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Incidence of Executive Functions on Reading Comprehension Performance in Adolescents

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Abstract

Introduction. Reading comprehension is a complex cognitive skill that has been associated with executive functions such as working memory (WM) and inhibition. Given that the development of these abilities continues through late adolescence, this study seeks to explore the role that both processes play with respect to varying levels of reading comprehension performance in adolescents in two age groups.

Method. We evaluated performance in the comprehension of texts, WM, inhibition, reading fluency and verbal skills in 104 adolescents (12/13 years of age n= 53; 17/18 years of age n= 51).

Results. We found that reading comprehension performance, WM and inhibition increased significantly with age. Further, a partial correlation showed that reading comprehension is associated with: verbal skills, WM and inhibition. Lastly, group difference testing indicates that students with high and low comprehension performance differ significantly in verbal skills and executive functioning in the 12/13 age group. In the 17/18 age group, however, they only differed significantly in terms of verbal skills.

Conclusion. Reading comprehension, WM and inhibition improve during adolescence. However, the relationship among these abilities differs by age group.

Keywords: Working memory, inhibitory processes, reading comprehension, adolescence.

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Incidencia del Funcionamiento Ejecutivo en el Rendimiento en Comprensión Lectora en Adolescentes

Resumen

Introducción. La comprensión lectora es una habilidad cognitiva compleja que se ha asociado a procesos ejecutivos como la memoria de trabajo (MT) y la inhibición. Dado que el desarrollo de estas habilidades continúa hasta la adolescencia tardía, esta investigación propone estudiar el rol que sobre los distintos niveles de rendimiento en comprensión lectora ejercen ambos procesos en adolescentes de dos franjas etarias.

Método. Se evaluó el desempeño en comprensión de textos, MT, inhibición, fluidez lectora y habilidades verbales en 104 adolescentes (12/13 años n= 53; 17/18 años n= 51).

Resultados. Se encontró que los desempeños en comprensión lectora, MT e inhibición presentan incrementos significativos según la edad. A su vez, la correlación parcial mostró que la comprensión lectora se asocia a: habilidades verbales, MT e inhibición. Por último, las pruebas de diferencia de grupos señalan que los estudiantes con alto y bajo rendimiento en comprensión difieren significativamente en habilidades verbales y funcionamiento ejecutivo en la franja 12/13 años. En cambio, sólo difieren significativamente en habilidades verbales en la franja 17/18 años.

Conclusión. La comprensión lectora, la MT y la inhibición mejoran durante la adolescencia. Sin embargo, la relación entre estas habilidades difiere según el momento etario considerado.

Palabras Clave: Memoria de trabajo, procesos inhibitorios, comprensión lectora, adolescentes.

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Introduction

Reading comprehension (RC) is a complex cognitive variable that constitutes one of the fundamental challenges in the study of human cognition (Kintsch, 1988). Deficient performance in this area may cause difficulties in everyday life situations, as well as impair academic and professional learning (Cain & Oakhill, 2007).

The ultimate goal of comprehension is the construction of a coherent and organized internal mental model of the information contained in the read text (Kintsch, 1988; Gernsbacher, 1990). To achieve this goal, a set of linguistic procedures must occur in the following areas: lexical, morphological and syntactical, semantic and pragmatic. However, the goal of comprehension cannot be realized without the contribution of a set of cognitive processes to make these linguistic procedures possible. As a result, some researchers suggest that successful comprehension requires the adequate functioning and contribution of cognitive and metacognitive processes of diverse orders (Cain, Oakhill & Bryant, 2004; Gernsbacher, 1990). Thus, RC not only requires low-level processes of the bottom-up type, such as perception processes that make possible the de-codification of the written word, but also the contribution of higher level, or top-down, cognitive processes, such as Working Memory (WM).

Several studies have linked RC with cognitive processes such as: comprehension monitoring (Kolić-Vehovec & Bajšanski, 2006; Oakhill, Hartt & Samols, 2005), WM (Abusamra, Cartoceti, Raiter & Ferreres, 2008; Daneman & Carpenter, 1980; De Beni, Borella & Carretti, 2007; Swanson & O´Conner, 2009) and inhibition (Cain, 2006; Chiappe, Hasher & Siegel, 2000; Gernsbacher, 1993).

Hence, it is assumed that the procedures involved in RC require top-down processes of executive and cognitive control (Diamond, 2013). These processes support complex, goal-oriented behaviors, and are considered necessary skills to control behaviors, cognitions and emotions in accordance with internal goals (Best, Miller & Jones, 2009; Diamond, 2013; Huizinga, Dolan & van der Molen, 2006). Presently, there is consensus that WM, inhibition and cognitive flexibility are included in this set (Davidson, Amso, Anderson & Diamond, 2006, Diamond, 2013; Gilbert & Burgess, 2008; Russell, 1999).

