Learning and Individual Differences 34 (2014) 86–92

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

The role of working memory, inhibition, and processing speed in text comprehension in children☆

Erika Borella [a,]*, Anik de Ribaupierre [b]

[a] Department of General Psychology, University of Padova, Italy
[b] Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

ARTICLE INFO

Article history:
Received 22 April 2013
Received in revised form 23 March 2014
Accepted 9 May 2014

Keywords:
Reading comprehension
Working memory
Inhibition
Processing speed
Children

ABSTRACT

The aim of the present study was to investigate age-related differences in text comprehension performance in 10- to 12-year-old children, analyzing the joint influence of working memory (WM), inhibition-related mechanisms, and processing speed. Children were administered: i) a text comprehension task in which the memory load was manipulated by allowing them to see the text while answering or withdrawing the text (text-present versus text-absent conditions); and ii) WM, inhibition and processing speed tasks. Results showed that age-related differences were not significant in the text-present condition, whereas older children performed better than younger ones in the text-absent condition. Regression analyses indicated that only WM accounted for a significant part of the variance in the text-present condition, whereas in the text-absent condition comprehension performance was explained by the combined contribution of WM and resistance to distractor interference. These findings confirm the crucial role of WM capacity in text processing and indicate that specific inhibitory mechanisms are involved in children's text processing when the comprehension task involves memory load.

It has been shown that processing resources (working memory, inhibition and processing speed) account for text comprehension performance in children (Cornoldi & Oakhill, 1996), once basic decoding skills have been sufficiently automated or acquired. In this article, we are concerned with how these processing resources are related to the text comprehension performance of 10- to 12-year-old children.

Among these processing resources, working memory (WM) – defined as the cognitive resources available for storing information while processing incoming or recently-accessed information for use in other cognitive tasks (de Ribaupierre, 2000; Miyake & Shah, 1999) – plays a crucial part in text comprehension. WM enables readers to process text information and keep it accessible in order to build a coherent representation of the text's meaning. In fact, poor comprehenders – individuals with a deficient reading comprehension performance despite a normal IQ and good decoding skills – have been found to perform poorly in WM tasks (see meta-analysis by Carretti, Borella, Cornoldi, & De Beni, 2009). A moderate-to-strong relationship between WM and text comprehension has also been demonstrated in typically-developing children of various ages (e.g. Swanson, 1996), and across the lifespan (e.g. Siegel, 1994). These results suggest that WM plays a central part in accounting for individual and age-related differences in text comprehension performance.

Cognitive inhibition has also frequently been considered in the text comprehension domain as contributing to the selection of relevant items that can subsequently be activated in WM – which has a limited capacity – to enable individuals to form a coherent representation of a text (e.g. Gernsbacher, Varner, & Faust, 1990). For instance, Lorsbach, Katz, and Cupak (1998) (see also Lorsbach & Reimer, 1997) attributed the worse comprehension performance observed in a "garden path" procedure (in which textual information is inserted to mislead readers by generating ideas that subsequently turn out to be wrong) of 9- and 12-year-olds, compared with young adults, to the children finding it more difficult to prevent the irrelevant information from occupying their WM, and to delete it. Poor comprehenders also reportedly encounter inhibitory problems. In particular, they have been shown to be more inclined to recall information that has become irrelevant; that is, they have a larger number of intrusions – recall of non-final words – in WM tasks than good comprehenders (De Beni, Palladino, Pazzaglia & Cornoldi, 1998). A number of studies have suggested that WM and comprehension deficits in poor or less-skilled comprehenders may be due to a deficit in inhibiting information that has been activated and elaborated, and later needs to be inhibited (for a meta-analysis, see Carretti et al., 2009).

Most studies focusing on the relationship between inhibition and text comprehension have considered inhibition as a single unitary construct, rather than as a family of functions (Nigg, 2000; de Ribaupierre, Borella & Delaloye, 2003; Friedman & Miyake, 2004). They consequently

---

☆ This work was supported by a grant from the Swiss National Science Foundation (No. 1114-52565.97).

* Corresponding author at: Department of General Psychology, Via Venezia, 8, 35131 Padova, Italy. Tel.: +39 049 8276035; fax: +39 049 8276600.
E-mail address: erika.borella@unipd.it (E. Borella).

http://dx.doi.org/10.1016/j.lindif.2014.05.001
1041-6080/

used a single measure, or studied inhibition by manipulating the text comprehension paradigm itself. Friedman and Miyake (2004) distinguished between three inhibition-related functions: i) "prepotent response inhibition", which blocks dominant and prepotent cognitive responses automatically activated by the stimulus presented; ii) "resistance to distractor interference", which helps attention to be focused on relevant items by ignoring simultaneously-presented irrelevant items; and iii) "resistance to proactive interference", i.e. the ability to limit the activation of no longer relevant items and thus resist memory intrusions. These three functions are akin to those previously defined by Hasher and Zacks (1988), as restraint, access, and deletion, respectively.

