Age Differences in Text Processing: The Role of Working Memory, Inhibition, and Processing Speed

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Objectives. Age-related changes in the efficiency of various general cognitive mechanisms have been evoked to account for age-related differences between young and older adults in text comprehension performance. Using structural equation modeling, we investigate the relationship between age, working memory (WM), inhibition-related mechanisms, processing speed, and text comprehension, focusing on surface and text-based levels of processing.

Methods. Eighty-nine younger (*M* = 23.11 years) and 102 older (*M* = 70.50 years) adults were presented text comprehension, WM, inhibition, and processing speed tasks. In the text comprehension task, the demand on the memory system was manipulated, by allowing (text present) or not (text absent) viewing the text during the answering phase.

Results. As expected, age differences were larger when the text was absent. The best fitting model showed that WM mediated the influence of age on both text processing conditions, whereas age-related variance in WM was, in turn, accounted for by processing speed and inhibition.

Discussion. These findings confirm the hypothesis that WM capacity explains age differences in text processing, while it is itself accounted for by the efficiency of inhibiting irrelevant information and by speed of processing.

Key Words: Aging—Inhibition—Processing speed—Text comprehension—Working memory.

I T is well documented that, with aging, there is a decline in some basic cognitive mechanisms, such as working memory (WM), inhibition, and processing speed, and that this decline is central to explaining age-related differences in older adults in many cognitive domains (Park et al., 2002; Borella, Carretti, & De Beni, 2008) including language processing (Wingfield & Stine-Morrow, 2002). Despite the crucial role of language processing in everyday life, surprisingly few studies in this area have adopted a multivariate design to examine how it relates to basic mechanisms in aging.

Using structural equation modeling (SEM), Van der Linden and colleagues (1999) found WM to be a crucial factor in explaining age differences in language and verbal performance, while inhibition and processing speed mediated the age-related variance in WM. In contrast, Kwong-See and Ryan (1995), through hierarchical regression analysis, identified processing speed and inhibition, but not WM, as crucial in explaining age-related differences in language performance. Using SEM, DeDe, Caplan, Kemtes, and Waters (2004) showed that WM mediated age-related decline only on a global measure of text comprehension—the Nelson–Denny reading comprehension test—but not on syntactic processing and sentence comprehension. However, in the latter study, no measures of inhibition and processing speed were included.

The results of these studies share some common characteristics.

First, they confirm, except for the Kwong-See and Ryan study, the fundamental role of WM, as proposed by models on adult reading comprehension (Daneman & Carpenter, 1980; Kintsch, 1998), in predicting reading comprehension performance also when older adults are considered (e.g., De Beni, Borella, & Carretti, 2007; DeDe et al., 2004). Poor WM performance in older adults (Park et al., 2002), for instance, has been found to determine the increased probability that recently processed text will be forgotten, compromising the construction of a coherent text representation (e.g., DeDe et al., 2004; Kemtes & Kemper, 1999).

Second, they show that inhibition and processing speed account for age-related differences in text comprehension. More specifically, these two mechanisms are found to mediate the relationship between WM and complex cognition (Hasher, Lustig, & Zacks, 2007; Park et al., 2002; Salthouse, 1996). In order to maintain the goal of a task, which is to form a coherent mental representation of the text, the reader must be able to suppress irrelevant or no-longer-relevant information from WM when confronted with off-goal information (Kintsch, 1998). The inefficient regulatory inhibitory processes of older adults (Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009; Hasher et al., 2007) might, thus, compromise their comprehension performance because WM capacity is saturated sooner. Older adults, for instance, similar to poor comprehenders (individuals with normal IQ and good decoding skills, but

deficient reading comprehension; Borella, Carretti, & Pelegrina, 2010; Carretti, Borella, Cornoldi, & De Beni, 2009), commit more memory errors in WM tasks than good comprehenders recalling off-goal information (e.g., De Beni et al., 2007). The ability to comprehend a text is also influenced by the speed at which information is processed (read and encoded) in memory. The age-related decline in processing speed (e.g., Salthouse, 1996) impairs the ability of older adults to maintain information from earlier sections of a text that will be needed to interpret later sections (Hartley, Stojack, Mushaney, Annon, & Lee, 1994; Kwong-See & Ryan, 1995). It is presently unclear whether inhibition and processing speed act independently from one another in influencing the quality of text comprehension.