Additionally, research on executive control processes suggests different patterns of development that begin in infancy and continue through late adolescence (Blakemore & Choudhury, 2006; Davidson et al., 2006; Gilbert & Burgess, 2008; Hughes, 2011). These processes become progressively more efficient and have a significant impact on various cognitive and behavioral aspects (Harnishfeger, 1995).

Given the importance attributed to WM and inhibition as principal executive functions (Russell, 1999) and the association prior research suggests between them and RC (Borella, Carretti & Pelegrina, 2010; Cain, 2006; Canet-Juric, Urquijo, Richard´s & Burín, 2009; Daneman & Carpenter, 1980), this study will address both processes jointly. Additionally, this study seeks to evaluate the importance of these processes with respect to differences in RC performance in adolescents.

The majority of the empirical studies in the literature examine RC and its association with various executive functions in populations of children and adults, leaving aside the adolescent years. Carretti, Borella, Cornoldi and De Beni (2009) undertook a meta-analysis in which they cite only two studies with participants between the ages of 7 and 18, and two others with participants between the ages of 12 and 15. However, none of these studies consider executive measures in the way this study does.

Consequently, it will be interesting to study the adolescent population in terms of these variables, given that adolescence is a time of behavioral, cognitive and cerebral change that affects executive functioning (Blakemore & Choudhury, 2006; Hughes, 2011; Huizinga et al., 2006), which implies that WM and inhibition performance during this stage of life is unique.

Contributions of executive functions to RC performance

Working memory

WM is a theoretical construct that, according to the classic definition by Baddeley & Hitch (1974) and Baddeley (1986), refers to an active system of temporary storage and simultaneous processing of information. Baddeley's model is considered structural and postulates the existence of storage differentiated by the type of content being processed: verbal, non-verbal and visual-spatial WM.

Baddeley (1986) considers WM as a complex system, comprised of subsystems that fulfill multiple functions. The components of WM are said to include: a central executive, where the processing resources of two subsidiary subsystems are administered; a phonological store, where verbal information is stored; and a visual-spatial sketchpad, where visual and spatial information is stored. Baddeley & Wilson (2000) added an episodic buffer to this model, which is dedicated to integrating information from diverse sources (in other words, multidimensional) and constructing mental models. In a recent revision, Baddeley suggests that the functions of the central executive can be divided into: the ability to concentrate and divide attention between two main stimuli; the flexibility to change from a task in progress to another; and, lastly, a connection or interface with long-term memory storage (Baddeley, 2012).

WM is a control process that explains superior cognitive processes such as learning, reasoning and comprehension. In particular, it has been noted that RC requires WM as a depository for the products that result from the processing of different phrases (textual and inferred statements) at the same time that the processes demanded by reading and the task in progress are being realized (Daneman & Carpenter, 1980; Swanson & O´Conner, 2009). For their part, Kendeou, Papadopoulos and Spanoudis (2012) note that WM is central to RC because comprehension requires the temporary storage of information, the activation of information from long-term memory and from the text being read, as well as the active integration of said information.

In recent decades, research has shown that the ability to maintain information in a mental workspace while other processes occur simultaneously (WM) is developed over the years. It has been confirmed that children and older adults possess lower span levels, in other words, a range of WM, than do young adults (Borella, Carretti & De Beni, 2008; Chiappe et al., 2000; Robert, Borella, Fagot, Lecerf, & de Ribaupierre, 2009). As Chiappe et al. 2000 indicates, WM performance is key to our cognitive development and increases functionally as we grow older, declining gradually as we approach the age of 50.

As conceptualized by Chiappe et al. (2000), WM is considered a set of attentional resources limited to a finite workspace that must be shared between processing and storage. Thus, if the demands of one task increase, fewer resources remain available in the central executive for the subsystems.

Building on the ideas of Chiappe et al. (2000), Hasher and colleagues (Hasher & Zacks, 1988; Hasher, Lustig & Zacks, 2007; Hasher, Tonev, Lustig & Zacks, 2001) add a key element to the study of the relationship between WM and reading skills. These researchers hypothesize that individual differences in reading skills may be due to inefficient inhibitory control.

Inhibitory Processes

As stated, inhibition is one of the main processes of cognitive regulation, since it exerts active control over cognitive content. Thus it plays key roles in learning, cognitive development and academic performance (Hasher et al., 2007; Hasher & Zacks, 1988).

