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Attention and Memory Evaluation Across the Life Span: Heterogeneous Effects of Age and Education

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The developmental sequences of attention and memory were studied by utilizing normative data derived from the neuropsychological battery named NEUROPSI ATTENTION AND MEMORY. A sample of 521 Spanish-speaking individuals, aged 6 to 85 years, participated in this study. In the adult sample, educational level ranged from 0 to 22 years of education. Data from subtests measuring orientation, attention and concentration, executive functions, working memory, immediate and delayed verbal memory, and immediate and delayed visual memory were included. The factor structure of the analyzed battery is presented. The effects of age and education on this structure were analyzed. Results suggested that although attention and memory are related, their developmental sequences are separated from one another. During childhood, the development of selective and sustained attention, attentional-working memory, and executive functions showed a fast improvement in performance. Development of verbal memory and place and person orientation showed a slower increment in scores. In the adult sample it was found that factors related to memory are sensitive to age, whereas those related to attention and executive functions are sensitive to education. The consideration of both the developmental sequence, as well as differential effects of education, can improve the sensitivity and specificity of neuropsychological measures, allowing early diagnosis of cognitive dysfunction and implementation of adequate rehabilitation programs.

Introduction

Appropriate performance and personal adjustment in daily life requires both attention and memory; which, in turn, are indispensable preconditions for suitable functioning of other cognitive domains (Lezak, 1995).

Although attention and memory research has been conducted across a wide variety of age groups, very few studies to date have encompassed a life-span analysis within a single project (Plude, Enns & Brodeur, 1994). Processes falling under the general rubric of development can occur at any point in the life course, from conception to death (Baltes, 1987). However, the scarcity of life-span studies restricts the comprehension of life-long

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development as a system of diverse change patterns that differ, for example, in terms of timing (onset, duration, termination), direction, and order.

Within these limitations, developmental research has pointed out that attentional changes across the life-span allow for greater selectivity and speed of processing during childhood and adolescence, and generally less selectivity and greater slowing during later adulthood (Gomes, Molholm, Christodoulou, Ritter & Cowan, 2000; Lewis, Kelland & Kupke, 1990; Plude et al., 1994; Trenerry, Crosson, DeBoe & Leber, 1990). A similar trend has been reported for memory functions. A developmental increase in memory span, immediate and delayed recall during childhood and adolescence, followed by a negatively accelerated trajectory during later adulthood, has been described (De Luca et al., 2003; Gathercole, 1998; Grady & Craik, 2000; Haaland, Price & Larue, 2003; Siegel, 1994). Nevertheless, differences in age groups and tasks employed make comparisons between developmental studies difficult.

In cognitive literature, a controversy regarding attention as a unitary mechanism or as a divisible function has been analyzed (Van Zomeren & Brouwer, 1994). In a similar vein, an important issue in the science of learning and memory has to do with the concept of memory as a unitary complex or as a group of two or more systems. Evidence of multiple attentional and memory systems is provided by experimental, neuropsychological, psychopharmacological and developmental dissociations between performances in a variety of situations. Classification of attention and memory has proved to be heuristically useful for describing specific problems (Tulving, 1987; Van Zomeren & Brouwer, 1994). Today, attention and memory are described as multidimensional constructs consisting of several subfunctions. The specifications of these subfunctions, however, are not consistent. Most descriptions of attention include subfunctions of regulation of arousal and vigilance, selective focusing of attention, sustained attention, shift or dividing of attention, and attentional control (Mirsky, Anthony, Duncan, Ahearn & Kellman, 1991; Van Zomeren & Brouwer, 1994). The concept of memory usually includes subfunctions such as sensory memory, short-term memory, long term memory, working memory, declarative memory, and procedural memory (Atkinson & Shiffrin, 1968; Tulving, 1987, 1992). These components of attention and memory are often related to each other and to other cognitive abilities as well, such as executive functions; yet the specifications and relationships among these components are not consistent, nor fully understood.

Development of attention and memory subfunctions involves a complex pattern of change, with some aspects exhibiting significant change and others exhibiting remarkable stability across the life span (Klenberg, Korkman & Lahti-Nuuttila, 2001; Plude, et al., 1994). The scarcity of developmental studies which include a wide age range, as well as a wide spectrum of attentional and mnemonic subfunctions, restricts the comprehension of development as a continuous and complex process.

In clinical settings, the evaluation of attention and memory is essential because impairments of these functions are frequently described in several different neuropathological and neuropsychiatric disorders (Larrabee & Crook, 1996; Lezak, 1995; Ruff, Light & Quayhagen, 1989; Squire & Shimamura, 1996). In order to establish an accurate clinical picture about the severity and nature of the attention and memory impairments, the clinician needs valid and reliable tests, with appropriate normative data (Bauer, Tobias & Valenstein, 1993; Mayes, 1986; Squire & Shimamura, 1996).

An additional variable potentially influencing developmental changes is education. Several studies have demonstrated a strong association between educational level and performance on various neuropsychological measures (Ardila, Ostrosky-Solis, Rosselli & Gomez, 2000; Ardila, Rosselli & Rosas, 1989a; Ardila, Rosselli & Ostrosky, 1992;

Castro-Caldas, Petersson, Stone-Elander, & Ingvar, 1998; Castro-Caldas, Reis. & Guerreiro, 1997; Finlayson, Johnson & Reitan, 1977; Heaton, Grant & Matthews, 1986; Ostrosky-Solís, Ardila, & Rosselli, 1999; Ostrosky-Solís, Ardila, Rosselli, López & Mendoza, 1998; Ostrosky-Solís, Arellano & Pérez, 2004; Ostrosky, Canseco, Quintanar, Navarro & Ardila, 1985; Ostrosky-Solís, Ramírez, Picasso & Vélez, 2004; Ostrosky, et al., 1986, 2003b). It has even been proposed that in neuropsychological testing, schooling is a more significant variable than age (Ostrosky-Solís et al., 1998).

