < 10, these 4 groups were subdivided into 15 smaller groups. At distances < 5, these 15 groups were divided into 57 smaller groups. The four groups at distances < 15 were used to perform the intergroup analysis in order to take advantage of their homogeneity and avoid using a larger number of groups.

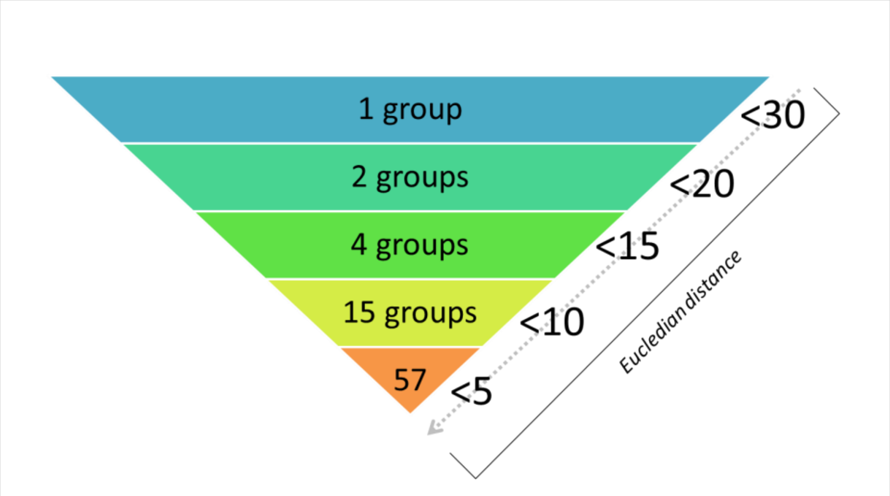


Figure 3 – Hierarchical clusters: Number of groups in each distance section

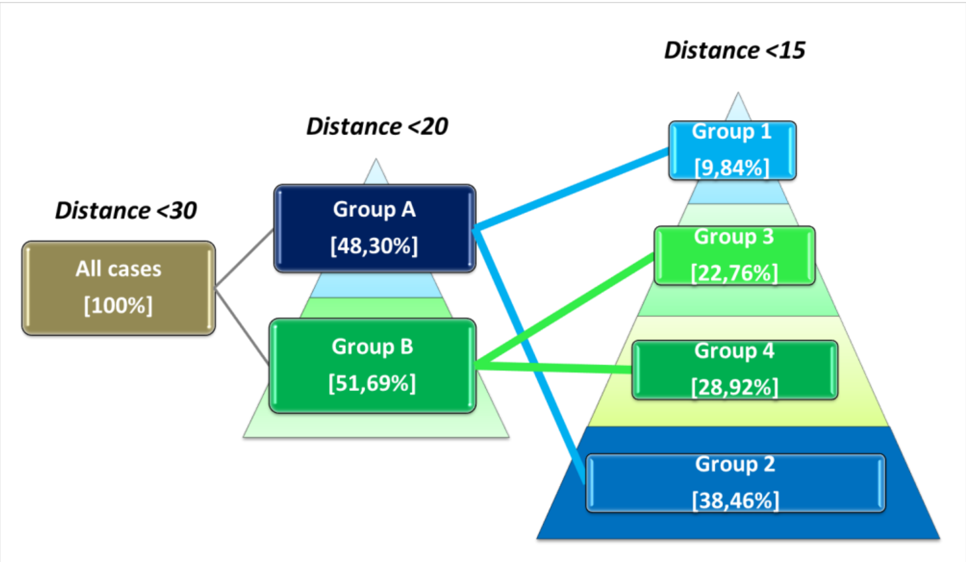


Figure 4 – Hierarchical clusters: Frequencies per distance in each subgroup

3.3.11 Groups A and B

The frequency of subjects in groups A and B (distance < 20) was very similar (Group A = 48.30%, Group B = 51.69%), forming a homogeneous division between younger children (M = 8.91, SD = 1.57, t = -12.21, p < 0.00) with lower levels of global performance (M = -0.08, SD = 0.34, t = -4.28, p < 0.00) and older children (M = 4.11, SD = 1.99) with higher levels of global performance (M = 0.07, SD = 0.31). The groups displayed significant differences in performance for all synthetic variables (5.40 > t < 5.10, p < 0.00) (Table 7).

Table 7 – T-test: Comparing groups A and B

	Group A (*n* = 157)	Group B (*n* = 168)	Comparison between groups	
	M (*SD*)	*M* (*SD*)	*t*	*p*
Age	8.91 (1.57)	11.33 (1.95)	-12.21	0.00*
Global Performance	-.08 (.34)	.07 (.31)	-4.28	0.00*
Organizational Performance	-.21 (.34)	.19 (.69)	-5.40	0.00*
Memory Performance	-.17 (.76)	.16 (.59)	-4.60	0.00*
Attentional Performance	-.11 (.43)	.10 (.36)	-5.10	0.00*

**95%, 2-tailed, p < 0.05*

3.3.1.2 Groups 1, 2, 3, and 4

Groups one through four were more heterogeneous in terms of frequency of cases than groups A and B; Group 1 was markedly smaller (9.84%). A considerable difference existed between groups in terms of age ($F_{(3,322)}$ = 161.83, p < 0.00), and this difference was significant for all group comparisons at p < 0.00, except between groups two and three (p = 0.08). There was also a significant main effect of group for each synthetic variable (Table 8 − 9.69 > $F_{(3,322)}$ < 11.47, p < 0.00).

Table 8 − Descriptive statistics of hierarchical clusters for the performance of groups 1, 2, 3, and 4

Variables	Groups			
	1 (*n* = 35)	**2** (*n* = 125)	**3** (*n* = 74)	**4** (*n* = 94)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Age	8.22 (1.38)	9.09 (1.57)	9.57 (1,34)	12.71 (1.04)
Global Performance	-0.03 (0.36)	-0.10 (0.35)	-0.02 (0.28)	0.16 (0.32)
Organizational Performance	-0.21 (0.85)	-0.21 (0.62)	-0.11 (0.58)	0.44 (0.68)
Memory Performance	0.02 (0.62)	-0.23 (0.79)	0.05 (0.60)	0.26 (0.57)
Attentional Performance	-0.10 (0.38)	-0.12 (0.45)	0.01 (0.28)	0.190.41)

3.3.2 Nonhierarchical cluster analysis

A nonhierarchical cluster analysis was performed in order to test the four-group solution found in the exploratory analysis. After dividing the subjects into four groups (G1, G2, G3, and G4), short distances separated G1, G2, and G3. Only G4 was a further distance from the other groups. Figure 5 illustrates the distances between the groups.