In general, inhibition, or interference control, refers to the suppression of external stimuli that can get in the way of cognitive functioning, internal stimuli that can interfere with WM operations, and prepotent or automatic responses that are irrelevant to achieving the primary task (Diamond, 2013). This description of the inhibitory process is based on a construct composed of a set of processes that are dissociated from one another (Grandjean & Collette, 2011; Harnishfeger, 1995). These differences were validated through experiments (Friedman & Miyake, 2004) and led researchers to postulate theoretical models to explain them.

Among these models are those developed by Hasher and Zacks, which suggest the existence of three inhibitory processes: access, deletion and restraint (Hasher et al. 2007; Hasher et al., 2001; Hasher & Zacks, 1988).The access function controls access of irrelevant information to the conscience, or attentional focus. If it fails, irrelevant information enters the focus, complicating the processing of relevant information. The deletion function suppresses the irrelevant information in the attentional focus, which either escaped the access function's control and was only later recognized as irrelevant, or was once relevant under previous circumstances but as a consequence of the organism's changing objectives, no longer is. Lastly, the restraint function suppresses prevailing but inappropriate responses.

In this context, various studies have suggested a relationship between language comprehension and inhibitory processes (Borella et al., 2010; Chiappe et al., 2000). For example, it has been noted that inhibitory processes allow the conscience to remain free of irrelevant information that can impede the construction of coherent representations. Accordingly, and given the strong relationship between WM and inhibition, the literature hypothesizes that differences in reading performance are due to the ability to limit attention to what is relevant. Additionally, numerous studies have addressed the differences between high and low levels of comprehension and the individual's capacity to inhibit irrelevant information and update relevant information (Abusamra et al., 2008; Borella et al., 2010; Canet-Juric et al., 2009; Chiappe et al. 2000).

This line of research considers comprehension as an active integration processor of information. In order to fulfill the objective of creating a coherent mental representation of the text, the reader must maintain certain information in WM while computing the relationship between words and sentences, and at the same time inhibit irrelevant information and update relevant information in WM (Cain, 2006).

Reading fluency and verbal skills

Given that prior studies have confirmed the relationships between RC/reading fluency and RC/verbal skills, we shall measure both variables. This will allow us to detect their possible effects on reading comprehension performance.

In terms of reading fluency, it has been shown that the decoding of words is a low-level skill that is necessary but not sufficient to achieve comprehension (Defior Citoler, 2000; Oakhill, Cain & Bryant, 2003). Decoding words requires that the reader translate the graphemic code into a phonological or orthographic code so as to later access the mental lexicon. It is known that this low-level process tends to become automatic, and when it does, cognitive resources are freed.

Although we do not expect to find reading fluency deficits in the population we are studying, it is important to document this variable because readers who do not decode efficiently utilize a greater amount of attentional resources in this process to the detriment of higher-level processes involved in comprehension (i.e. the elaboration of inferences) (Perfetti, 2007).

In terms of verbal skills, it has been established that both general knowledge of the world as well as knowledge of vocabulary have an effect on RC performance. Stahl, Hare, Sinatra and Gregori (1991) show that individuals who possess greater prior knowledge achieve better RC performance because such knowledge: facilitates the elaboration of inferences during reading; permits attention to be directed at relevant information; and provides a possible plan to remember what was read.

Similarly, readers who have stored a greater number of word meanings achieve better RC performance compared to others with limited vocabularies. Stahl et al. (1991) suggest that knowing the meaning of words allows the reader to access the literal definition, establish relationships with other words and, in turn, attribute various meanings according to different sentence contexts.

Aims of the present study

Consequently, given that the ability to comprehend written texts is associated with this set of executive functions and these functions undergo development through late adolescence, it is reasonable to hypothesize that reading-comprehension performance will be differentiated by age and show differences according to the development of WM and inhibition. Therefore, we propose the following objectives: first, analyze if adolescents in high school aged 12/13 and 17/18 show differences in RC, WM and inhibition performance; second, evaluate the relationships between WM, inhibition and RC performance; third, analyze whether groups with high and low RC performance show differences in their corresponding executive performances.

Thus, this study's hypotheses are as follows: RC, WM and inhibition performance will differ according to age group, with performance in all three areas improving with age; RC performance will be associated with performance levels in the executive functions of WM and inhibition; groups with high and low RC performance will have statistically significant differences in their corresponding executive functions of WM and inhibition. Therefore, participants scoring high in RC will also perform well in tests on WM and inhibitory processes.

Method

Participants

A non-probabilistic sample of 104 male and female students from Mar del Plata, which was divided into four conformed groups, two of 12/13 year olds (n=53) and two of 17/18 year olds (n=51), was assessed. The following inclusion criteria were considered: students not under psychological and/or psychiatric treatment who do not have a history of a learning or developmental disability according to reports provided by the school they attend.