In this article, data for attention and memory subfunctions are provided in a sample of Spanish speaking subjects from 6 to 85 years of age, and analyzed to determine factor structure. The first aim of this study was to gain insight into the separateness versus clustering of these functions. A second aim was to analyze the effects of age and education in the factor structure.

Methods

Participants

The sample consisted of 521 nonpaid volunteers who participated in the standardization of the NEUROPSI ATTENTION AND MEMORY (Ostrosky-Solís et al., 2003a). Sample age ranged from 6 to 85 years, and, in the adult sample (16 to 85 years), educational level ranged from 0 to 22 years of education. Although both age and education were treated as continuous variables, in order to illustrate the demographic characteristics, Table 1

Table 1
Age and education distribution. (N = 521)

	Age group (years)								
Education group (years)	6–7	8–9	10–11	12–13	14–15	16–30	31–55	56–64	65–85
0–3									
M age	6.6	8.4				21.9	46.8	58.5	71.6
(SD)	(0.47)	(0.50)				(4.62)	(6.99)	(2.50)	(7.37)
M education	1.3	3.2				0.2	0.6	1.4	1.3
(SD)	(0.54)	(0.73)				(0.86)	(0.97)	(1.51)	(1.52)
N	33	35				26	27	25	22
4–9									
M age			10.51	12.4	14.4	21.9	48.4	57.7	69.9
(SD)			(0.50)	(0.50)	(0.50)	(5.85)	(4.97)	(1.39)	(4.61)
M education			5.31	6.9	8.8	8.5	7.5	7.1	6.2
(SD)			(0.52)	(0.95)	(0.87)	(1.14)	(1.42)	(1.36)	(1.84)
N			39	41	25	26	42	26	23
10–22									
M age						20.9	44.2	58.8	74.7
(SD)						(3.52)	(7.51)	(2.36)	(6.39)
M education						13.6	14.4	15.2	13.7
(SD)						(2.24)	(2.82)	(3.27)	(3.77)
N						44	36	29	22

presents the mean values of age and education for nine age groups (6 to 7 years, 8 to 9 years, 10 to 11 years, 12 to 13 years, 14 to 15 years, 16 to 30 years, 31 to 55 years, 56 to 64 years and 65 to 85 years); and three educational levels: (zero to 3 years of education, 4 to 9 years of education and 10 to 22 years of formal education), according to NEUROPSI ATTENTION AND MEMORY norms.

Volunteers were recruited from four different states of the Mexican Republic (Mexico City, Colima, Guadalajara and Zacatecas) over a 4-year period (1998–2002). Sources of participants included in the present analysis were as follows: regional medical facilities (medical and paramedical people and spouses, friends or relatives of patients who attended for medical check-ups (5.8%); retirement community (33.2%); social community centers (19.5%); primary schools, secondary schools, high-schools and university students (22.1%); volunteers and self-referred participants (19.4%).

The following inclusion criteria were used: 1) no neurological or psychiatric disorders (such as brain injury, cerebrovascular disease, epilepsy, Parkinson's disease, depression, psychiatric hospitalizations, and the like), according to a health history questionnaire; 2) absence of current and/or history of chronic alcohol and/or drug abuse; 3) normal or corrected-to-normal vision and hearing; 4) children were screened for childhood behavioral and neurological problems including Attention Deficit Disorder and reading and learning disabilities. All participants were nonpaid volunteers. All participants were native Spanish-speakers and were active and functionally independent. Participants with questionable health histories (e.g., those reporting history of craneoencephalic trauma, cerebrovascular disease, and/or subjects under medication for psychiatric and/or central nervous system disorders), were excluded.

Materials

NEUROPSI ATTENTION AND MEMORY (Ostrosky-Solis et al., 2003) has standardized procedures for both administration and scoring. It includes several measures that are based on principles and procedures developed in cognitive neuroscience. The covered domains encompass orientation, attention and concentration, executive functions, working memory, immediate verbal memory, delayed verbal memory, immediate visual memory and delayed visual memory, each having its own subtests. Each area includes assessment of different aspects of that particular cognitive domain. Thus, assessment of attention includes level of alertness, span or efficiency of vigilance–concentration, and selective attention. Executive function assessment comprises concept formation, flexibility, inhibition and several motor programming tasks. Memory assessment includes immediate and delayed recall of auditory-verbal and visual–nonverbal functioning. Word list learning includes three learning trials of 12 words. Each of the 12 items belonged to one of three high frequency semantic categories in Spanish language (animals, fruits or body parts). Delayed recall includes free and semantic cued recall, as well as a recognition trial, which includes a 24 words list that does not contain high frequency words within each category.

It is important to point out that items were not simply translated but adapted according to frequency and relevance for Spanish-speaking individuals, for example it included language and picture tests that were previously standardized in our laboratory according to high, medium, and low frequency of occurrence in the Spanish language (Aveleyra, Gómez, Ostrosky-Solís, Rigalt & Cruz, 1996). Phonological verbal fluency was evaluated using letter *P*. This letter was selected based on the ratio of words in the Spanish language starting with this letter, relative to the total number of words in a Spanish dictionary.

According to this analysis, there is a good proportion of high frequency words beginning with this letter in Spanish.

The following subtests were included in the NEUROPSI ATTENTION AND MEMORY neuropsychological battery:

Orientation. was evaluated taking into account general information regarding subject's orientation in time, place and person. (Maximum score = 7 points).