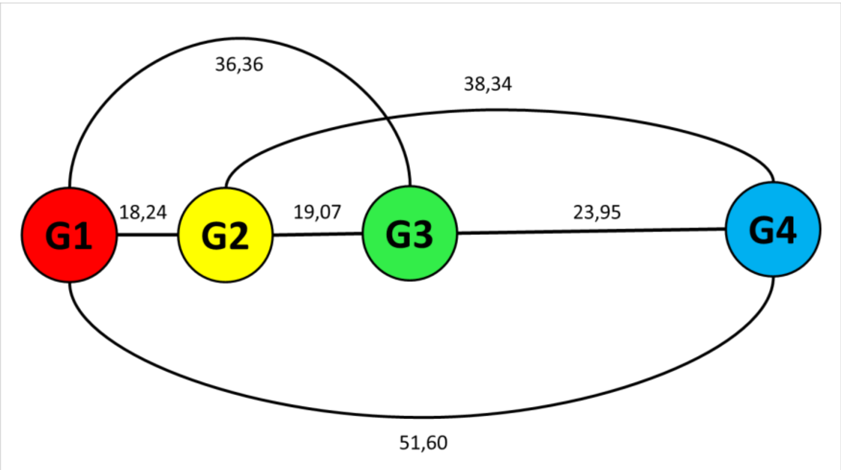


Figure 5 − Nonhierarchical clusters: Distance between centroids of the four groups

3.3.2.1 Frequencies

The frequencies of the cases in each group were different. As illustrated in Figure 6, G2 has the highest frequency followed by G3 and then G1. Group 4 has the lowest frequency. Group 2 was the largest group (36.61% of the sample), G1 and G3 were intermediate in size (36.61% and 33.23%, respectively), and G4 was the smallest group (8.61% of the sample).

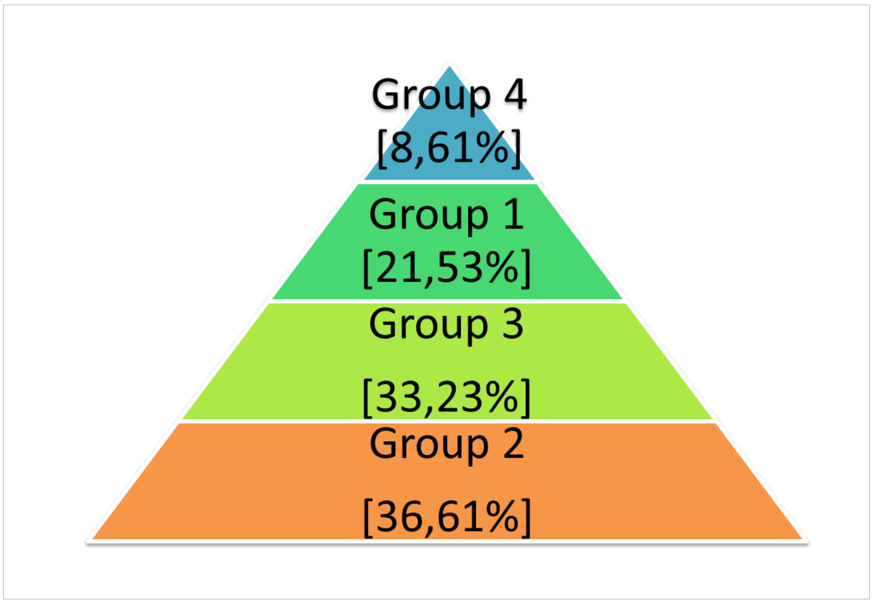


Figure 6 – Nonhierarchical clusters: Frequencies per group

3.3.2.2 Age composition

There was a significant effect of group for age ($F_{(3,322)} = 84.89$, $p < 0.00$). All the pairwise post-hoc comparisons significant ($p < 0.05$), with the exception of G3 and G4 ($p = 0.57$). Group 1 was the oldest ($M = 12.07$, $SD = 1.64$), G2 was the intermediary age group ($M = 10.86$, $SD = 1.71$), and G3 and G4 were the youngest ($M_{G3} = 8.66$, $SD_{G3} = 1.53$; $M_{G4} = 8.21$, $SD_{G4} = 2.15$) (Figure 7, Table 9 and 10).

Group 1 included the vast majority of subjects ages 13 and 14 (Table 10 – 55%) and the lowest percentage of 7- and 8-year-olds (Table 10 – 2.2%). Group 2 contained mostly subjects between ages 9 and 14 (Table 10 – 92.4%) and only a small number of younger children (7.5%). Group 3 had the highest frequency of subjects ages 7 and 8 (Table 10 – 67% of the total sample). Group 4 was composed almost exclusively of subjects who were less than 10 years of age; many of the subjects in this group were 8-year-old children (Table 9 − 67.9%). However, unlike G3, which contained relatively more subjects between ages 11 and 14 (Table 10 – 16.1%), G4 was composed almost entirely of younger children (Table 8 – 67.9%).

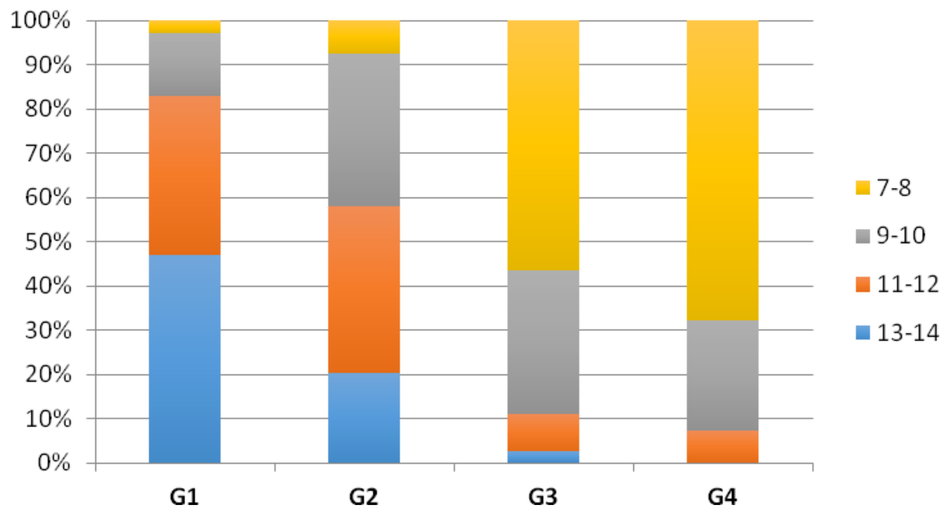


Figure 7 − Age composition of each group

Table 9 − Absolute frequencies of age ranges in each group, number of subjects, and average age