Based on reading comprehension performance, both age groups were divided into two groups as follows: 1) A group of high comprehension performers, comprised of those who scored at least one standard deviation above the group mean (12/13: n=12; 17/18: n=13); 2) A group of low comprehension performers, comprised of those who scored at least one standard deviation below the group mean (12/13: n=8; 17/18: n=9). Additionally, the groups showed the same levels with respect to reading fluency (12/13: $t(18)= 2.06$; $p>.05$; 17/18: $t(20)=0.607$; $p>.05$). (see Table 1)

***Table 1*. Characteristics of the total sample (n=104) and sub-samples by cut-off point (n=42).**

	n=104		HPR*	LPR**	HPR*	LPR**
	Age 12/13 n= 53	Age 17/18 n= 51	Age 12/13 n=12	 n=8	Age 17/18 n= 13	 n= 9
Sex						
Female	60 %	41%	83%	75%	54 %	11 %
Male	40 %	59 %	17%	25%	46 %	89 %
Age						
M	12.15	17.38	12.08	12.07	17.28	17.48
SD	.277	.448	.017	.035	.417	.499
Youngest	12.01	17.02	12.06	12.02	17.03	17.05
Eldest	13.01	18.03	12.11	12.10	18.03	18.03

Note. * High performance reader.
** Low performance reader

Instruments

The research objectives required the selection of a set of ad-hoc tasks. The following tests were administered:

Reading comprehension. Consisted of the silent reading of a text and ten open-ended questions (Ávalos & Díaz, 1997). The test was adjusted based on educational level, the cognitive operations involved, the reading material and the reading difficulty. For this reason, two tests were used: one for 12/13 year olds (*"El peligro de las transfusiones"*) and another for 17/18 year olds (*"La salud no se mide con espejos"*).

Executive performances were evaluated using the following tasks:

Working Memory: A listening span task from the WM Test Battery (AWMA) adapted into Spanish (Injoque-Ricle, Calero, Alloway & Burín, 2011). The test provides two scores: *span and total score*. The latter is obtained by adding up all of the correct answers. Additionally, *intrusion errors* were used as indirect measures of inhibition. Errors were classified as per Chiappe et al. (2000): words from the test in progress but non-target, which show an inhibition deficiency as the result of the increased input of irrelevant information (Access); words from previous lists, which reflect proactive interference that could be the result of the failure of inhibition to delete irrelevant information (Deletion); words that do not appear in any of the tests, which reflect deficiencies in the functioning of inhibition restraint (Restraint).

Inhibition. Hayling test (adapted by Cartoceti, Sampedro, Abusamra, & Ferreres, 2009). Evaluates the processes of verbal initiation and suppression. The instrument consists of two sections. In the first, the subject completes 15 sentences in which the final word is missing, with a stimulus that is consistent with the syntactic-semantic context (response initiation). In the second, the sentence is to be completed with a word that is inconsistent with the context of the sentence (response suppression). For the inhibition variable, we considered: latency time in the initiation test (Initiation); latency time in the suppression test (Suppression); and an inhibition score based on a scoring system that assigns points to penalize the semantic proximity of the response in a given sentence, thus evaluating the difficulty to inhibit a dominant response (Restraint).

Reading fluency: E.N.I. sub-test, Speed of reading a text aloud (Matute, Rosselli, Ardila, & Ostrosky-Solís, 2007). The subject is given a text (*Tontolobo y el carnero*) to read aloud and the reading time is computed. The same task was used for both age groups.

Verbal skills: A vocabulary sub-test from WISC III (Wechsler, 1991) or the WAIS was used (Wechsler, 2002), depending on the age of the participant. The task consisted of soliciting the meaning of a set of words. Both the stimuli and responses were verbal. The number of words was 33 and the test was stopped after 4 consecutive scores of 0. The scoring system rated each response 0, 1 or 2 points depending on quality. The general scoring criteria were as follows: 2 points for a response that demonstrated a good understanding of the word (i.e. a good synonym); 1 point for a response that was not incorrect but was of poor content (i.e. a vague or imprecise synonym); and 0 points for an incorrect response.

Procedure

Informed consent was solicited from the participants' parents or guardians, and clearly stated the study's objectives and the tasks involved. Additionally, just prior to the administration of the tests, students agreed to participate in the study and were free to cease participating whenever they wished. They were explained the study in detail and received a guarantee that the information obtained would remain confidential and used exclusively for scientific purposes under National Law 25.326 on the protection of personal information.