Auditory/verbal Attention and Concentration. was evaluated using the *Digit Forward Span, Digit Detection and Mental Control* tests. *Digit Forward Span* consisted of pairs of random number sequences that the examiner read aloud, at the rate of one per second, the subject's task was to repeat each sequence exactly as it was given. (Maximum score = 9 points). Digit Detection was a vigilance test that examined the ability to sustain and focus attention. It involved the sequential presentation of digits over a period of time with instructions for the subject to tap only when the target item 5 was preceded by the item 2. (Maximum score = 10 points). Mental Control required the subject to count from 1 to 40 by 3's within a time limit. (Maximum score = 3 points). *Visual/nonverbal attention and concentration* was evaluated using the Spatial Forward Span and *Visual Search* test. The Spatial Forward Span material included a board with blocks attached in an irregular arrangement. Each time the examiner tapped the blocks in a prearranged sequence, the patient must attempt to copy this tapping pattern exactly as it was given. (Maximum score = 9 points). The Visual Search test required visual selectivity at fast speed on a repetitive motor response task. It consisted of rows of figures randomly interspersed with a designated target figure. The subjects were requested to cross out those figures equal to the one presented as a model. Two scores were obtained: total number of correct responses (maximum score = 24), and number of intrusions.

Auditory/verbal working memory. This function was assessed using the Digit Backward Span test. In this test pairs of random number sequences were read aloud, at the rate of one per second, and the subject's task was to repeat each sequence in an exactly reversed order. (Maximum score = 8). *Visual/nonverbal working memory* was evaluated using the *Spatial Backward Span* test. This test included a board with blocks. Each time the examiner tapped the blocks in a prearranged sequence, the subject must attempt to copy the tapping pattern in an exactly reversed order. (Maximum score = 9). *Auditory/verbal immediate and delayed recall* was assessed using Word List, Verbal Paired Associates and *Logical Memory* tests. Immediate trials in the *Word List* consisted of three presentations with recall of a 12-word list. Each of the 12 items belonged to one of three semantic categories (animals, fruits or body parts). After each presentation, the subject repeated those words that he/she remembered. The total score was the average number of words repeated in the three trials (maximum score = 12). The delayed presentation provided one first free recall on the long term (20 min) (maximum score = 12). The second long term recall trial utilized the item categories as cues, asking the subject for items in each of the three categories (maximum score = 12). A recognition trial, in which the examiner asked the subject to identify as many words as possible from the list, when shown a list of 24 words containing all the items from the list, as well as words that were semantically associated or phonemically similar, was also provided (maximum score = 12 points). In addition, intrusions, perseverations and false positive errors scores were noted. The Verbal Paired Associates test included twelve word pairs, four of which were not readily associated (i.e., coche-payaso), four forming phonetic associations (i.e., camión-melón) and four forming semantic associations (i.e., fruta-uva). The list was read three times, with a memory trial following each reading. The words were randomized in each of the three learning trials to prevent positional learning. The total score was the average number of words repeated in the three trials (maximum score = 12). A 20 min. delayed recall was also provided (maximum score = 12). In addition, intrusions, perseverations and errors were noted. Logical Memory I and II were prose learning tests that allowed to score thematic recall and factual knowledge. The examiner read two stories, stopping after each reading for an immediate free recall. Each story contained 16 story units and five thematic units. A delayed recall trial after 20 minutes was also given. *Visual/Nonverbal immediate and delayed recall* was evaluated using the Rey-Osterreith Complex Figure or the Semicomplex Figure, and a Face Memory test. In the copy administration, subjects were shown the Rey-Osterreith Complex Figure or the Semicomplex Figure which they must copy. A delayed recall was also provided in which subjects were asked to recall what they had drawn on the administration trial. (Maximum scores = 36 in Rey-Osterreith Complex Figure, 12 in Semicomplex Figure). On the immediate trial of the Face Memory test subjects were shown two photographs with their respective names. After seeing each of them for five seconds, subjects were asked to repeat the names (maximum score = 4 points). On the delayed recall subjects were asked to remember the names of the persons (maximum score = 8 points) and to identify the previously shown persons among a set of four photographs (maximum score = 2 points). In addition, false positive errors were noted.

Executive functions evaluation included the Category Formation test, Verbal Fluency, Design Fluency, Conjugate Eye Movement, Conflicting Commands, Go/no go paradigm, Luria's Hand Sequences, Alternating Pattern and Stroop test. The Category Formation test included five visually presented sets, each one containing four figures of common objects. Each set was organized on the basis of different principles. On each set trial the subjects were asked to form as many categories as they could (maximum score = 25). Verbal Fluency measured the quantity of words produced within a time limit of one minute and consists of a semantic as well as a phonological trial. On the semantic trial subjects were required to generate items in a category (animals), whereas on the phonological trial subjects were required to generate words according to an initial letter ("P"). Total number of correct words, intrusions, perseverations, clusters and switchings were noted in both tests. Design Fluency required the subjects to draw different patterns by connecting the dots in each five-dot matrix using four lines. Subjects were given three minutes to perform this test. Total number of correct designs, intrusions and perseverations were noted. In Conjugate Eye Movement assessment a pencil was shown to the subject and he/she had to follow it with his/her eyes to the left and then to the right. (maximum score = 4 points). The instruction for Conflicting Commands was: "Tap once, when I tap twice; tap twice when I tap once" (maximum score = 2 points). The instruction for *Go/No-Go* paradigm was: "Tap twice, when I tap once, but when I tap twice, don't tap at all" (maximum score = 2 points). In Luria's Hand Sequences the examiner with his right hand made a fist, then extended his fingers, holding his hand horizontally and finally turned his hand by 90° with the extended fingers still pointing forward. After seeing this sequence of movements, subjects with their right hand must repeat it exactly as it was given. In a second trial the examiner repeated the sequence in an exactly reversed order with his left hand and subjects must repeat it with their left hand, exactly as it was given (maximum score = 4). Alternating pattern required the subject to copy a drawing without lifting his/her hand from the paper. The test required alternating between peaks and blocks (maximum score = 8). In Stroop test subjects were required to read, as fast as they could, a set of color words printed in black ink. On the second trial, subjects were required to call out, as fast as they could, the color names of colored ovals. On the third trial subjects were asked to call out, as fast as they could, printed color names when the print ink was in a different color than the name of the colored word. In the three trials, the total number of correct answers and the time employed to perform each trial were noted (maximum score = 36).