Group	Number of Subjects	Average Age	Age Composition (%) of Each Group			
	***N* (%)**	***M (SD)***	**7-8**	**9-10**	**11-12**	**13-14**
G1	70 (21.53%)	12.07 (1.64)	2.86%	14.29%	35.71%*	47.14%*
G2	119 (36.61%)	10.86 (1.71)	7.50%	34.40%*	37.80%*	20.20%*
G3	108 (33.23%)	8.66 (1.53)	56.50%*	32.40%*	8.40%	2.80%
G4	28 (8.61%)	8.21 (1.42)	67.90%*	25.00%*	7.20%	0.00%

**Predominant ages in each group*

Table 10 − Relative frequencies of subjects of each age range in the four Groups

	Age Groups			
Cluster Group	**7-8**	**9-10**	**11-12**	**13-14**
G1	2.2%	10.8%	30.9%*	55%*
G2	9.9%	44.1%*	55.6%*	40%*
G3	67%*	37.6%*	11.1%	5%
G4	20.9%*	7.5%	2.5%	0%

**Predominant ages in each group*

3.3.2.3 Cognitive profile of the groups

3.3.2.3.1 Comparison of intergroup performances on synthetic Variables

There was a significant effect of group for all synthetic variables (Figure 8), as follows: global performance ($F_{(3,322)} = 61.12$, $p < 0.00$), organization performance ($F_{(3,322)} = 195.35$, $p < 0.00$), memory performance ($F_{(3,322)} = 31.20$, $p < 0.00$) and attentional performance ($F_{(3,322)} = 75.90$, $p < 0.00$).

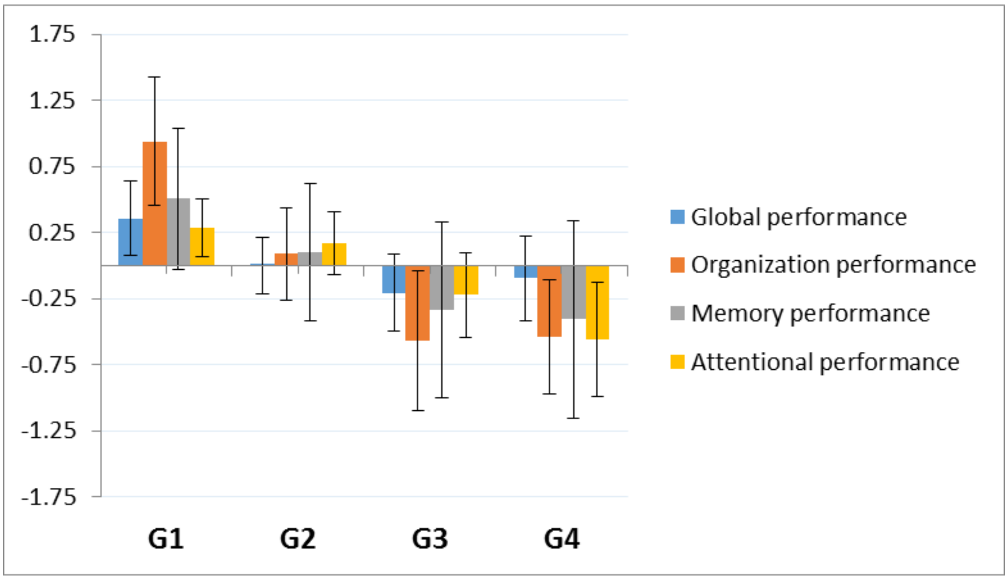


Figure 8 − Performance of each group on synthetic variables

Concerning the synthetic variable for global performance, pairwise comparisons made using Tukey HSD post-hoc tests revealed that G1 had the highest level of accomplishment, outperforming all of the other groups (Figure 8 – $p < 0.00$). Group 2 had an average global performance ($MP = 0$) that was only comparatively smaller than that of G1 ($p < 0.00$) and was greater than that of G3 ($p = 0.00$). But no difference existed between the average global performance of G2 and G4 ($p < 0.32$). Group 3 displayed below average levels of global performance. The difference in the global performance of G3 compared to all other groups was significant for G1 and G2 ($p < 0.00$), but it was not significant for G4 ($p = 0.24$). Group 4 also had global performance below average ($MP < 0$). However, the difference between G4's global performance and that of the other groups was significant only in relation to G1 (p < 0.00).

In the other synthetic variables, G1 and G2 consistently outperformed the other groups ($p < 0.00$). G1 only differ to G2 in terms of organization and memory; in these variables, G1 performed better than G2 ($p < 0.00$). Group 1 and G2 did not differ significantly in attentional performance ($p = 0.07$).

In turn, G3 and G4 had very similar performance patterns in organization and memory ($p > 0.95$), and these groups differed only in attentional performance ($p < 0.00$). In this variable, G3 displayed superior performance compared to G4 ($M_{G3} = -0.22$, $SD_{G3} = 0.43$; $M_{G4} = -0.56$, $SD_{G4} = 0.32$).

3.3.2.3.2 Intragroup comparisons of synthetic variables

The repeated ANOVAs indicated significant intragroup differences in performances for the four synthetic variables. A significant effect existed between the groups and the synthetic variable factors (Wilks Lambda = 0.11, $F_{(1,69)} = 264.90$, $p < 0.00$).

G1 presented consistent intragroup differences in all three synthetic variables (Figure 8 – $p < 0.00$). This group had the greatest discrepancy between organization and memory performance ($MD = 0.43$, $p < 0.00$), with considerably better performance in organization ($M = 0.94$, $SD = 0.49$) than in memory ($M = 0.51$, $SD = 0.53$, $p < 0.00$). Attentional performance was the only lower variable for this group (M = 0.29, SD = 0.22, $p < 0.00$), though the performance of this group on this variable was still above average.

G2 displayed homogeneous performance (Figure 8) close to the average (0.09 > M < 0.17, 0.22 > SD < 0.35) in all synthetic variables. However, G2's organizational and memory scores were equivalent (p = 1.00), while its attentional performance score was slightly lower ($p < 0.00$).

Group 3 displayed consistent difference in its performance for the three synthetic variables ($p < 0.00$); this performance pattern was the opposite of that of G1. G3's best performance was reached in the attentional test (M = -0.22, SD = 0.43, $p < 0.00$), followed by memory performance (M = -0.33, SD = 0.75, $p < 0.00$), and finally by organization performance (M = -0.57, SD = 0.43, $p < 0.00$).