The RC instrument was applied collectively. The tests on vocabulary, reading fluency, WM and inhibition, however, were administered during individual sessions. Finally, comprehension performance groups were formed according to the level of RC performance based on statistical cutoff points (+1 SD/-1 SD).

Statistical Analysis

We conducted a descriptive-correlational study with a hypothesis on group differences, using a non-experimental and transversal research design. All data were analyzed with version 19 of the SPSS software. Specifically central and dispersion measures were carried out to analyze the participants´ performance in all the variables. In addition partial correlation was applied to obtain the statistical relationship among RC, WM and inhibitory processes controlling the effect of the participants´ age. Finally Student´s *t* test and effect size indicator were used to analyze the statistically significant differences in the groups.

Results

Central tendency and dispersion measures confirm that the 17/18 age group performed more efficiently in terms of reading comprehension, mental lexicon richness, manipulation and information processing capacity, and the ability to suppress non-pertinent information (see Table 2).

Table 2. **Descriptive statistics for the variables evaluated for the total sample (n=104) by age group.**

	Age 12/13 (n= 53)			Age 17/18 (n=51)		
	M (SD)	Min.	Max.	M (SD)	Min.	Max.
1.Comprehension test	18.11 (3.87)	8	26	25.35 (2.66)	19	29
2.Verbal skills	39 (4.32)	31	49	41.63 (6.52)	25	55
3. Reading fluency (sec.)	35.59 (5.18)	26.16	51.94	27.91 (3.96)	20.76	41.63
Working memory						
4.Span	2.49 (.50)	2	3	3.14 (.69)	2	5
5.Total score	15.52 (2.07)	12	19.5	19.19 (3.33)	14	30
Inhibition: Indirect measures						
6. Access	.13 (.34)	0	1	.20 (.40)	0	1
7. Deletion	.51 (.69)	0	2	.65 (.74)	0	3
8. Restraint	.34 (.64)	0	3	.33 (.71)	0	3
Inhibition: Direct measures						
9. Initiation (sec.)	1.42 (.57)	.68	2.76	1.08 (.18)	.76	1.53
10. Suppression (sec.)	2.31(1.45)	.63	7.01	1.42 (.52)	.82	3.34
11. Restraint	3.83 (2.77)	0	12	1.39 (2.02)	0	10

Further, with respect to the indirect measures of inhibition, it was observed that these indicators showed similar patterns in both age groups. The fewest errors were in the inhibitory function of access, followed by the inhibitory function of restraint and, lastly, deletion. Additionally, the latter had the greatest number of errors indicating proactive interference. However, when age groups were compared, it was observed that the older students had more intrusion errors corresponding to the access and deletion functions. In principle, this finding is the opposite of what was expected at the start of the study, and it will be discussed further in our conclusions. With respect to the restraint function, the values indicate an almost equal performance.

To achieve the first objective, a Student's *t* test was used to establish the existence of statistically significant differences between the performances of each age group. Later, an effect size indicator was used to evaluate the magnitude of the differences found: Cohen's *d* (Morales-Vallejo, 2009) calculated using the Effect Size Calculator (Watkins, 2003). The results are shown in Table 3.

***Table 3*. Effect size (*Eta*²) and *t* test on RC performance and executive functions by age group (n=104).**

	t	*df.*	Sig. (bilateral)	*Eta*² / Cohen's *d*
Reading comprehension	-11.05	102	.001***	-2.17
Verbal skills	-2.42	102	.05*	-.47
Reading fluency	8.45	102	.001***	1.66
WM				
Span	-5.45	102	.001***	-1.08
Total score	-6.76	102	.001***	-1.32
Inhibition: Indirect measures				
Access	.87	102	NS	-.18
Deletion	-.97	102	NS	-.19
Restraint	.04	102	NS	.01
Inhibition: Direct measures				
Verbal initiation	4.06	102	.001***	.79
Verbal suppression	4.07	102	.001***	.81
Restraint	5.10	102	.001***	1.00

Note. *$p < .05$;
**$p < .01$;
***$p < .001$.
NS: Not significant.

Statistically significant differences with respect to RC performance ($p < .001$), verbal skills ($p < .05$) and reading fluency ($p < .001$) were found. The same was found for WM executive performance (*span*= $p < .001$; total score= $p < .001$) and inhibition (verbal initiation= $p < .001$; verbal suppression= $p < .001$; restraint= $p < .001$). Effect sizes were found to correspond with the *t* test.