In total, 30 different scores were obtained. The Stroop subtest (Stroop, 1935) was not used with adults having fewer than 4 years of education. In children aged 6 to 7 years and in adults having fewer than 4 years of education, the Rey-Osterreith figure (Osterreith, 1944) was replaced by the semicomplex figure. (Ostrosky-Solís et al., 1999). Since data of these populations were missing for Stroop and Rey-Osterreith figure, both tests were excluded from the present analysis.

Procedure

The NEUROPSI ATTENTION AND MEMORY neuropsychological battery was administered independently by trained psychologists. Testing was performed in single sessions. Administration time was 60 to 70 minutes.

Statistical Analysis

Statistical analyses were carried out using the Statistical Package for Social Science (SPSS 11.0 for Windows). Factor components were obtained using varimax (orthogonal) rotated factor matrix to identify groups of variables in the neuropsychological battery and six components were extracted. Factor scores were computed and saved as variables for further analysis. In the children-adolescents sample (6 to 15 years), a linear regression design was used to examine age-related performance on each of the extracted components. In the adult sample (16 to 84 years), a multiple stepwise linear regression model was used to describe the relationship between each of the extracted components and both age and education as independent variables.

Results

Factor Analysis

A factor analysis with varimax rotation of the neuropsychological test battery was performed with the quantitative scores. Six different factors with an eigenvalue higher than 1.000 were disclosed. These six factors accounted for 63.6% of the total variance. A loading of 0.40 was used as a criterion. The loadings of the different subtests on the six factors are presented in Table 2.

Factor I (36.6% of the variance) best correlated with the category formation test (0.66), visual search (0.62), semantic verbal fluency (0.74), phonological verbal fluency (0.70) and design fluency (0.69). Factor I appeared to include a wide range of cognitive processes: sustained and selective attention, speed and ease of verbal production; as well as executive functions (ability to vary one’s responses rapidly, self monitoring, inhibition of inappropriate responses, remembering and following rules, use of strategies, and cognitive flexibility (Bryan & Luszcz, 2000; Estes; 1974; Lezak, 1995). This factor was considered an attentional-executive functions factor. Factor II (7.26% of the variance) best correlated with logical memory immediate (0.67) and delayed recall (0.70), verbal paired associates immediate (0.78) and delayed recall (0.79), and motor functions (0.45). This factor grouped together memory tests which allow to evaluate the contribution of context,

Table 2
Correlations between the test scores and the six factors

Tests	Factors I	II	III	IV	V	VI
Orientation						
Time	0.17	0.09	0.07	0.58	0.17	0.26
Place	0.16	–0.08	0.08	0.12	0.07	0.88
Person	0.01	0.10	0.05	0.01	–0.02	0.89
Attention and Concentration						
Digit forward span	0.34	0.26	0.08	0.37	0.47	–0.02
Digit detection	0.32	0.09	0.13	0.61	0.13	–0.04
Mental control	–0.03	0.13	0.06	0.70	0.13	0.08
Spatial forward span	0.18	0.18	0.17	0.16	0.69	0.05
Visual search	0.62	0.11	0.27	0.17	0.28	0.12
Memory						
Working memory						
Digit backward span	0.21	0.30	0.17	0.35	0.48	–0.03
Spatial backward span	0.28	0.08	0.23	0.16	0.65	–0.00
Immediate and Delayed recall						
Encoding						
Word list	0.25	0.22	0.70	0.18	0.15	0.05
Verbal paired associates	0.20	0.78	0.34	0.02	0.14	0.04
Logical memory	0.34	0.67	0.26	0.24	0.08	0.03
Faces	0.37	–0.12	0.29	0.44	–0.02	–0.13
Retrieval						
Word list free recall	0.19	0.29	0.78	0.13	0.15	0.07
Word list cued recall	0.24	0.24	0.81	0.14	0.19	0.07
Word list recognition trial	0.09	0.34	0.75	0.04	0.06	0.03
Verbal paired associates	0.17	0.79	0.36	0.03	0.13	0.04
Logical memory	0.30	0.70	0.34	0.21	0.09	0.06
Faces	0.29	0.09	0.12	0.40	–0.14	–0.14
Executive functions						
Category formation test	0.66	0.36	0.05	0.13	0.05	0.05
Semantic verbal fluency	0.74	0.20	0.24	0.13	0.12	0.01
Phonological verbal fluency	0.70	0.21	0.22	0.18	0.16	0.09
Design fluency	0.69	0.26	0.09	0.14	0.20	0.13
Motor functions	0.17	0.45	0.08	0.30	0.20	0.06