The organization and memory variables did not differ for G4 (MD = 0.13, p = 0.97). Differences only existed in attentional performance; this was lower than in the other two categories ($p < 0.00$).

3.3.2.3.3 Intergroup comparison of each test score

The performances in each test are illustrated in Figure 9. The multivariate analysis comparing the four groups in all neuropsychological scores demonstrated a significant main effect, with a Wilks' Lambda of .023 ($p < 0.01$). Significant differences between the groups were found for several scores (Table 11 – 2.80 > $F_{(3,322)}$ < 214.56, $p < 0.05$) excepting for the PVF-size ($F_{(3,322)} = 0.48$, $p < 0.70$), proactive ($F_{(3,322)} = 1.96$, $p < 0.12$)**,** retroactive ($F_{(3,322)} = 0.15$, $p < 0.93$), forgetting ($F_{(3,322)} = 2.09$, $p < 0.10$) and ERR1 ($F_{(3,322)} = 2.80$, $p < 0.06$) variables.

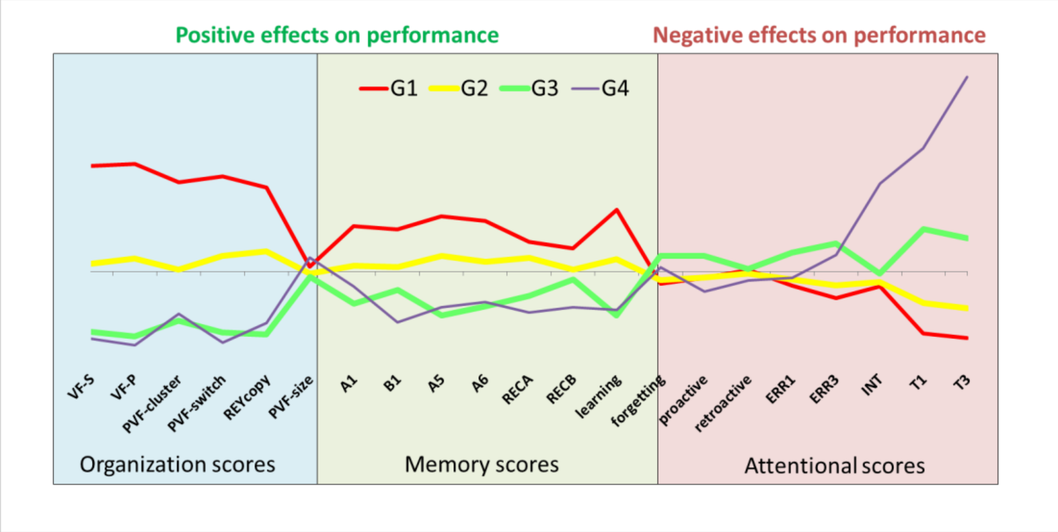


Figure 9 – Nonhierarchical cluster analysis: Performance in each score per category and group

* *The positive effects relate to the variables that contribute to better global performance, and the negative effects relate to the variables that decrease global performance.*

Table 11 − Nonhierarchical cluster analysis: Mean, standard deviation, and intergroup differences for test scores

Scores	Groups - M (SD)				Differences between groups	ANOVA, p*
	G1	G2	G3	G4		
VF-S	1.21 (0.75)	0.09 (0.66)	-0.69 (0.7)	-0.77 (0.58)	G1>G2>G3=G4	F(3,322)=121.88, p<.00**
VF-P	1.23 (0.8)	0.15 (0.57)	-0.74 (0.63)	-0.84 (0.67)	G1>G2>G3=G4	F(3,322)=147.65, p<.00**
PVF-clust	1.02 (1.15)	0.02 (0.72)	-0.56 (0.64)	-0.48 (0.74)	G1>G2>G3=G4	F(3,322)=57.27, p<.00**
PVF-switch	1.09 (0.92)	0.18 (0.64)	-0.7 (0.67)	-0.81 (0.66)	G1>G2>G3=G4	F(3,322)=100.72, p<.00**
REYcopy	0.96 (0.79)	0.23 (0.8)	-0.72 (0.69)	-0.59 (0.84)	G1>G2>G3=G4	F(3,322)=76.67, p<.00**
PVF-size	0.06 (0.77)	-0.02 (1.02)	-0.06 (1.1)	0.16 (1.04)	no interactions	F(3,322)=0.48, p=0.70
A1	0.52 (0.93)	0.07 (0.84)	-0.37 (1.03)	-0.17 (1.1)	G1> all groups ; G2>G3=G4	F(3,322)=12.78, p<.00**
B1	0.48 (1.01)	0.05 (0.96)	-0.21 (0.93)	-0.58 (0.88)	G1>G2=G3=G4	F(3,322)=11.34, p<.00**
A5	0.63 (0.82)	0.18 (0.82)	-0.5 (0.99)	-0.41 (1.07)	G1>G2>G3=G4	F(3,322)=25.79, p<.00**
A6	0.58 (0.9)	0.11 (0.79)	-0.4 (1.02)	-0.35 (1.15)	G1>all groups ; G2>G3=G4	F(3,322)=17.74, p<.00**
REC-A	0.34 (0.51)	0.16 (0.76)	-0.28 (1.24)	-0.47 (1.32)	G1=G2>G3=G4	F(3,322)=9.18, p<.00**
REC-B	0.27 (0.85)	0.02 (0.94)	-0.09 (1.08)	-0.41 (1.1)	G1>G4	F(3,322)=3.75, p<.00**
learning	0.71 (0.78)	0.14 (0.75)	-0.5 (1.08)	-0.44 (0.92)	G1>G2>G3=G4	F(3,322)=29.21, p<.00**
T1	-0.71 (0.53)	-0.36 (0.58)	0.49 (0.81)	1.41 (1.53)	G1<G2<G3<G4	F(3,322)=73.66, p<.00**
T3	-0.76 (0.56)	-0.42 (0.55)	0.38 (0.5)	2.23 (0.93)	G1<G2<G3<G4	F(3,322)=214.56, p<.00**
INT	-0.17 (0.93)	-0.12 (0.91)	-0.02 (0.93)	1.01 (1.24)	G1=G2=G3<G4	F(3,322)=11.73, p<.00**
ERR1	-0.16 (0)	-0.09 (0.34)	0.22 (1.67)	-0.07 (0.33)	no interactions	F(3,322)=2.80, p=.05
ERR3	-0.3 (0.39)	-0.16 (0.74)	0.32 (1.36)	0.19 (1.04)	G1=G2<G3=G4	F(3,322)=7.74, p<.00**
proactive	-0.07 (0.57)	-0.07 (0.7)	0.18 (1.42)	-0.23 (0.89)	no interactions	F(3,322)= 1.96, p=0.12
retroactive	0.02 (0.22)	-0.02 (0.27)	0.03 (1.69)	-0.1 (0.41)	no interactions	F(3,322)=0.15, p=0.93
forgetting	-0.14 (0.72)	-0.1 (0.92)	0.18 (1.2)	0.05 (1.01)	no interactions	F(3,322)=2.09, p=0.10