To achieve the second objective, a partial correlation was applied to obtain the relationship between the variables while controlling for the effect attributable to the age of participants. The results indicate that RC is associated with verbal skill performance ($p<.01$), WM

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(*Span*= *p*< .05; *Total score*=*p*<.01) and inhibition indicators: Suppression (*p*<.01) and Restraint (*p*<.01). (see Table 4)

Table 4. **Partial correlation between the tests controlling for the age variable (n=104).**

	2	3	4	5	6	7	8	9	10	11
1. Reading comprehension	.423 **	NS	.217 *	.279 **	NS	NS	NS	NS	-.261 **	-.272 **
2. Verbal skills	-	NS	.222 *	.253 *	NS	NS	NS	NS	NS	-.216 *
3.Reading fluency		-	NS	NS	NS	NS	NS	.273 **	NS	NS
WM										
4. Span			-	.885 ***	NS	NS	NS	-.195 *	NS	NS
5. Total score				-	NS	NS	NS	NS	NS	-.200 *
Inhibition: Indirect measures										
6. Access					-	NS	NS	NS	NS	NS
7. Deletion						-	.217 *	NS	NS	NS
8. Restraint							-	NS	NS	NS
Inhibition: Direct measures										
9. Initiation								-	.355 **	NS
10. Suppression									-	.456 **
11. Restraint										-

Note. *$p < .05$;
**$p < .01$;
*** $p < .001$.
NS: Not significant.

With respect to the third objective, differences in executive performance were analyzed by RC level. The results are shown in Table 5.

***Table 5.* Descriptive statistics of evaluated variables for each RC level**

	Age 12/13 (n= 20)		Age 17/18 (n=22)	
	HPR n=12 M (SD)	LPR n=8 M (SD)	HPR n=13 M (SD)	LPR n=9 M (SD)
1.Reading comprehension (Correct answrs./30)	23.53 (1.11)	12.75 (2.05)	28.23 (.43)	20.78 (1.09)
2. Verbal skills	41,33 (4.07)	34.75 (3.54)	45.7 (5.23)	36.22 (7.69)
3. Reading fluency	33.48 (2.75)	37.74 (6.38)	26.44 (2.68)	27.05 (1.56)
WM				
4. Span	2.67 (0.49)	2.13 (0.35)	3.46 (1.05)	3 (.001)
5. Total score	16.41 (1.60)	14 (2.13)	20.73 (4.86)	18.56 (1.37)
Inhibition: Indirect measures				
6. Access	0.08 (0.28)	0.13 (0.35)	.08 (.27)	.22 (.44)
7. Deletion	0.58 (0.66)	0.25 (0.46)	.62 (.76)	.67 (1.11)
8. Restraint	0.33 (0.65)	0.25 (0.46)	.15(.55)	.67 (1.11)
Inhibition: Direct measures				
9. Initiation	1.24 (0.58)	1.69 (0.58)	1.08 (.165)	1.06 (.109)
10. Suppression	1.93 (1.33)	3.19 (1.83)	1.28 (.192)	1.36 (.35)
11. Restraint	2.50 (2.81)	5.50 (2.20)	1 (1.00)	1.44 (1.74)

To establish the existence of statistically significant differences, a Student's *t* test was applied and the *effect size* was calculated. In the 12/13 age group, statistically significant differences were found in the verbal skill testing ($p < .001$), WM (*Span*= $p < .015$, *Total score* = $p < .010$) and restraint inhibition ($p < .021$). However, the 17/18 age group differed significantly in terms of verbal skills ($p < .001$).

According to Cohen's guidelines (in Morales-Vallejo, 2009), the effect sizes in the 12/13 age group were of high magnitude for the following variables: verbal skills, WM, restraint inhibition and verbal suppression. However, there were moderate levels of effect magnitude for the following variables: verbal initiation and deletion inhibition.

With respect to the 17/18 age group, verbal skills were observed to possess a high effect size. Additionally, moderate effect sizes were found for the indirect measures of restraint inhibition and WM. Finally, low effect sizes were found for the following variables: access inhibition, restraint inhibition and verbal suppression.

Discussion and Conclusions

RC requires the interaction of a set of cognitive skills in order to obtain a semantic representation of the content of what is read (Kendeou, van den Broek, Helder, & Karlsson, 2014). For this reason, this study sought to evaluate a group of skills related to comprehension with the intent of: comparing the performance of these processes by age group; observing if an association exists between said skills and reading comprehension; and, lastly, analyzing if differences in executive functions exist according to RC performance.

Age differences and RC, WM and inhibition performance

With respect to the first objective, the empirical results support the hypothesis on the association between age and RC, WM and inhibition. The older adolescents achieved performance levels that were superior to that of the younger adolescents in terms of efficiency of the reading comprehension process, the capacity or scope of WM and the restraint inhibition process (Davidson et al., 2006; Diamond, 2013; Huizinga et al., 2006).