Another factor that influences text comprehension ability is the speed at which information is processed (read, encoded and retrieved) in an individual's memory. Processing speed has been seen to account for the ability to retain information from earlier sections of a text that will be needed to interpret later sections, both in children (Johnston & Anderson, 1998), and in young and older adults (e.g. Borella, Ghisletta, & de Ribaupierre, 2011). Significant differences in children's information processing speed were found, for instance, between skilled readers and poor comprehenders (Swanson, 1996).

Although the crucial importance of one and/or the other of these processing resources for text comprehension in children is widely acknowledged, they have rarely been seen together as accounting for age-related differences. In the literature, text comprehension is measured with our without allowing participants to refer to the text while answering the questions (Cain & Oakhill, 2006), although there is clearly a memory load to consider when the text is withdrawn, but not when the text remains available while answering the question.

One of the objectives of the present study was therefore to examine the joint influence of WM and inhibition on text comprehension. Moreover, we have argued elsewhere (e.g. de Ribaupierre, 2000) that inhibition and processing speed exert an influence on WM capacity. The faster information can be processed, the more it can be considered almost simultaneously. On the other hand, when inhibition is efficient, less irrelevant information clutters the processing system and a larger part of WM can be allotted to elaborating and maintaining relevant information. Text comprehension was consequently examined in children in the final grades of elementary school, when reading has become relatively automatized, i.e. at 10–12 years of age, by: i) manipulating the role of memory, and ii) focusing on the combined influence of WM, inhibitory functions, and processing speed. Concerning the first aim, two experimental conditions were used: in the text-present condition (TP), participants could refer to the text while they answered the questions; in the text-absent condition (TA), the text was withdrawn. The TA condition thus imposes an additional memory load in the retrieval phase, and possibly also in the encoding phase (e.g. Borella et al., 2011). These two conditions are believed to measure reading comprehension (Kintsch, 1998), and they reflect common situations in the learning domain. They are rarely distinguished in the literature (Cain & Oakhill, 2006), and yet – given the extra memory load in the TA condition – they are likely to give rise to a different performance, particularly in individuals with fewer processing resources, such as young children, or low-span individuals.

As for our corollary aim, a multivariate design was adopted in which the children were administered tasks measuring WM and processing speed, and tasks assessing inhibitory functions. The following set of tasks was used: i) the Color Stroop and the Hayling tasks to tap prepotent response inhibition (e.g. Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009; de Ribaupierre et al., 2003); ii) intrusion errors to measure resistance to proactive interference (e.g., Carretti et al., 2009); and iii) a negative priming paradigm, embedded in the Color Stroop task (see Borella et al., 2009; Hartley, 1993) to identify resistance to distractor interference.

We expected age-related differences in all the tasks, since older children have more resources available to them than younger children and should consequently perform better. As concerns the two text comprehension conditions, we predicted that age-related differences should be larger in the TA condition, as it presumably taxes processing resources more heavily: older children have more resources available to them than younger children and should consequently perform better. Furthermore, younger children were expected to perform less well in WM and processing speed tasks than older children (e.g. de Ribaupierre, 2000; Fry & Hale, 1996). Given that developmental changes take place gradually, 11-year-old children's performance was generally expected to lie in between (and possibly differ little from) that of the 10- and 12-year-olds. We also explored whether age-related differences were detectable in each of the three inhibitory functions, since few studies have looked into this issue in typically-developing children (but see de Ribaupierre et al., 2003, 2004).

Regarding the relations between processing resources and text comprehension, WM was expected, in line with the literature (e.g. Kintsch, 1998; Seigneuric & Ehrlich, 2005), to influence both text comprehension conditions because it affects an individual's ability to carry out many of the processes involved in constructing a mental representation of a text. We also explored whether processing speed could explain text comprehension performance, and which of the inhibition-related functions, if any, might account for text comprehension in typically developing children. Our hypothesis was that both WM and inhibitory functions have a more important role in the TA condition because it demands more cognitive resources than the TP condition.

1. Method

1.1. Participants

The sample included 20 ten-year-olds, 20 eleven-year-olds, and 20 twelve-year-olds attending the 4th, 5th and 6th grades, respectively (see Table 1). They were selected by age, school year (normal age for grade) and gender. Concerning the families' socio-economic status, based on the Geneva educational yearbook data, 33% of parents were in higher managerial occupations, 33% in lower management roles, 12% were small employers, 20% were blue-collar workers, and 2% were unemployed. This is representative of the general Geneva population.

A series of tests were presented to assess automatic word components based on reading speed, with the one-minute test (Khomsi, 1998), and on the reading of non-words (Mousty et al., 1994). Reading comprehension performance was assessed with the standardized Orlec-L4 reading comprehension task (Lobrot, 1980). In all these tasks, each age group performed adequately when compared with available normative scores; this also ensured that reading skills were automatized and ruled out any comprehension difficulties.

1.2. Materials

1.2.1. Working memory

As WM serves essentially to retain and process attentionally-relevant information and is relatively domain-free (e.g. Engle, Kane, & Tuholski, 1999; de Ribaupierre, 2000), one verbal and one visuospatial WM task were presented.