It is worth noting that reading comprehension involves several processes and levels of representation (surface, text-based, and situation model) that are generated, maintained, and processed over time in the memory (Kintsch, 1998). However, the level of text representation constructed depends much on the type of task the reader must handle (Thornton & Light, 2006). Young adults outperform older adults when surface or text-based level of representation is assessed; in contrast, no age-related decline is usually found in the creation of situation models (Radvansky & Dijkstra, 2007). If the level at which the text has to be processed influences the size of the age difference, it might also be the case that the role played by general mechanisms (such as WM) in explaining comprehension also varies as a function of the level of text processing required. The relationship found between general basic mechanisms and reading comprehension (Kwong-See & Ryan, 1995; Van der Linden et al., 1999) may, thus, be a consequence of the demands of the comprehension tasks used, relying mainly on surface form and text-based level (Radvansky & Dijkstra, 2007). Nonetheless, because the paradigms used to examine reading comprehension in multivariate studies include a number of different measures, interpreting the role of the underlying processes involved still needs clarification, including when lower levels of text processing are considered.

In view of these considerations, we used an individual differences approach plus a variety of indicators to investigate the role played by age, WM, inhibition, and processing speed in text processing, using SEM.

One objective of the present study was to evaluate whether age differences in text comprehension, when tested at the surface and text-based processing levels, vary as a function of the variation in the demand placed on processing resources. The same text comprehension task was used in two conditions. In the first condition, participants were allowed to review the text when responding to questions (text present [TP]), to mirror reading comprehension situations typical of everyday life (De Beni et al., 2007). In the second condition, the text was no longer available when participants responded to questions (text absent [TA]). This latter condition replicates the majority of the reading com-

prehension paradigm used in aging studies (Johnson, 2003). The manipulation of the text presentation mode is based on evidence that, using a more realistic comprehension procedure—passages available in the answering phase—age-related differences are nearly null (Brébion, Smith, & Ehrlich, 1997; De Beni, Palladino, Borella, & Lo Presti, 2003; De Beni et al., 2007; Ehrlich, Brebion, & Tardieu, 1994; Verhaeghen, Marcoen, & Goossens, 1993). These studies are of particular interest because a closer look at the reading comprehension tasks reveals that their overall comprehension score only partly reflects situation model processing.

The two conditions used—TP and TA—clearly call on a common set of basic processes (see Kintsch, 1998). In both conditions, text processing levels sensitive to aging are involved. Nevertheless, the lack of environmental support in the retrieval phase in TA should increase the importance of processing resources (e.g., Craik & Byrd, 1982). Because processing resources are supposed to be deficient in aging (e.g., Zacks & Hasher, 1988), older adults would be expected to experience more difficulties in the TA than in the TP condition. In the TA condition, as the reader cannot access the text, search strategies at retrieval are not available to compensate for deficient encoding. Accordingly, we expected (a) null or reduced age-related differences in TP, compared with TA, as concerns specific information explicitly stated in the text (verbatim words, surface level), and (b) age differences in both text presentation conditions, but larger in TA than in TP, when questions probe text-based representation (text-based level) as such probing should be particularly resource consuming for older adults (e.g., Zacks & Hasher, 1988).

A second objective was to determine whether these two conditions relied on the same processes or not. Therefore, an SEM approach was used to evaluate (a) whether TP and TA, because of the different retrieval condition, could be represented as two separable but related constructs, and (b) whether text processing, as far as age differences are concerned, would relate similarly with WM, inhibition, and processing speed. Our hypothesis was that a model in cascade (Fry & Hale, 1996) would apply: WM should mediate the influence of age on complex cognition (text processing: TP and TA), whereas processing speed and inhibition should, in turn, mediate the influence of age on WM, contributing only indirectly, via age differences in WM (DeDe et al., 2004; de Ribaupierre, 2001; Park et al., 1996; Salthouse, 1996), to text processing.