The significantly better RC performance of the 17/18 year-old adolescents suggests that they accomplish in a more efficient manner the linguistic procedures (lexical, syntactic, semantic and pragmatic) and the cognitive skills required to construct internal and coherent mental models that are organized based on the textual information.

Further, the age groups differ in their executive performances. In terms of WM, it was observed that older participants had a greater amplitude or *span* level, meaning they demonstrated greater skill in maintaining and processing information mentally when it is unavailable perceptually (Diamond, 2013; Lalonde, Henry, Drouin-Germain, Nolin, & Beauchamp, 2013). This increase in WM capacity provides adolescents aged 17/18 a greater number of cognitive resources to assign to complex cognitive tasks (Chiappe et al., 2000; Huizinga et al., 2006).

Similarly, with respect to inhibition performance, they showed a greater ability to detain or block the automatic response (cognitive in this case) that is activated when performing a task. In other words, the older adolescents have greater skill in: accessing the pertinent lexical content; detaining non-pertinent content; and avoiding errors when the automatic response must be passed over in favor of another response that meets the objectives of the task being performed. This skill avoids interference from irrelevant information while complex cognitive tasks are performed, and provides more efficient cognitive control (Borella et al., 2010; Harnishfeger, 1995; Robert et al., 2009).

The results discussed thus far concur with Blakemore and Choudhury (2006), who maintain that adolescence is a developmental phase characterized by cerebral, behavioral and cognitive changes. Specifically, these researchers state that changes observed to the prefrontal cortex during adolescence are manifested in improved executive abilities. The findings of this study provide evidence that performance in the executive functions of WM and restraint inhibition improves during adolescence (Blakemore & Choudhury, 2006). In line with these statements, the empirical evidence presented coincides with the statement made by Huizinga et al. (2006) that maintains that WM and inhibition continue to develop over a good part of our adolescent years and, this author argues, continue to change even into adulthood. Another aspect to highlight is the greater variability in WM performance that was observed among the older students. This could indicate that individual variability in executive task performance increases over the course of development.

The performances described by the indirect measures of inhibition deserve to be discussed. First, the increase in the number of errors in the inhibition function of access and deletion among older adolescents seems to run counter to expectations. However, it should be kept in mind that these errors are committed in the execution of a WM task. As stated by Kane, Conway, Hambrick & Engle (2007), WM capacity is related to the functioning of the central executive. This WM component or system of control focuses and divides attentional resources, and is capable of changing the focus of attention. Kane et al. (2007) indicate that individuals with a broader *span* have a greater number of intrusion errors because they are affected by interference processes. This is due to the efforts these individuals make to retain and process large amounts of information, thus dedicating more attentional resources to these tasks. Those possessing high levels of *span* use strategies to manipulate large amounts of cognitive content, and so they tend to be affected by information overload and, consequently, higher levels of interference. On the other hand, those with lower WM performance only use their resources to hold limited amounts of information, and do not divide them among tasks; this results in their being less affected by interference.

Likewise, it appears that verbal initiation processes (access to the cognitive system of verbal response pertinent to the syntactic-semantic context) and verbal suppression (detaining the non-pertinent automatic verbal response) are executed more quickly by older students. This difference in processing speed could indicate that as individuals grow, the functioning of these abilities becomes more efficient. Hughes (2011) postulates that there should be an increase in processing speed during adolescence due to the changes in the brain during that stage of life. The cerebral modifications, given the increase in white matter, should generate a quicker and more efficient exchange of information between the frontal cortex and other regions of the brain, which would have direct consequences on the level of functioning.

Second, the only intrusion error that decreased in older adolescents was the restraint indicator, which is consistent with the findings from the direct measures of this mechanism. Thus, this adds new evidence in favor of the idea that older adolescents are more skilled at detaining automatic responses and instead providing responses that are adequate for the objectives of the task being performed (Huizinga et al., 2006; Robert et al., 2009).

Relationships between RC, WM and inhibitory processes

The study's second objective sought to establish the relationships between RC performance in adolescents and the executive performance of WM and inhibition. The partial correlations allow us to state that, independent of age, RC is associated with verbal skills and the performance of WM (Christopher et al., 2012) and the inhibitory process of restraint (Kieffer, Vukovic, & Berry 2013).