1.2.1.1. Reading span task – Rspan. In this task, adapted from Daneman and Carpenter (1980; see de Ribaupierre & Bailleux, 1995; de Ribaupierre & Lecerf, 2006; Delaloye, Ludwig, Borella, Chicherio, & de Ribaupierre, 2008), participants were asked to read a short series of simple sentences aloud (from 2 to 5 sentences in each series), and to say whether each sentence was semantically plausible, and at the end of each series they had to recall the last word in each sentence. Four items were administered at each level of difficulty to all the children, irrespective of how accurate their answers were. WM was scored as the mean number of words correctly recalled across the 16 items.

Table 1
Descriptive statistics and results of ANOVA by age group and task.

Females	10-year-olds		11-year-olds		12-year-olds		Group comparison ANOVA	η^2
	65%		40%		45%		(2,59)	
Text comprehension								
Correct answers with text (TP)	0.71	0.11	0.76	0.13	0.79	0.13	2.84*	0.09
Correct answers without text (TA)	0.64	0.15	0.69	0.11	0.74	0.10	3.66*	0.12
Working memory								
Rspan	2.33	0.40	2.69	0.34	2.81	0.28	10.59****	0.27
Matrices	1.50	0.46	1.94	0.57	2.00	0.44	6.12***	0.18
Inhibition								
Color Stroop								
Control^{RT}	893.55	167.69	793.75	133.26	787.88	122.67		
Incongruent^{RT}	1065.47	206.26	955.54	253.86	921.47	181.97		
NP, prime^{RT}	1066.55	217.50	932. 29	211.49	959.43	253.56		
NP, probe^{RT}	1091.90	239.26	991.71	316.84	954.36	225.00		
Interf. index^{RT}	0.20	0.12	0.19	0.14	0.16	0.10	<1	
NP index^{RT}	0.02	0.08	0.05	0.09	0.00	0.08	1.96	0.06
Hayling								
Initiation^{RT}	3184.73	821.66	2876.35	902.03	2877.05	1127.06		
Inhibition^{RT}	6397.00	2339.31	5930.05	5930.05	6157.40	2296.37		
Interf. index^{RT}	1.28	1.01	1.20	1.05	1.26	0.73	<1	
Intrusion errors (Rspan)	0.06	0.05	0.07	0.05	0.06	0.05	<1	
Processing speed								
Pattern comparison (in ms)	133.45	23.26	111.68	21.52	111.82	17.57	7.17***	0.20

Notes: TP = text present, TA = text absent; Rspan = reading span test; NP = negative priming; Interf. = interference; RT = response times in ms.
Indices are calculated on the basis of response times as follows: [(RT experimental condition − RT control condition) / RT control condition].
$^{*}p < .05$; $^{***}p < .001$.

1.2.1.2. Matrices task. In this visuo-spatial task (see de Ribaupierre & Lecerf, 2006), the children had to recall positions combined with words. A matrix consisting of 25 cells (5 × 5) was presented on a computer screen. Words were presented in some of the cells, and the number of cells containing a word defined the item's level of difficulty. The task was to recall the words and their respective positions, by saying the word aloud and pointing to the cell. Presentation time depended on the number of cells containing a word (1 s per word cell). The number of cells containing a word in a given item ranged from 2 to 6. Fifty-three items were constructed: 3 practice items, 12 for difficulty level 2, 11 for level 3, 10 for level 4, 9 for level 5, and 8 for level 6. The practice phase was followed by the 12-item test phase. An adaptive procedure was used, i.e. if participants answered correctly, a trial containing one more word (and position) to recall was administered, if not, a lower level of difficulty was adopted.

The score used in the present study was the mean number of correct word-position associations across the items.

1.3. Inhibition

Several tasks were used to assess the three functions (prepotent response inhibition, resistance to distractor interference, and resistance to proactive interference) discussed in the literature (e.g. Borella, Carretti, & Pelegrina, 2010; de Ribaupierre et al., 2003; Friedman & Miyake, 2004).

1.3.1. Prepotent response inhibition

1.3.1.1. Color Stroop task. In this computerized test (e.g. Borella et al., 2009; de Ribaupierre et al., 2003), participants had to name the color in which words or word-like stimuli were presented in various conditions: two control conditions ("signs" such as ++++ and "neutral words" such as "neuf" ["new"]), a congruent condition (when the color to name matched the color of the word, e.g. "red" written in red), an incongruent one (e.g. "red" written in blue), and a negative priming one (prime and probe trials). In this last condition, the word to inhibit in the prime display was presented in the same color as the target color to name in the subsequent probe display (e.g. the word "red" written in blue was followed by the word "yellow" written in red). The more a word color is inhibited, the longer it takes to retrieve it when it becomes the target response in the next trial; this delay qualifies the negative priming effect (Tipper, 1985).

Twenty-four items, randomly distributed throughout the task, were administered in each condition (12 pairs in the negative priming condition). Stimulus response latency – recorded by means of a voice key, and corresponding to the time elapsing from the onset of the stimulus to that of the response – and accuracy were recorded for each trial. All response times (RTs) of less than 200 ms, or associated with voice key failures and wrong answers were eliminated.