meaning and cueing to retention and recall (Lezak, 1995). Besides, motor functions (including conjugate eye movement, conflicting commands, go/no go, Luria's hand sequences and alternating pattern), evaluating the executive performance of motor tasks (Luria, 1973), were also enclosed. Since the adequate performance in memory tasks, mainly in delayed recalls, also requires the participation of executive functions, this factor was considered to evaluate a contextual-executive memory. Factor III (6.66% of the variance) was mainly represented by word list encoding (0.70), word list free recall (0.78), word list cued recall (0.81) and word list recognition trial (0.75). Obviously, it was a verbal memory factor. Factor IV (4.59% of the variance) best correlated with time orientation (0.58), digit detection (0.61), mental control (0.70) and faces immediate (0.44) and delayed recall (0.40). Orientation, the awareness of self in relation to one's surroundings, requires integration of different mental activities, such as attention, perception, and memory. Digit detection is a vigilance test examining the ability to sustain and focus attention. Mental control is a task involving mental tracking, as well as mental operations, and has proved to have a consistent attentional character, having little to do with memory (Lezak, 1995). Faces immediate and delayed recall is a recognition test of unfamiliar faces involving memory. Make up, earrings and hairstyle were eliminated from photographs, thus requiring the subjects to selectively attend to the internal features of faces. This factor may have represented a selective and sustained component of attention and orientation. Factor V (4.37% of the variance) primarily involved digit forward span (0.47), digit backward span (0.48), spatial forward span (0.69) and spatial backward span (0.65). Depending upon the theoretical bias of the examiner, or the battery in which the test is embedded, forward span has been considered as a measure of attentional capacity or of very short-term memory (Lezak, 1995); whereas backward span has been considered as a measure of working memory (Baddeley, 1992, 1998). Factor V was in consequence an attentional-working memory factor. Factor VI (4.10% of the variance) included place (0.88) and person orientation (0.89). Obviously, it was an orientation factor.

Effects of Age in the Children-Adolescents Sample

The effect of age was examined in the groups of children and adolescents by a linear regression analyses. The variable gender was shown to have no significance on scoring and was thus excluded from the regression formula.

Age was a significant variable in affecting the factor scores generated in all the extracted components, except for component II: Factor I (attentional-executive functions factor) [$r^2 = 0.27$, $F_{(1,165)} = 63.592$, $p < 0.001$]; factor III (verbal memory), [$r^2 = 0.03$, $F_{(1,165)} = 5.063$, $p = 0.02$]; factor IV (selective and sustained attention and orientation) [$r^2 = 0.13$, $F_{(1,165)} = 25.477$, $p < 0.001$]; factor V (attentional-working memory) [$r^2 = 0.13$, $F_{(1,165)} = 26.577$, $p < 0.001$] and factor VI (place and person orientation) [$r^2 = 0.03$, $F_{(1,165)} = 5.802$, $p = 0.01$]. Although the effect of age was significant for all of the above mentioned components, for components III (verbal memory) and VI (orientation), age accounted for only 3% of the variance of the performance. Figure 1 presents the mean factor score for each extracted component by age in the children-adolescent sample. The predictive function for the factor scores, as established by a linear regression model and taking into account *B* values for age, can be calculated by applying the presented formulas for each factor.

According to the value of *B* in the linear regression, scores in factor I (attentional-executive functions factor) increase by one point every 6 years, in factor III (verbal memory) scores increase by one point every 16 years, in factor IV (selective and sustained attention and orientation) scores increase by one point every 6 years, in factor V (attentional-working memory) scores increase by one point every 7 years, and in factor VI (place and person orientation) scores increase by one point every 22 years.

It can be followed, from the present results, that although attention, executive functions and memory are interrelated functions, their developmental sequences are separated from one another. During childhood, the development of functions related to selective and sustained attention, attentional-working memory, as well as executive functions, shows a fast improvement in performance and continue to develop into adolescence. On the other