3.4 Conclusions

The aim of this paper was to characterize subgroups of cognitive functioning throughout development based on performance in four classical neuropsychological paradigms that evaluate executive functions (especially in terms of organization), short- and long-term memory, and attentional characteristics (especially in terms of interference control). To accomplish this goal, a hierarchical cluster analysis was used as an exploratory method, and a nonhierarchical cluster analysis was used as a confirmatory classification method.

3.4.1 Exploratory analysis: hierarchical clusters

First, in the most distant level of the hierarchical analysis, it was possible to identify two similarly sized groups, Group A and Group B. Group A was composed of younger children with lower levels of performance, and Group B was composed of older subjects with higher levels of performance. In the next segment of the hierarchical classification, groups A and B were both split into two groups. Group A was divided into groups one and two, and Group B was divided into groups three and four.

At shorter distances (< 10), these 4 groups were subdivided into 15 and then 55 smaller clusters. The segment containing only four groups (distance < 15) was selected as the cutoff point for confirmatory analysis, due to greater intergroup homogeneity and also to avoid an excessive number of clusters in the subsequent analysis.

The four-group section exhibited more heterogeneity among configurations when compared to groups A and B. Groups 1 through 4 displayed differences in terms of frequency (Group 1 < 3 < 4 < 2) and age (Group 1 < 2 = 3 < 4).

3.4.2 Confirmatory analysis: nonhierarchical clusters

The confirmatory analysis was based on the four-groups solution found in the exploratory analysis, which led to the classification of four distinct subgroups in the total sample. The results of the second analysis displayed a very similar configuration to that of the first one. The groups exhibit heterogeneous patterns in terms of the frequencies of their subjects (G2 > G3 > G1 > G4) as well as in their constitution in terms of chronological age and specific performance. Information about the classification of the groups is displayed in Figure 8.

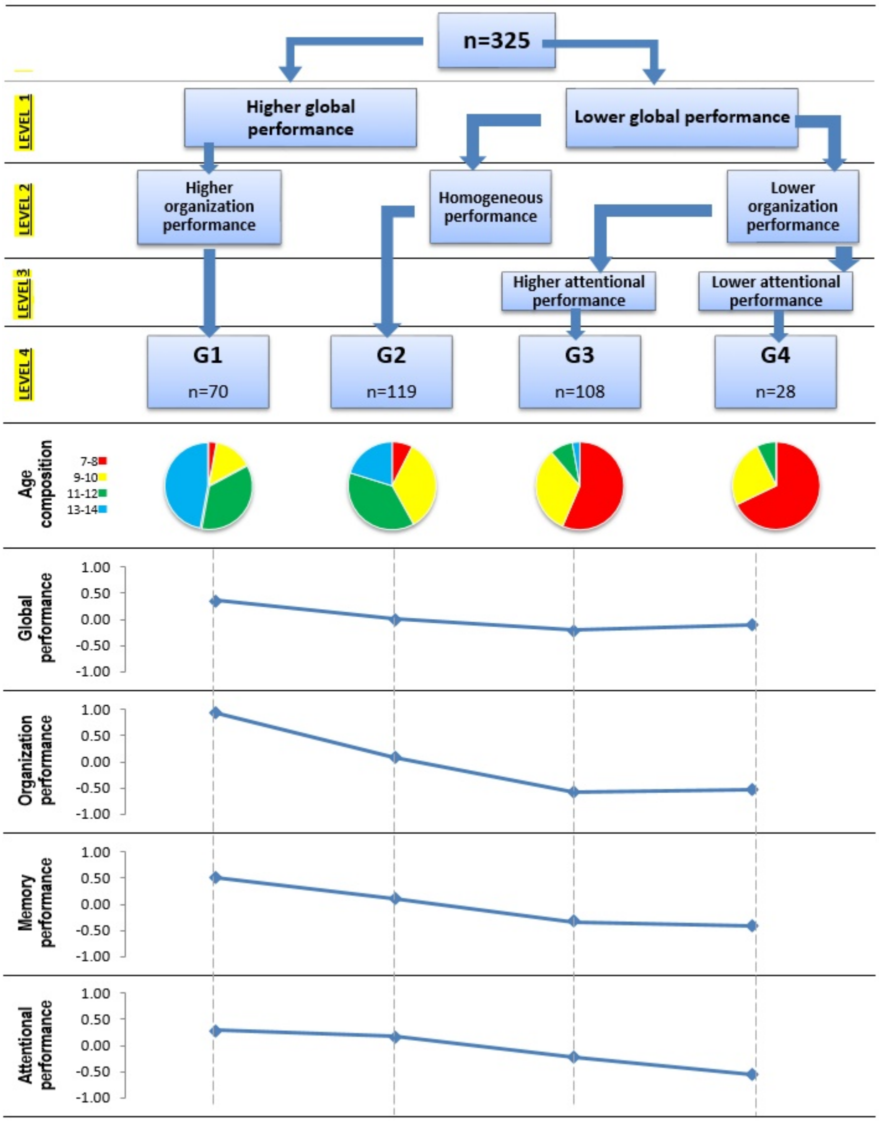


Figure 10 − Classification of each group based on discriminant profiles

3.4.2.1 Distinguishing patterns by chronological age

The groups were different in terms of mean age, as demonstrated by the examination of the composition of their age ranges. The groups can be organized in decreasing order, from the oldest to the youngest group. To elaborate, G3 had an average age similar to that of G4. This age progression revealed that, in the most general characterization of this sample, the age variable was a key factor in differentiating cognitive functioning between groups.