The dependent variable considered was the interference index. This was computed to control for individual differences in baseline performance (see Borella et al., 2009), as follows: Interference index, ([RT incongruent − RT signs] / RT signs).

1.3.1.2. Hayling task. This task (adapted from Burgess & Shallice, 1997; see Borella et al., 2009) consisted of 30 high-cloze sentences in which the final word was omitted. Half of the sentences (initiation phase) had to be completed with the most appropriate word; the other half (inhibition phase) with an ending that made no sense at all in the context of the sentence. A practice phase was presented before each test condition.

The experimenter manually recorded accuracy, and the computer recorded RT latencies. All RTs exceeding 7000 ms, or associated with voice key and other errors were eliminated.

The interference index – ([RT inhibition − RT initiation] / RT initiation) – was considered as the dependent variable.

1.3.1.3. Resistance to distractor interference. The negative priming (NP) condition, embedded in the Color Stroop task (see de Ribaupierre et al., 2003; Hartley, 1993), was used to measure this inhibitory function.

The NP index, computed as the relative ratio ([RT probe − RT prime]/ R T prime), was used as the dependent variable.

1.3.1.4. Resistance to proactive interference. The percentage of intrusion errors (i.e. non-final words wrongly recalled) was calculated in the Rspan test, which is generally considered a measure of resistance to proactive interference (see Robert, Borella, Fagot, Lecerf, & de Ribaupierre, 2009).

It should be noted that higher scores for the interference and NP indexes reflect a greater susceptibility to interference and a more effective inhibition, respectively.

1.3.2. Processing speed

1.3.2.1. Pattern comparison task. In this paper-and-pencil test (adapted from Salthouse, 1992; de Ribaupierre & Lecerf, 2006), participants had to decide whether the two members of a pair of line segments were identical or not. The pairs were presented on an A4 page (two pages). The experimenter used a stopwatch to record the time it took to complete each page.

The dependent variable was the total time taken to complete the answers on the two pages.

1.3.3. Reading comprehension

1.3.3.1. Text comprehension task. Participants were presented with 6 short narrative texts (short stories in which characters and/or events were described) selected from a standardized French battery (Aubert & Blanchard, 1988) for 8- to 16-year-olds. The texts were grouped into two sets of 3 texts of similar difficulty (see Borella, 2006) and they were presented in two conditions: one (TP) in which the texts remained available to participants when they answered the questions; and the other (TA) in which the texts were withdrawn. To obtain a global measure of text comprehension, each text was followed by 6 open-ended questions on the characters/events described, 3 of which addressed details and 3 were inferential.

Each text was presented in full on a computer screen. Participants were asked to silently read each text carefully to understand its content, and then answer a set of questions that appeared one at a time. When they were ready, participants pressed the space bar to bring up the first question below the text at the bottom of the screen. Before starting the test, they were told that the text would remain available while they answered the questions during the first series of texts. They were also told explicitly that the questions would be displayed but the text would disappear in the second series. Practice trials were run for both conditions.

The order of presentation of the texts and questions was fixed, and the two sets of texts were counterbalanced across participants. Detail and inferential questions were alternated. The task always started with the TP condition because it is more similar to everyday reading situations, as shown by other studies (e.g. Borella et al., 2011), and also to limit the use of memory strategies in TP (if the TA condition was presented first).

Each answer was scored as: 0 (wrong), 0.5 (partially right – used for some questions on events/characters) or 1 (completely right). Four judges independently classified the accuracy of participants' answers. Inter-judge agreement was higher than 95%. The total number of correct answers in the TP and TA conditions was considered. Performance in this task correlated significantly ($r = 0.48$, $p < 0.001$) with the performance in the Orlec-L4 reading comprehension task.

1.4. Procedure

The tests were administered individually as follows: Session 1: One-minute, pseudo-words, Pattern comparison, and Color Stroop tests; Session 2: Matrices and Hayling tests; Session 3: Rspan and Orlec-L4 tasks; and Session 4: Text comprehension task.

2. Results

ANOVA was conducted to identify age-related differences in the measures of interest between the three age groups (see Table 1 for descriptive statistics and results of ANOVA).

In the WM measures, results showed a main effect of age for both Rspan and Matrices: 10-year-old children performed less well than the other two age groups (10- vs 11-year-olds, $p < 0.01$ and $p < 0.05$, respectively; 10- vs 12-year-olds, $p < 0.001$ and $p < 0.01$, respectively), while the 11- and 12-year-olds did not differ significantly from one another.

In the three inhibition tasks[1], the three age groups did not differ significantly, neither for raw times nor for the relative indexes.

In the Pattern comparison test (processing speed), the main effect of age was significant, 10-year-old children taking longer to complete the test than either of the older age groups ($p < 0.01$ for both), which did not differ from one another.

For text comprehension, no significant difference emerged between the groups in the TP condition, while 10-year-olds had lower comprehension scores than 12-year-olds in the TA condition ($p < 0.05$); the 11-year-olds' performance did not differ significantly from either of the other two groups.