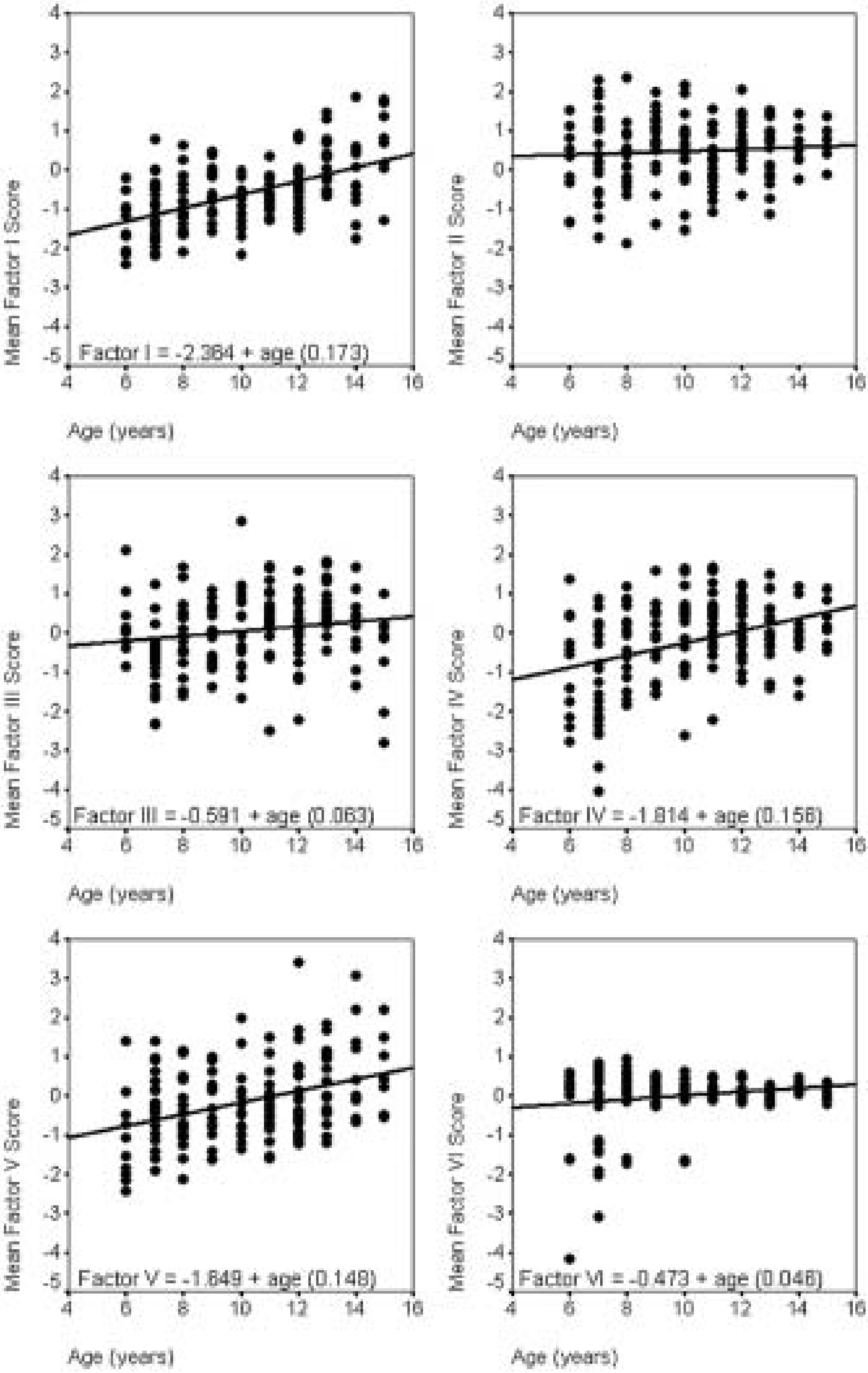

Figure 1. Mean factor score for each extracted component by age in the children - adolescent sample.

hand, development of functions related to verbal memory and place and person orientation show a slow increment in scores, reaching adult levels of performance at a young age.

Effects of Age and Education in the Adult Sample

The effects of age and education were examined in the groups of adults (16 to 84 years) by a multiple stepwise regression analyses. The variable gender was shown to have no significance on scoring and was thus excluded from the regression formula.

For factors II (contextual-executive memory) [r^2 = 0.13, $F_{(1,351)}$ = 54.389, p < 0.001];and III (verbal memory), [r^2 = 0.15, $F_{(1,351)}$ = 61.863, p < 0.001], only age was selected for the equation.

On the other hand, for factors I (attentional-executive functions) [r^2 = 0.15, $F_{(1,351)}$ = 66.546, p < 0.001]; IV (selective and sustained attention and orientation) [r^2 = 0.05, $F_{(1,351)}$ = 21.558, p < 0.001]; V (attentional-working memory) [r^2 = 0.01, $F_{(1,351)}$ = 5.040, p = 0.02]; and VI (place and person orientation) [r^2 = 0.02, $F_{(1,351)}$ = 7.104, p = 0.008], only education was entered into the equation. Although the effect of education was significant for all of the above mentioned factors, for factors IV, V and VI, education accounted for only 5%, 2% and 2% of the variance, respectively, and results should be interpreted with caution. Figure 2 presents the mean factor score for each extracted component by age or education in the adult sample. The predictive function for the factor scores, as established by a linear regression model and taking into account *B* values for age or education, can be calculated by applying the presented formulas for each factor.

According to the value of *B* in the linear regression, scores in factor II (contextual-executive memory) decrease by one point every 45 years of age, scores in factor III (verbal memory) decrease by one point every 42 years of age, scores in factor I (attentional-executive functions) increase by one point every 19 years of education, scores in factor IV (selective and sustained attention and orientation) increase by one point every 31 years of education, scores in factor V (attentional-working memory) increase by one point every 62 years of education and scores in factor VI (place and person orientation) increase by one point every 45 years of education.

These results suggested that the effects of age and education affect the performance of various factors differently. In reviewing the current results, it is evident that factors related to memory (II and III) are sensitive to age, whereas those related to attention and executive functions are sensitive to education. Even more, attentional and executive functions are extremely sensitive to education, whereas orientation, selective and sustained attention and attentional working memory are minimally affected by this variable.

Discussion

Factor analysis disclosed six NEUROPSI ATTENTION AND MEMORY factors that accounted for 63.6% of the total variance. Factors were related to attentional-executive functions (factor I), contextual-executive memory (factor II), verbal memory (factor III), orientation, selective and sustained attention (factor IV), attention and working memory (factor V), and place and person orientation (factor VI). Thus, factor analysis confirmed the presence of the independent cognitive domains that underlay the NEUROPSI ATTENTION AND MEMORY quantitative scores.

Specifications of attention and memory subfunctions are not consistent. Analysis of attentional subfunctions distinguished among place and person orientation (factor VI); an integrative factor including functions such as time orientation, sustained and selective