The most evident explanation for this effect is the maturation of the neural apparatus, which is closely linked to age and has relatively specific chronological peaks in healthy humans (CASEY; GIEDD; THOMAS, 2000; PAUS, 2005; QUARTZ; SEJNOWSKI, 1997). The existence of specific maturational stages can be explained as a result of both organic and environmental factors related to age. Among the organic factors, it is possible to mention the genetic milestones that regulate gene expression in pre-established developmental periods and the hormonal regulation of growing; one example of this regulation is the increase in sex hormones during puberty (DIAMOND et al., 2014; MCEWEN, 1997). External factors include regular milestones throughout the lifespan that mediate cognitive progression at specific times. Prime examples are the development of language (GREENFIELD, 1972; NELSON, 1996), the beginning of formal schooling (COLE, 1990), literacy (ECHOLS et al., 1996), the gradual complexity of classroom content, and the formation of knowledge hierarchies (BLAIR; RAZZA, 2007b; CARPENTER; MOSER, 1984; PASSOLUNGHI; MAMMARELLA; ALTOÈ, 2008).

3.4.2.2 Distinguishing patterns by performance

Similar to the exploratory analysis, the solution of four nonhierarchical clusters created a primary section based on higher versus lower levels of global performance (Figure 10 – level one). The examination of performance in each of the synthetic variables (organization, memory and attention) helps to further specify differences between the four groups and define specific profiles of cognitive functioning for each one (Figure 10 – levels two and three).

Higher global performance (higher executive functioning) versus lower global performance

G1 is the only group to display particularly superior global performance, while G2, G3, and G4 present comparatively lower global performance. This result establishes G1 as the higher performing group and the others as lower global performing groups (Figure 10 – level 1).

Considering the performance of G1 in each synthetic variable, this group, composed of a higher proportion of older subjects with higher levels of global performance, is the only group to display significant difference between organizational performance and memory and attentional performance. Thus, G1 can be labeled as the group with a higher level of executive functioning (Figure 10 – level 2). This result is possibly due to the fact that G1 was the only group composed mostly of children over 12 years of age; this age is described in scientific literature as an important developmental stage for executive functions and especially for organizational and planning abilities (ANDERSON et al., 2001; BLAKEMORE; CHOUDHURY, 2006; WELSH; PENNINGTON; GROISSER, 1991).

It is also possible that the development of organizational capacities enabled these subjects to achieve superior performance on memory and attentional measures, which put them at a distinct overall advantage. This hypothesis is supported by several studies that suggest that older children with higher levels of executive functioning have the greatest advantage in memorizing lists (BJORKLUND, 1997), reading and arithmetic skills (PARIS; MYERS, 1981), and general school performance (BLAIR; RAZZA, 2007b). This reality is possibly due to the mediating role of executive functions in metacognition, strategic memory, and self-regulation processes (BROWN, 1987; COMOLDI et al., 1999).

Lower global performance profiles

Among the groups with lower levels of global performance, there are clear sections between sub-profiles. Group 2 displayed more balanced performance in different cognitive functions than G3 and G4, which displayed more heterogeneous results (Figure 10 – level 2). Attentional control ability was the most distinguishing factor for G3 and G4 (Figure 10 – level 3).

Homogeneous cognitive functioning

G2 was mainly composed of individuals of intermediate ages and performance levels who were close to the global average of the entire sample. This group also displayed the greatest homogeneity in subjects' scores on the organizational, memory, and attentional variables. Among the groups with lower levels of global performance, G2 exhibited the greatest achievement and was also the most similar to G1, which was the group with higher levels of executive functioning.

Group 2 contained balanced numbers of children ages 9 to 12, and this group still contained many subjects ages 13 to 14. One hypothesis is that these individuals were in a transitional phase; they had not yet reached the performance level of G1, but they were closer to this level than subjects in G3 and G4. The existence of a significantly larger cluster that contained multiple age ranges, such as G2, may represent the normal variation found in pattern of cognitive development that is expected at the end of childhood and the beginning of adolescence. Some studies of heterogeneity in cognitive development indicate the same pattern. These studies also identify the ages of 9 and 12 as transitional phases (FRY; HALE, 1996; KLIMKEIT et al., 2004) because of peaks in neurological prefrontal maturation and consequent enhancements of executive functions (GIEDD et al., 1999; SOWELL et al., 2001).

Higher and lower attentional performance

Group 3 and G4 had very similar cognitive profiles with lower levels of global performance that differed from each other only in Stroop scores. This result established the attentional factor as the difference between these two groups, as G4 underperformed in both processing speed (T1) and interference control (T3 and INT). Thus, while G3 can be characterized as a group with a lower level of cognitive functioning, G4 displayed lower levels of cognitive functioning specifically in the form of poor attentional control. Group 4 was the group furthest away from the others, and it manifested the highest degree of dissimilarity. Group 4 was also the smallest group in terms of the number of individuals in it. Unlike G3, which also contained a small proportion of subjects ages 11 to 14, G4 was constituted predominantly of younger children.

Taking into consideration age compositions and cognitive distinctions based on attentional performance, it can be speculated that the lower levels of global performance displayed by younger children, such as those in G4, are justified by one specific factor: their lower attentional capacities. However, older children, such as those in G3, may present lower levels of global functioning because of multiple factors. Some authors have also reported the same pattern that was found in G4; this result indicates attentional control of interference as one of the last cognitive skills to be acquired in childhood (MIYAKE et al., 2000; WILLIAMS et al., 1999), making it the key factor in determining the overall performance of children ages 7 to 9. It can be hypothesized that it is essential for younger children to gain the ability to resist interference in order for them to reach higher levels of selective attention. In turn, these higher selective attention levels prevent irrelevant information from draining the working memory resources of children (BJORKLUND; HARNISHFEGER, 1990; GATHERCOLE, 1999).

Following the same developmental pattern found in the hierarchical clusters analysis, the factors that primarily characterize the distinction between the four nonhierarchical groups are also the EF variables and especially the verbal fluency scores. While these EF variables showed an accentuated progression curve, the changes in memory variables between groups remained subtle. This observation suggests a more heterogeneous developmental profile for the EFs than for memory components, the changes of which are less clear and more gradual in all of the groups.

This difference between the EFs and memory curves suggests that these functions may have different trajectories throughout childhood and improve at different speeds. Imaging studies suggest that some changes in children’s neuroanatomy and neurophysiology may occur in regional peaks of maturation and involve only certain areas of the brain (CASEY; GIEDD; THOMAS, 2000; GIEDD et al., 1999; PAUS, 2005). For example, a consensus exists that after the age of 12, a large overall reduction of gray matter in the cortex occurs. However, the dorsolateral prefrontal lobe, which is largely related to organizational capacity, appears not to change simultaneously with the rest of the brain (GIEDD et al., 1999; SOWELL et al., 2001). This observation indicates that these two cognitive functions can achieve different degrees of maturation at asynchronous moments due to their anatomically correlated areas.