3.1. Correlation analyses

Significant correlations (see Table 2) were found for Age with both text comprehension conditions, and with WM tasks and processing speed measures, but not with inhibition-related indexes. TP and TA performance correlated significantly with WM and processing speed. TA performance also correlated with the NP index. As for the processing resources, the only significant correlations were WM with both processing speed and intrusion errors. Among the inhibitory measures, only the Color Stroop interference and the NP indexes correlated with one another (see Table 2).

3.2. Regression analyses

Hierarchical regression analyses were run to estimate the percentage of variance in the TP and TA conditions (criterion variables), which was explained by WM[2], inhibitory functions and processing speed, and age. Two different models were used: in Model 1, WM was entered in Step 1, the resistance to proactive interference index in Step 2, the resistance to distractor interference index in Step 3, and the prepotent response inhibition index in Step 4, while processing speed and age were entered in Steps 5 and 6, respectively (see Table 3). The order was consistent with our hypotheses and their theoretical importance in reading comprehension abilities, as suggested in the literature. For Model 2, to control for age-related differences, age was entered in the first step, followed by WM and then inhibitory measures and processing speed. For both models, WM was always entered before the inhibitory measures and processing speed because of its central role in reading comprehension, as suggested in the literature.

The predictors explained 29% of the variance in the TP condition and 34% in TA.

---

[1] For the Color Stroop task, two 3 (age groups) × 2 (incongruent vs. control conditions for the interference effect and probe vs. prime conditions for the negative priming effect) ANOVA were run on raw response times. The results showed a main effect of condition, with longer RT in the incongruent (M = 980.83, SE = 27.90) than in the control condition (M = 825.06, SE = 18.40), and in the probe (M = 1012.75, SE = 34.01) than in the prime condition (M = 986.09, SE = 29.47), $F(1,57) = 101.67$, $p < 0.001$, $\eta^2 = 0.64$ and $F(1,57) = 3.97$, $p < 0.05$, $\eta^2 = 0.07$, respectively. There was no effect of age, nor any Age $*$ Condition interaction.For the Hayling test, the 3 (age groups) × 2 (inhibition vs initiation conditions) ANOVA showed a main effect of condition, $F(1,57) = 115.12$, $p < 0.001$, $\eta^2 = 0.67$, with longer RT in the inhibition (M = 6162.15, SE = 329.97) than in the initiation condition (M = 2979.37, SE = 123.81).

[2] WM measures were reduced to a composite score based on standardized scores computed for the whole sample. This could not be done for the inhibitory measures because of the low/null correlations.

Table 2
Between-task correlations.

	Age	2	3	4	5	6	7	8	9	10
Text comprehension										
TP (2)	0.30*	–								
TA (3)	0.34**	0.40***	–							
Working memory										
Rspan (4)	0.50***	0.40**	0.47***	–						
Matrices (5)	0.39**	0.41***	0.34**	0.42***	–					
Inhibition										
Color Stroop interf. index (6)	−0.13	−0.20	−0.08	−0.13	−0.02	–				
NP index (Color Stroop test) (7)	−0.10	−0.08	−0.22*	−0.04	0.18	0.22*	–			
Hayling interf. index (8)	0	0.19	0.20	0.15	0.17	−0.09	−0.07	–		
Intrusion errors (Rspan) (9)	0.06	−0.25*	−0.10	−0.32**	−0.22*	0.09	−0.02	−0.17	–	
Processing speed										
Pattern comparison (10)	−0.39**	−0.29**	−0.37**	−0.37**	−0.43**	0.16	0.18	−0.18	0.11	–

Notes. N = 60. TP = text present; TA = text absent; Rspan = reading span test; NP = Negative Priming; Interf. = interference.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 3
Hierarchical regression analyses for text present and absent conditions, Model 1: Processing resources entered before age.

	Text present		Text absent	
Predictors	ΔR^2	β	ΔR^2	β
Working memory	0.23	0.48***	0.23	0.48***
Resistance to proactive interference	0.01		0.00	
Intrusion errors		−0.10		0.06
Resistance to distractor interference	0.02		0.08	
NP index (Color Stroop test)		0.14		0.29*
Prepotent response inhibition	0.02		0.01	
Color Stroop interf. index		−0.14		0.04
Hayling interf. index		0.08		0.10
Processing speed	0.00		0.01	
Pattern comparison		−0.03		−0.10
Age	0.00	0.06	0.00	0.05
Total R^2	0.29		0.34	

Notes: NP = Negative Priming; interf. = interference.
$^{*}p < 0.05$; $^{***}p < 0.001$.

Table 4
Hierarchical regression analyses for text present and absent conditions, Model 2: Age entered before processing resources.