In principle, the RC/verbal skills relationship indicates that a broader vocabulary contributes to the construction of coherent mental models based on the text. In other words, knowing the definition of words and having efficient access to them suggests one should be able to: more quickly attribute meaning to the various words and sentences; more easily realize the inferences required during reading; and free cognitive resources for other processes. In this regard, it has been postulated that a broad vocabulary and prior knowledge enriches and favors the construction of semantic representations of textual content in memory processes (Cain, Oakhill, Barnes & Bryant, 2001; Kendeou et al., 2014; Perfetti, 2007). Thus, the results coincide with previous reports indicating that vocabulary is one of the major predictors of comprehension (Canet-Juric et al., 2009; Stahl et al., 1991).

Second, the RC/WM correlation adds empirical evidence in terms of the intervention of this executive function during the comprehension process. This implies that WM enables us to hold the meaning of written and inferred propositions while the processes of integration and significance necessary to construct global and coherent semantic representations of the read text are carried out. In other words, it is necessary to efficiently process and store information in order to mentally construct the meaning of what is read (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Cain et al, 2004; Carretti et al., 2009; Christopher et al., 2012; Daneman & Merikle, 1996).

Third, the inverse relationship between RC/inhibition indicates that at higher comprehension performance levels, less time is required to suppress irrelevant information and there is less difficulty in restraining dominant responses. In this way, the evidence indicates that the ability to inhibit irrelevant information and activate only what is relevant is implied in the comprehension process. Some researchers suggest that during comprehension, more content than necessary is activated, and it is up to the inhibitory process to suppress interference according to the objectives of the task. These findings coincide with the literature (Borella et al., 2010; Canet-Juric et al., 2009; Chiappe et al., 2000; Kieffer et al., 2013).

Therefore, the results show that RC is associated with the executive functions of WM and restraint inhibition during adolescence. They also show that prior world and language knowledge continues to be one of the abilities that exercise major influence on reading comprehension (Kendeou et al., 2014).

Differences in executive performance of WM and inhibitory processes by RC level

With respect to the third purpose of our study—establishing differences between the groups of readers in terms of executive indicators—we found that the 12/13 age groups displayed the following characteristics: high level reading performers had better verbal skills, possessed greater WM amplitude and managed to more efficiently detain dominant but inadequate responses; low level reading performers, on the other hand, displayed poorer performances in vocabulary, less efficiency in storing and maintaining information in the attentional focus, and lesser performance in the inhibitory process of restraint (Borella, & de Ribaupierre, 2014; Canet-Juric et al., 2009; Pimperton, & Nation, 2010).

In the 17/18 age groups, we observed the following: readers with a higher performance level possessed a richer and broader mental lexicon; on the other hand, low level reading performers displayed poorer performance in this area (Cain, & Oakhill, 2006). Although there weren't statistically significant differences in executive performances between the groups, the magnitude of the effect sizes make their influence clear. This would explain why high level reading performers are more skilled at manipulating and sustaining information while realizing complex tasks (WM) (Christopher et al., 2012) and manage to efficiently detain dominant but inadequate responses (restraint inhibition) (Arrington et al., 2014; Borella, & de Ribaupierre, 2014).

Therefore, the differences found between the groups of readers in both age groups indicate that those who attain efficient reading processes also achieve optimal development of the executive functions of WM and restraint inhibition (Peng, Sha, & Li, 2013). However, two points should be emphasized. The first is the differential weight that the executive function exerts on the different levels of RC performance by age group. The second is the importance of some verbal skills with respect to RC performance. This allows us to make some additional hypotheses.

We should keep in mind that for the 12/13 age group, the executive functions are still in development and have not yet reached adult performance levels. Therefore, we can assume that complex cognitive abilities like RC would be susceptible to these processes in development, given the reduced level of control younger adolescents would be capable of exercising over complex cognition. This is reflected in the differences found between high and low reading performers at this age. In the 17/18 age group, however, the executive functions are closer to adult levels and the development of the control mechanisms seems to have stabilized. Thus, cognition control would be an ability that comes at that age. This would mean that differences in reading processes would not be due predominantly to executive functions (given that they have now become quicker and more controlled) but rather to the reader's amount of world and language knowledge. Thus, the differences between the groups of readers would be based more on verbal skills and previous knowledge more so than executive abilities.

Our study is somewhat limited, in that it uses a small sample size of high and low level reading performers. Likewise, while different measures were carried out to assess inhibition, it would be appropriate to use direct measures with verbal modalities for each inhibitory processes. In addition, it would be necessary to apply more advanced statically measures like that path analysis.

Lastly, future research may wish to develop specific techniques to measure each inhibitory process, so that empirical evidence could be gathered on the influence of the different types of inhibition on RC. Similarly, it would be valuable to further explore the relationship WM/inhibitory processes and verbal skills/WM. All this would contribute to our knowledge of complex cognitive processes such as RC.

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