The prefrontal cortex in particular is largely responsible for coordinating EFs (JACOBS; HARVEY; ANDERSON, 2011). Because the prefrontal cortex is the last area to reach full neurophysiological maturation, the performance of EF tasks is more affected by age-related changes than other cognitive functions like memory and attention (BUNGE et al., 2002; CASEY; GIEDD; THOMAS, 2000). The prefrontal cortex also remains in a state of plasticity for a prolonged interval, and as a result, EFs are also reported to be more susceptible to environmental influences such as level of parental stimulation, quality of early childhood education, and the socioeconomic status of a family (CASEY; GIEDD; THOMAS, 2000; NOBLE; NORMAN; FARAH, 2005; TAMIS-LEMONDA et al., 2004). The literature on neuropsychological development seems to support these deductions and also suggests that changes in EFs mainly occurring between the ages of 12 and 14 may be key factors in the further improvement of the retention, retrieval, and manipulation capacities of memory components (CASE; KURLAND; GOLDBERG, 1982; KANE; ENGLE, 2003; SHING; DIAMOND; DAVIDSON, 2010).

While the groups differed primarily according to EF variables, they did not differ in terms of VF cluster size, errors in the first Stroop trial, or scores of proactive and retroactive interference on the RAVLT. These findings suggest that these scores do not vary in the age groups included in this study and in turn, this result suggests a different developmental trajectory when compared to other components analyzed in this paper. Other studies have found a similar pattern in clusters sizes (KOREN; KOFMAN; BERGER, 2005) and interference scores on the RAVLT (VAKIL; GREENSTEIN; BLACHSTEIN, 2010).

3.4.2.3 Divergent developmental patterns

Although the EF variables were the most differential score between groups, the divergent patterns identified in this study do not seem to emerge from a unique explanation. Even chronological age could not be assumed as an established cofactor. In other words, the heterogeneity found between different groups does not seem to be only a result of a sequential transition between profiles.

For example, the confirmatory analyses suggested the emergence of a single group belonging to G4 that was atypical when compared to profiles displayed by other groups. This group consisted of a reduced number of subjects that presented lower levels of general performance, and it mostly contained children ages 7 and 8. This group underperformed in general, but it demonstrated a specific lack of attentional control. According to this observation, a single explanation for the existence of all of the groups cannot be provided. Several scenarios are hypothesized below:

1. **The hypothesis of a late developmental pattern**

   It is possible that these individuals constitute an expected subgroup normally found in healthy populations, but they do not follow the rhythm of development of the majority of subjects of the same age group. In contrast to the average pattern, these individuals may maintain poor levels of cognitive functioning throughout childhood. However, rather than continuing to develop atypically, their development may begin to resemble the expected pattern during adolescence. This change could be explained by the global leverage afforded by the peak of EF development between the ages of 12 and 14 (BLAKEMORE; CHOUDHURY, 2006; HUIZINGA; DOLAN; VAN DER MOLEN, 2006). After this occurrence, the children begin to mirror the levels of cognitive functioning expected for their age, although they reach this level later than the average population.

2. **The hypothesis of expected variability**

This group may have a unique cognitive profile that is less frequent in a given healthy population. This hypothesis could explain both the high and the low overall performance levels of a particular group. In the course of development, such groups may maintain a uniform level of either higher or lower performance, but their performance never reaches a critical level. In the future, these children would constitute a portion of the expected cognitive variation in a heterogeneous adult population but display no clear strengths or neuropsychological impairments. In the case of poor attentional profiles such as that of the individuals in G4, the individuals may tend to compensate for their lack of attentional performance by using more strategies based on memory or organizational capacities (DIRETTE, 2002; FAIR et al., 2012; WASSERSTEIN; LYNN, 2001), as their performance in these functions is closer to the average levels.

3. **The hypothesis of subclinical profiles**

The existence of a small group of individuals with markedly reduced attentional capacity may indicate the presence of a subclinical population that displays attentional performance above the average. Some of these individuals who have more impulsive profiles could produce more errors or false positives in attentional tests due to the lack of resources available for self-monitoring. Others, in a more subtle way, may mask their poor attentional capacities by reducing their response times in cognitive activities; reducing response may to reduce their amount of possible errors (EYSENCK et al., 2007; MEICHENBAUM; GOODMAN, 1971). This hypothesis highlights the importance of early cognitive screening in order to prevent further complication from attentional disadvantages.

Given the age distributions and the specific cognitive profiles of each group, it is likely that the second hypothesis, the hypothesis of expected variation, is most suited to describe the variation found in G2 and G4. For example, children in G2, the homogeneous performance group, appeared to be in transition to the same profile as G1, the group with higher levels of executive functioning. In the meantime G4, the group with lower levels of attentional performance, seemed to be in transition to the G2 profile.

On the other hand, the second hypothesis, the hypothesis of expected variability, applies best to G1, which consists of a small sample of older individuals with higher levels of executive functioning. This pattern is expected and commonly found in the transition from adolescence to adulthood. The second hypothesis may also be used to explain the pattern of G3. A possible explanation of the lower levels of executive performance of G3 is that this group possibly consisted, in part, of children who will continue displaying low levels of performance overall throughout development but who do not display an obvious disadvantage in relation to the average population of the same age. However, the third hypothesis, the hypothesis of subclinical profiles, can possibly be used to explain the appearance of older children in G3 who seemed to be outside of the cognitive stage expected for their chronological age group. They had already exceeded some of the expected important neuropsychological milestones, such as the marked improvement in EFs found around the age of 12 (MIYAKE et al., 2000), but they remained at a similar level of executive functioning to that of younger children (under 10 years old, like in G4).

This atypical cognitive profile present in G3 is commonly found in a smaller but significant portion of the adolescent population in developing countries (DE GRAAF et al., 2008; ROHDE; JELLINEK, 2002). Although other studies of low-income children have also indicated significant cognitive heterogeneity in this age group, it is well known that functions such as language, organization, and working memory suffer negative effects because of the specific socioeconomic profile of these populations (GRANTHAM-MCGREGOR et al., 2007; MCLOYD, 1998; NOBLE; NORMAN; FARAH, 2005; QI et al., 2006). Growing up in a low-income family and poor quality of education are acknowledged risk factors during cognitive development.

The results of this study may be useful in efforts to better define the borderlines between healthy and pathological patterns of development. This study may also be helpful in predicting the progress curve of organization, memory, and attentional capacities in heterogeneous populations in which demographic variables such as socioeconomic status or quality of formal education can create specific neuropsychological profiles that are not only attributable to age groups.