	Text present		Text absent	
	ΔR^2	β	ΔR^2	β
Age	0.09	0.30*	0.11	0.34*
Working memory	0.14	0.44**	0.13	0.42*
Resistance to proactive interference	0.01		0.01	
Intrusion errors		−0.12		0.04
Resistance to distractor interference	0.01		0.08	
NP index (Color Stroop test)		0.13		0.29*
Prepotent response inhibition	0.02		0.01	
Color Stroop interf. index		−0.14		0.04
Hayling interf. index		0.08		0.11
Processing speed	0.02		0.00	
Pattern comparison		−0.02		−0.09
Total R^2	0.29		0.34	

Notes: NP = Negative Priming; interf. = interference.
$^{*}p < 0.05$; $^{**}p < 0.01$.

In TP and TA, when WM was entered in the regression first, it accounted for 23% of the variance. WM was the only significant predictor in the TP condition. In TA, the NP index accounted for an additional 8% of the variance in Step 3 (see Table 3). WM and the NP index contributed to the variance explained in TA.

Model 2 (Table 4) showed that age explained 9% in TP and 10% in TA, but in both conditions age was no longer a significant predictor when WM was inserted in Step 2, and WM contributed significantly to the variance explained. In the other steps, the results mirrored those obtained with Model 1: after controlling for age, WM was still the only critical predictor in TP, and WM and NP in TA.

3. Discussion

This study pursued several objectives marking its specific contribution. First, it aimed to disentangle text comprehension per se and memory for text in children old enough to have already mastered basic reading skills, i.e. 10- to 12-year olds. The distinction drawn here between text-present and text-absent conditions has not really been tackled in the literature (even though it may seem rather obvious), and text comprehension is often measured in tasks taxing memory (Cain & Oakhill, 2006). Second, the role of inhibition was studied using external, independent tasks assessing the three inhibitory functions proposed by Friedman and Miyake (2004); it was not examined in children without reading difficulties, to our knowledge at least. Third, a multivariate design was adopted to assess the combined influence of WM, inhibitory functions and processing speed on text comprehension (with or without memory loading): these three cognitive functions are theoretically supposed to be the most closely related to text comprehension, once basic reading skills have been mastered and become automated in typically-developing children. The specificity of the present study lies in the assumption that they might have a joint role, rather than offering alternative explanations.

As regards the age-related differences in comprehension performance, larger age-related differences were found for TA than for TP, as expected: the 10-year-olds performed less well than the 12-year-olds when they had to answer comprehension questions without being able to refer to the text, whereas no significant age-related differences emerged in the TP condition. Although TP and TA share the same processes, we had expected TA to tax more processing resources and therefore be relatively more difficult for younger children than TP. It is worth adding that the 11-year-olds did not differ significantly from either the 10- or the 12-year-olds, in either of the text comprehension conditions. This would suggest that text comprehension improves gradually and it takes an interval of at least two years for significant age-related differences to become apparent.

As for WM and processing speed, as expected and consistently with the literature (e.g. Fry & Hale, 1996), our results showed a clear improvement with age, 12-year-old children performing better than 10 year-olds. No significant age-related differences emerged for the inhibition-related functions examined, regardless of the measures considered (RTs vs relative ratio indexes). Although these results contrast with some other reports of inhibitory efficacy improving as children grow older (de Ribaupierre et al., 2004; Harnishfeger, 1995), there is no consensus on the developmental trends of inhibition (see Gerstadt, Hong, & Diamond, 1994; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). It may also be that the age range considered in the present study was too narrow to capture any age-related differences in inhibition-related functions.

Correlational analyses confirmed the results of the ANOVA for the processing resources. Age correlated with WM and processing speed, but not with inhibition-related functions (see de Ribaupierre & Lecerf, 2006). In line with the literature, WM correlated with processing speed (Fry & Hale, 1996), and with resistance to proactive interference (e.g. Robert et al., 2009).

The results of our regression analyses seem particularly interesting. They showed that the contribution of age, WM, inhibition-related functions and processing speed to text comprehension performance depended on the demands of the text comprehension task. In particular, WM explained a significant, considerable part of the variance in text comprehension performance whatever the presentation condition and the influence of age. This finding underscores and confirms the crucial role of WM in text comprehension. Without the text to consult, resistance to distractor interference also became a significant predictor of text comprehension performance. This result is consistent with studies by Lorsbach and collegues (Lorsbach & Reimer, 1997; Lorsbach et al., 1998) showing that text comprehension performance depends on the ability to inhibit distractors, though Lorsbach et al. relied on the text comprehension paradigm itself (text with distractors) to define resistance to distraction, whereas an “external” task was used in the present study. Actively preventing irrelevant information from entering and cluttering the WM thus appears to be an important process when there is a memory load to cope with in the retrieval condition, more important than the other two inhibitory functions. Poor comprehenders' weak performance in text comprehension tasks is also attributed to a specific inhibition-related function (e.g. Borella et al., 2010). In the Borella et al. study (2010), however, which also examined the three inhibitory functions in poor comprehenders, it was proactive interference (measured with intrusion errors) that was specifically involved in the reading comprehension performance of poor comprehenders, rather than resistance to distractor interference as in the present study. These different results raise an interesting question, as they point to a potentially qualitative difference between typically-developing children and poor comprehenders that also depends on the text presentation mode. Perhaps poor comprehenders have a specific (or larger) difficulty in inhibiting information that becomes irrelevant after they have activated and processed it in their WM, and not necessarily in preventing irrelevant information from entering the WM (as in the NP paradigm used here) – even when the text does not impose a memory load. If so, a measure of resistance to proactive interference would be a good predictor of text comprehension for poor comprehenders, as in the De Beni et al. study (1998). In contrast, typically-developing children might select and maintain the relevant information better than poor comprehenders, and would be less bothered by proactive interference. On the other hand, inhibition might not help them to prevent irrelevant information from entering the WM when the processing load is higher. As a result, the NP paradigm could be a better predictor of text comprehension, in presence of a memory load, than proactive interference. This is mere speculation, however, and different tasks were used in Borella et al. (2010) and in the present study. We also know from the literature that inhibitory indices are specific and might not be very reliable. Only a direct comparison of typically-developing children and poor comprehenders could help to clarify this difference. It would be particularly interesting to use the same TP/ TA comparison and the same inhibitory tasks in both groups of children.