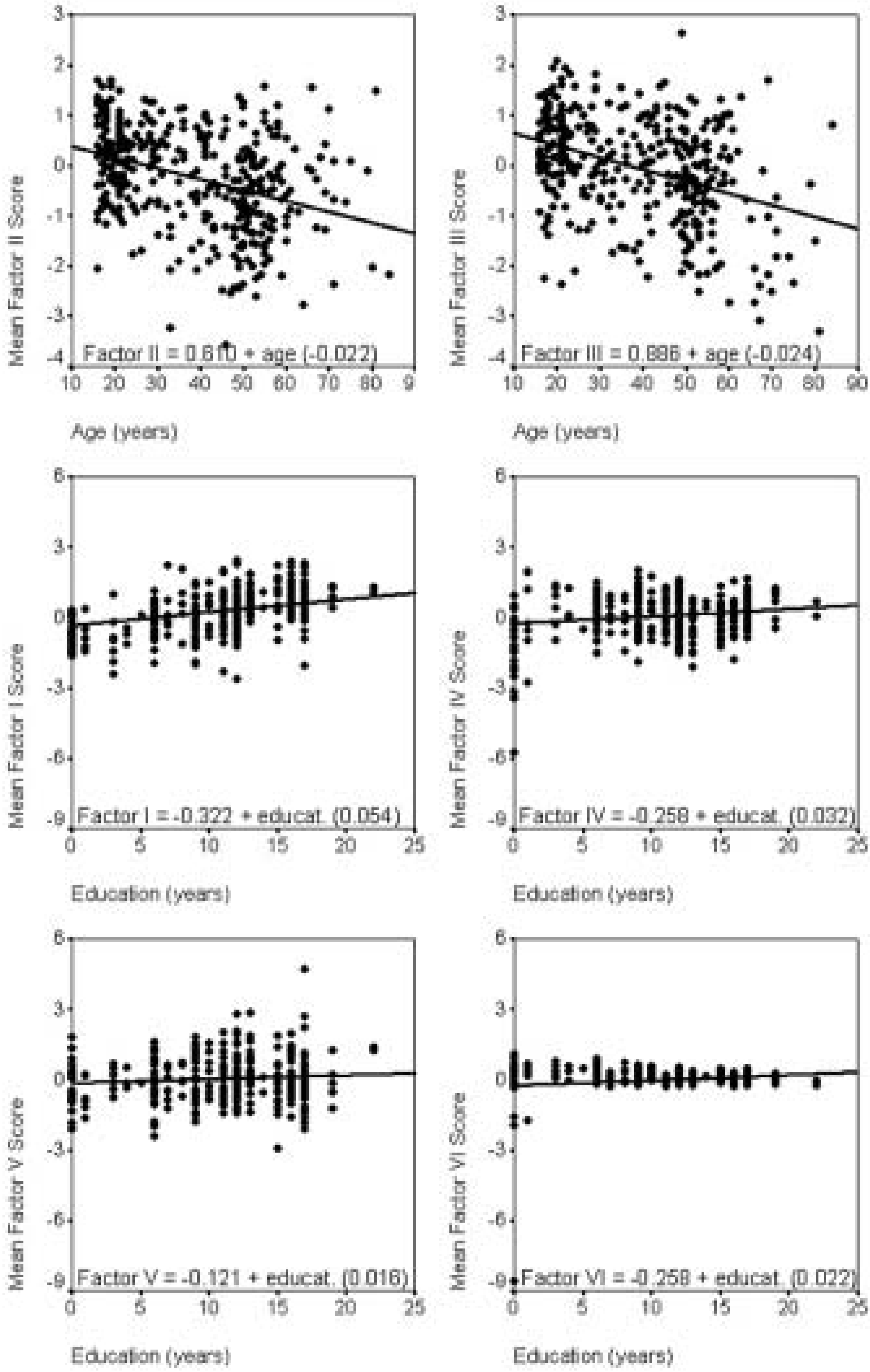

Figure 2. Mean factor score for each extracted component by age/education in the adult sample.

attention (factor IV); a factor enclosing forward and backward span tests, considered as a measure of attentional capacity or of very short-term memory and working memory, respectively (factor V); and processes related to selective and sustained attention, speed and ease of verbal production, and executive functions (ability to vary one's responses rapidly, self monitoring, inhibition of inappropriate responses, remembering and following rules, use of strategies and cognitive flexibility) (factor I). Distinctions among memory subfunctions were not dependent upon type of delay (immediate versus delayed recall), but upon the nature of the presented material. Word list test constituted factor III. Memory for words, either associated with other words or integrated in a paragraph constituted factor II. These tests allow to evaluate the contribution of context, meaning and cueing to retention and recall (Lezak, 1995). Motor functions (conjugate eye movement, conflicting commands, go/no go, Luria's hand sequences and alternating pattern), also included in this factor, evaluate the executive performance of motor tasks (Luria, 1973). Therefore, factor II was considered a contextual-executive memory function. Since developmental trajectories were different for these attention and memory factors, comparisons between developmental studies employing different tasks should be interpreted with caution.

The present factor analysis supported the notion of a close relationship among cognitive functions. Factor I enclosed cognitive functions related both to attention and executive functions (category formation test, semantic and phonological verbal fluency and design fluency). The relationship between attention and executive functions can be appreciated in Norman's and Shallice's concept of Supervisory Attentional System (Shallice, 1982, 1988), in Van Zomeren's (Van Zomeren & Brouwer, 1994) concept of supervisory attentional control, and in Mirsky's et al. (1991) focus-execute factor. Factor V enclosed functions related both to attention and working memory. The relationship between these two functions can be appreciated in Baddeley's (1990, 1996) concept of central executive, a component of working memory responsible for the control and regulation of cognitive processes, as well as for the allocation of attention to the relevant information.

Although a general tendency toward an increment in tests scores during childhood and a decrease during aging has been described (De Luca et al., 2003; Gathercole, 1998; Gomes, et al., 2000; Grady & Craik, 2000; Haaland et al., 2003; Lewis et al., 1990; Plude et al., 1994; Siegel, 1994; Trenerry et al., 1990), comparisons of a wide age range, evaluated in a variety of cognitive functions, allowed us to determine that developmental trajectories may not be homogeneous. During childhood, the development of functions related to selective and sustained attention, attentional-working memory, as well as executive functions, showed a fast improvement in performance and continued to develop into adolescence. On the other hand, development of functions related to verbal memory and place and person orientation showed a slow increment in scores, reaching adult levels of performance at a young age.