However, a limitation of the current study is that it does not provide longitudinal information about how the transition between different profiles occurs over time. A second restriction is the fact that the neuropsychological paradigms used in this study are not specific measures of EFs or attention, this fact could mask deficits in secondary abilities not explicitly involved in the main investigation. For example, verbal fluency is one of the executive abilities that is most difficult to test in young children due to their lack of phonological awareness. The incongruent condition of the Stroop test requires great levels of literacy in order to better indicate the real magnitude of interference control processes in infants. Thus, future investigations should include longitudinal analysis and EF and attentional tests that are not so closely related to secondary abilities.

4
Final considerations

This dissertation presented two integrated studies focusing on the cognitive characterization of low-income Brazilian students. The main goals of this project were to conduct an analysis of multiple cognitive domains based on the results of the same four classical paradigms. The project also included a substantially large sample of up to 365 individuals from a wide age group of children ages 7 to 14.

Additionally, both studies employed multivariate analyses in order to establish a classification system. In the first study, multivariate analysis was used as a method to explore the relationship between different cognitive functions, like EFs and memory subdomains, in order to establish points of similarity or difference between the scores. In the second study, multivariate analysis was employed as a taxonomic method used to subdivide cases in order to characterize each subgroup in terms of their performance in the distinguished domains found in the first study and described in neuropsychological literature.

The results of this project suggest a clear dissociation between the domains of EFs and memory. In the first study, the high levels of intergroup heterogeneity in test scores also suggest the existence of specific subdomains of each paradigm applied. In the RAVLT for example, the recall of list-B differs clearly from that of list-A, although both of the lists are considered scores of short-term memory. This result could be explained in terms of the specific demands of each score. While the first trial of the list-A was a precise measure of short-term memory retrieval, the list-B demanded additional resources such as the attentional capacity to avoid the proactive interference caused by list-A (VAKIL; GREENSTEIN; BLACHSTEIN, 2010). This result is consistent with the hypothesis that when short-term memory scores are computed while another parallel attentional activity, such as the unconscious activity to prevent inference from list-A, is being processed that score will also reflect working memory capacities (KANE; ENGLE, 2000).

The large difference between most of the variables may indicate a heterogeneous developmental trajectory in the range of ages included in this study. This result is consistent with neuropsychological literature, which indicates a non-linear and non-homogeneous pattern of progressions during development (JURIC et al., 2013; MIYAKE et al., 2000; SHING et al., 2010). Almost all of the VF and long-term memory scores from the RAVLT (A5 and A6) suggested high levels of intragroup homogeneity. This result suggests that these variables are equally related to one another throughout the developmental stages that occur from ages 7 to 14 and that they change only in terms of magnitude.

Additionally, due to this homogeneous pattern found in almost all of the VF scores, it is possible to assume that verbal fluency is the most consistent explanation for the variation in performance for other measures used in this study. For example, the Rey copy is also linked to the VF variables, and this indicates a cognitive cofactor underlying the two abilities. It is likely that the same ability used to perform strategic searches in lexical memory in order to achieve improved word fluency is also used in order to perform a strategic copy of the Rey complex figure. Although the two tests measured different domains, verbal in the VF test and visuospatial in the Rey copy, they clearly shared a common executive component referred to here as organizational capacity.

Finally, the Stroop scores, normally used as measures of executive components such as inhibitory control or interference control (STRAUSS; SHERMAN; SPREEN, 2006), were very different from the other EF scores. This result suggests that executive functioning cannot be assumed as a global and unique variable that has multiple and divergent subdomains and different interactions with other cognitive variables (MIYAKE et al., 2000).

The second study proposed a classification system based on the similarities found in the cognitive profiles of all subjects. To accomplish this goal, a hierarchical cluster analysis was used as an exploratory method, and a nonhierarchical cluster analysis was used as a confirmatory classification method.

Each group was compared in terms of age and performance on organizational, memory, and attentional variables.

The results of this study suggest that the key distinguishing factor between different cognitive profiles throughout childhood is executive performance, while the memory and attentional variables causes subtler and less decisive changes in overall performance. This result is very consistent with the most recent lifespan and neuroimaging studies, which indicate the progression of executive capacities as a better explanation for the gradual improvement in measures of global functioning (ARFFA, 2007; BLAIR; RAZZA, 2007b; CARLSON; MOSES; BRETON, 2002; CONWAY et al., 2002). It is possible that improvements in EFs account for a larger percentage of the variation in age-related improvements on span tasks because the most strategic people can use their skills of mental repetition. Consequently, they can hold and manipulate more words in their minds. As strategic efficiency improves, word-span memory also improves (COMOLDI et al., 1999; GATHERCOLE, 1998).

Additionally, attentional ability was more useful in distinguishing the cognitive profiles of younger children, which have low or very low levels of performance. However, attentional ability was less useful in differentiating the cognitive profiles of older children. It is possible that younger children depend more on attentional factors to perform slightly better on several cognitive tasks because they still lack the executive capacities needed to maintain and manipulate important information. Such capacities normally only improve around the age of 12 (BLAKEMORE; CHOUDHURY, 2006). Because of this, younger children are more dependent on primary skills such as processing speed or interference control in order to prevent the loss of information relevant to a task (FRY; HALE, 1996; SHING et al., 2010).

Although the formation of subgroups in this sample indicates an age-related progression of cognitive abilities, the relationships between components are not only attributable to chronological time. In the current sample, some individuals from very different age groups achieve similar levels of performance, what indicates the existence of a normal range of variation in performance levels, even in healthy populations.

Regarding the general contributions of both studies summarized here, the characterization of organizational, memory, and attentional aspects of cognitive development in Brazilian students may provide important information for use in distinguishing normal and pathological patterns of development. The developmental classification hypothesized can be used as a tool to promote early diagnosis and proper interventional planning in order to avoid the appearance of subsequent cognitive deficits or the aggravation of current ones. These findings may also be very useful in determining which neuropsychological measures should be included in short cognitive assessment batteries or in a neuropsychological map for planning the best rehabilitation approach in accordance with the trajectory of cognitive development.

In order to better define the cognitive subgroups found in this study, a future goal of this project is to compare the neuropsychological patterns detected in this sample to samples that present different socioeconomic profiles. Another future goal is to find out how these profiles manifest in each age group in a longitudinal study.

Acknowledgments

This study was supported by the Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ, grant number E-26/103.193/2012) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, grant number 155700/2013-8). The authors have no conflicts of interest to report.

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