By contrast, processing speed did not contribute to explaining the variance in text comprehension, indicating that its correlation with TP and TA was probably mediated by WM, so processing speed no longer contributes to the variance after controlling for WM.

Some limitations of the present study have to be acknowledged, one of which is the narrow age range of the children considered, which would explain why few age-related differences were observed in the inhibition tasks. Other inhibitory tasks could be used to support the present results and thus confirm qualitative and quantitative differences between children with and without comprehension problems. Future studies should also consider metacognitive knowledge, control (e.g. Meneghetti, Carretti, & De Beni, 2006) and strategy aspects to obtain a more complete picture of the factors influencing text comprehension, particularly as concerns the difference between the text presentation modes in children. Other inhibitory tasks could be used to confirm the present results.

In conclusion, our results shed further light on the often-hypothesized relationship between processing resources and text comprehension in children, confirming the role of WM in text comprehension performance (e.g. Cornoldi & Oakhill, 1996; Kintsch, 1998) and demonstrating that individual differences in text comprehension performance depend on a specific inhibitory function, i.e. resistance to distractor interference. Our results also highlight the role of having to retrieve information from memory (in the TA condition), which in turn probably influences the way in which the text is read and the information is encoded. Our findings also have relevant educational implications since the distinction drawn here between the two conditions (with and without a text to consult) is infrequent in the literature, while pupils are often tested for text comprehension at school in either condition, without distinguishing between them. Bearing in mind the difference between text comprehension per se and text comprehension with memory could help us to refine our understanding of text comprehension problems. Text comprehension with memory taxes processing resources more heavily than when the text remains available for reference, and might warrant teaching some other strategies (such as memorizing chunks of information); comprehension with the text available might be more specific to reading. It would therefore be useful to separate these two text comprehension conditions when: i) testing comprehension levels, not only at school but also for clinical purposes; and ii) planning text comprehension training, which should include exercises to enhance both WM and resistance to distractor interference. Moreover, taking into consideration the specific role of inhibition in text comprehension could help learning activities to be structured in order to prevent difficulties related to distractor interference.

References

Aubert, J., & Blanchard, S. (1988). *L'évaluation des compétences d'un lecteur. Présentation d'épreuves relatives à la maîtrise de la langue française et de la Lecture Silencieuse [Evaluation of a reader's skills. Presentation of tasks for the mastery of the French language and silent reading].* Paris: INETOP.

Borella E. (2006). Reading comprehension, working memory and inhibition: A life span perspective. Unpublished doctoral thesis, University of Geneva

Borella, E., Carretti, C., & Pelegrina, S. L. (2010). The specific role of inhibitory efficacy in good and poor comprehenders. *Journal of Learning Disabilities*, *43*, 541–552.

Borella, E., Delaloye, C., Lecerf, T., Renaud, O., & de Ribaupierre, A. (2009). Do age differences between young and older adults in inhibitory tasks depend on the degree of activation of information? *European Journal of Cognitive Psychology*, *21*, 445–472.

Borella, E., Ghisletta, P., & de Ribaupierre, A. (2011). Age differences in text processing: The role of working memory, inhibition and processing speed. *Journal of Gerontology: Psychological Sciences*, *66*, 311–320.

Burgess, P. W., & Shallice, T. (1997). *The Hayling and Brixton test. Harcourt Assessment.* : The Psychological Corporation.

Cain, K., & Oakhill, J. V. (2006). Assessment matters: Issues in the measurement of reading comprehension. *British Journal of Educational Psychology*, *76*, 697–708.

Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining the performance of individuals with specific reading comprehension difficulties: A meta-analysis. *Learning and Individual Differences*, *19*, 246–251.

Cornoldi, C., & Oakhill, J. V. (Eds.). (1996). *Reading comprehension difficulties: Processes and remediation*. Mahwah, N.J.: Lawrence Erlbaum Inc.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466.

De Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficits of poor comprehenders. *Quarterly Journal of Experimental Psychology*, *51A*, 305–320.