During childhood and adolescence, an effect of age was seen in all the factors, except for factor II (contextual-executive memory). Factor II enclosed memory tests which allow to evaluate the contribution of context, meaning and cueing to retention and recall, as well as tests evaluating the executive performance of motor tasks (Lezak, 1995). Cognitive psychology research suggests that memory formation is a byproduct of certain kinds of information processing. For example, items for which meaning and relationship to other remembered items are elaborated, are better remembered than items processed in a shallow fashion where only surface characteristics are examined (Craik & Lockhart, 1972; Craik & Tulving, 1975; Challis, Velichkovsky & Craik, 1996). The results concerning absence of age effects in factor II suggested that items for which meaning and relationships to other remembered items are elaborated are not only better remembered, but also reach adult performance levels at an early age.

The scarcity of developmental studies which include a wide age range, as well as a wide spectrum of cognitive functions, restricts the comprehension of development as a continuous pattern of change, with some areas exhibiting significant change and others exhibiting remarkable stability across the life span. The above mentioned results pointed out that different developmental trends can be traced for distinct attention and memory subfunctions. The contribution of orientation, context, meaning and cueing may play an important role as basic functions which precede the development of more complex functions of sustained and selective attention, working memory and executive functions. Developmental trends for these complex functions were characterized by a fast improvement in performance during childhood and continued into adolescence. Performance in memory tasks when the presented material is not embedded in a particular context, nor accompanied by cues, and the strategic search of information is advised, showed a gradual and slower increment during childhood.

On the other hand, in the adult sample, while some functions (time, place and person orientation, selective and sustained attention attentional-working memory and attentional-executive functions) remained relatively preserved, from 16 up to 85 years of age; functions related to verbal memory (factors II and III) were affected during this age range. The factors with no particular sensitivity to normal aging effects, may be useful when diagnosing pathological aging (i.e., dementia) or mild cognitive impairment. It is interesting to point out that those functions showing a fast improvement in performance during childhood and adolescence (selective and sustained attention, attentional-working memory, as well as executive functions), were not affected by age in the adult sample. On the other hand, verbal memory functions, showing minimal or even no association to age during childhood and adolescence, were the functions affected during adulthood.

Our results, concerning education effect, agreed with several other studies that have shown effects of educational level on neuropsychological test performance (Ardila et al., 2000; Ardila et al., 1989, Ardila et al., 1992; Finlayson et al., 1977; Heaton et al., 1986; Ostrosky et al., 1985, 1986, 1998; 1999). Learning opportunities play a crucial role in the development of some abilities frequently included in neuropsychological tests (Ardila, 1995). As Vygotsky (1962) and Luria (1976) pointed out, complex psychological processes such as oral and written language, decision making, and the solution of problems have a social origin and they depend upon internalized social relations. Therefore, living conditions and learning opportunities influence the development and organization of such processes. Furthermore, several studies have shown that literacy may somehow influence the brain organization of cognition, including language (Matute, 1988) and handedness (Ardila et al., 1989b). Studies about the consequences of brain damage in illiterate populations evidence a more bilateral representation for linguistic and visuospatial abilities (Rosselli, Rosselli, Vergara & Ardila, 1985), or a different intrahemispheric organization (Ostrosky, Arellano & Perez, 2004).

However, the effect of education on neuropsychological test performance is uneven. In reviewing current results, it was evident that some functions were sensitive to education (attentional-executive functions, selective and sustained attention and orientation, attentional-working memory and place and person orientation) whereas others were not (contextual-executive memory and verbal memory).

Although the effect of education was significant for all of the above mentioned factors, for factors IV, V and VI, education accounted for only 5%, 2% and 2% of the variance, respectively, and results should be interpreted with caution.

Furthermore, although it has been pointed out that the educational effect is not represented by a linear effect, but by a negatively accelerated curve (differences between 0–3 and 10–22 years of education are huge, and differences between 4–9 and 10–22 years of education are lower) (Ardila et al., 2000; Ostrosky-Solis et al., 1998); the differences among educational ranges may be distinct depending upon the evaluated ability. These heterogeneous effects of education on cognition have not been carefully studied. For example, cross-cultural reports, evaluating the effect of education on cognitive functions, have clustered subjects according to different criteria and there is a lack of general agreement regarding which age ranges can be grouped. The results reported in our study suggested that education has a more gradual effect on tests such as category formation, visual search, verbal and nonverbal fluency (factor I), than on tests such as forward and backward span (factor V). In sum, the years of education that can be clustered together may vary depending upon the ability to be studied, and further reports should take this into account.

These data could help to refine the cognitive reserve hypothesis (Scarmeas & Stern, 2003), since protective effects of education could depend on cognitive function. Our current results pointed to a complex relationship between education and cognitive ability associated with age. The interaction between age and education may be different depending upon the specific cognitive domain and, undoubtedly, this is an area that deserves more research and analysis. Further studies should also analyze the effects of other modulating variables such as occupational effects and quality of education (i.e., reading comprehension).

The consideration of both the developmental sequence, as well as differential effects of education, can improve the sensitivity and specificity of neuropsychological measures, allowing early diagnosis of cognitive dysfunction and implementation of adequate rehabilitation programs. From a clinical perspective, attention and memory are frequently disturbed as a consequence of brain damage in children, adolescents, adults and geriatric populations. Adequate assessment of these populations requires the incorporation of data about the normal ontogenetic cognitive development. Even more, educational interventions depend on information about the available capacities of people at different age ranges. Therefore, assessment of cognitive functions in healthy populations provides a reference frame to understand attention and memory disorders in populations suffering from brain damage, and allows the development of rehabilitation techniques best suited for different age ranges.

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