Delaloye, C., Ludwig, C., Borella, E., Chicherio, C., & de Ribaupierre, A. (2008). L'empan de lecture comme épreuve mesurant la capacité de mémoire de travail: normes basées sur une population francophone de 775 adultes jeunes et âgés. *Revue Européenne de Psychologie Appliquée. European Review of Applied Psychology*, *58*, 89–103.

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

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101–135.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*, *7*, 237–241.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 430–445.

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of 3.5 to 7 year olds on Stroop-like day–night test. *Cognition*, *53*, 129–153.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In F. N. Dempster, & C. J. Brainerd (Eds.), *Interference and inhibition in cognition*. San Diego, CA, USA: Academic Press.

Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old age. *Psychology and Aging*, *8*, 371–379.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation* (pp. 193–225). New York: Academic Press.

Johnston, R., & Anderson, M. (1998). Memory span, naming speed, and memory strategies in poor and normal readers. *Memory*, *6*, 143–163.

Khomsi (1998). *Epreuve d'évaluation de la compétence en lecture. Lecture de mots et compréhension-révisée. L.M.C-R [Assessment test for reading competence. Word reading and comprehension – Revised]*. Paris: Editions du Centre de Psychologie Appliquée.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York, NY, USA: Cambridge University Press.

Lobrot, M. (1980). *Lire avec épreuves pour évaluer la capacité de lecture. (D-OR-LEC) [Reading with tests to assess reading comprehension]*. Paris: Editions ESF.

Lorsbach, T. C., Katz, G. A., & Cupak, A. J. (1998). Developmental differences in the ability to inhibit the initial misinterpretation of garden path passages. *Journal of Experimental Child Psychology*, *71*, 275–296.

Lorsbach, T. C., & Reimer, J. F. (1997). Developmental changes in the inhibition of previously relevant information. *Journal of Experimental Child Psychology*, *64*, 317–342.

Meneghetti, C., Carretti, B., & De Beni, R. (2006). Components of reading comprehension and scholastic achievement. *Learning and Individual Differences*, *16*, 291–301.

Miyake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York, NY, USA: Cambridge University Press.

Mousty, P., Leybaert, J., Alegria, J., Content, A., & Moraïs, J. (1994). Bélec. In J. Grégoire, & B. Piérart (Eds.), *Evaluer les troubles de la lecture. Les nouveaux modèles théoriques et leurs implications diagnostiques* (pp. 127–145)*Assessment of reading deficit. New theoretical models and their diagnostic implications* (pp. 127–145). Bruxelles: De Boeck.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *126*, 220–246.

de Ribaupierre, A. (2000). Working memory and attentional control. In W. J. Perrig, & A. Grob (Eds.), *Control of human behavior, mental processes, and consciousness: Essays in honor of the 60th birthday of August Flammer* (pp. 147–164). Mahwah, NJ, USA: Lawrence Erlbaum Associates.

de Ribaupierre, A., Atzeni, T., Fagot, D., Jouffray, C., Lecerf, T., & Ludwig, C. (2004). Dimensionnalité de l'inhibition cognitive au travers du lifespan. Rapport final. [Dimensionality of cognitive inhibition across the lifespan. Final report]. Unpublished manuscript, University of Geneva.

de Ribaupierre, A., & Bailleux, C. (1995). Development of attentional capacity in childhood: A longitudinal study. In F. Weinert, & W. Schneider (Eds.), *Memory performance and competencies: Issues in growth and development* (pp. 45–70). Hillsdale, N.J.: Lawrence Erlbaum.

de Ribaupierre, A., Borella, E., & Delaloye, C. (2003). Inhibition et variabilité individuelle: généralité ou spécificité des processus inhibiteurs [Inhibition and individual variability: generality or specificity of inhibitory processes]. In S. Moutier (Ed.), *Inhibition Neurale et Cognitive. Traité de Sciences Cognitives*. (pp. 103–124). Paris Hermès: Hermes Sciences.

de Ribaupierre, A., & Lecerf, T. (2006). Relationships between working memory and intelligence: Convergent evidence from a neo-Piagetian and a psychometric approach. *European Journal of Cognitive Psychology*, *18*, 109–137.

Robert, C., Borella, E., Fagot, D., Lecerf, T., & de Ribaupierre, A. (2009). Working memory and inhibitory control across the life span: Intrusion errors in the Reading Span Task. *Memory & Cognition*, *37*, 336–345.

Salthouse, T. A. (1992). *Mechanisms of age-cognition relations in adulthood*. Hillsdale, NJ, England: Lawrence Erlbaum.

Seigneuric, A., & Ehrlich, M. (2005). Contribution of working memory capacity to children's reading comprehension: A longitudinal investigation. *Reading and Writing*, *18*, 617–656.

Siegel, L. S. (1994). Working memory and reading: A lifespan perspective. *International Journal of Behavioral Development*, *17*, 109–124.

Swanson, H. L. (1996). Individual and age-related differences in children's working memory. *Memory and Cognition*, *24*, 70–82.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *37A*, 571–590.

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology*, *25*, 205–213.