Finally, from a methodological viewpoint, independent indicators were used for these general mechanisms considered to be predictors of age differences. In contrast to previous studies that tested the efficacy of inhibition in reading comprehension using a single indicator (intrusion errors: De Beni et al., 2007) and/or using only a single task (the Stroop color task: Kwong-See & Ryan, 1995; Van der Linden et al., 1999), different inhibitory tasks were used.

Methods

Participants

The study involved 89 university students (18–35 years of age, $M = 23.11$ years, $SD = 3.52$) and 102 older adults (60–88 years of age, $M = 70.50$ years, $SD = 5.57$). All participants were French speakers. No participants were excluded because of vision problems. Visual acuity was screened by requiring words, which varied in font size, to be read aloud, and colored patch on the monitor to be named. All participants had normal or corrected-to-normal vision. The older adults presented no signs of incipient dementia and were active (de Ribaupierre et al., 2004). The older adults had a higher vocabulary score (French adaptation of the Mill Hill; Deltour, 1998) than younger counterparts; the younger adults displayed slightly better performance in the French adaptation of the Nelson–Denny reading comprehension test (Ehrlich et al., 1994; see Table 1A).

Materials

Working memory.—Working memory serves essentially to hold and process attentionally relevant information and is relatively domain free (e.g., de Ribaupierre & Lecerf, 2006). Two tasks were used for its assessment: one verbal (the reading span test, Rspan) and one presenting both a verbal and a visuospatial component (the matrices task) (de Ribaupierre & Lecerf, 2006). The Rspan required participants to read and to judge very simple sentences and, at the end of a series of sentences (variable in length), to recall the final word of each sentence. In the matrices task, words appeared in different cells of a 5×5 matrix; participants had to recall both the words and their positions. The mean number of words correctly recalled in the Rspan and word–position associations correctly recalled in the matrices test were considered.

Inhibition.—Referring to Friedman and Miyake's (2004) taxonomy of inhibition-related functions, we selected tasks to measure prepotent response inhibition, which allows the blocking of dominant and prepotent motor or cognitive responses automatically activated by the presented stimulus; response to distractor inhibition, which allows the focusing of attention on relevant items by ignoring simultaneously presented irrelevant ones; and resistance to proactive interference, which considers the ability to dampen the activation of no-longer-relevant items and thus to resist memory intrusions (intrusion errors). For the first function, the Stroop color and the Hayling tasks (Burgess & Shallice, 1997; see Borella et al., 2009) were presented; both tasks require participants to inhibit predominant and automatic responses yielded by (a) the color word in the Stroop color task and (b) the high-cloze sentences that have to be completed with a word that provides no sense to the sentence in the Hayling task. For the second function, which determines which representation enters in WM, we used the negative priming (NP) task (embedded in the Stroop color task). Finally, the directed forgetting (Df) task (adapted from Harnishfeger & Pope, 1996) was selected for assessing resistance to interference function. (After listening to the first 10 words, participants had to perform under the following conditions [see Harnishfeger and Pope's, 1996, procedure]: remember all—continue to remember, and, at the end, remember all the words; forget only—forget the first 10 words and then remember the final 10 word*s*; remember only—continue to remember but at the end remember only the final 10 words; forget all—forget the first 10 words while remembering the following ones and, at the end, remember all the words.) Except for the Df, all indices were calculated to control for individual differences in baseline performance (relative differences), in order to avoid contamination by age differences in speed (Borella et al., 2009). For the Df, we calculated a mean index, representing the cost of the Df procedure in the inhibition of irrelevant information (see MacLeod, 1998). Larger indices reflect a lower efficiency in inhibition. We also calculated intrusion errors (non-target words recalled) in the Rspan and in the Df task-items to be forgotten in the forget-only condition, and items to be remembered belonging to the first part of the list recalled in the remember-only condition. These measures were considered in order to assess the efficiency of resistance to proactive interference.

Processing speed.—The paper-and-pencil pattern and letter comparison tests (de Ribaupierre & Lecerf, 2006, adapted from Salthouse & Babcock, 1991) were administered. The mean completion time (seconds) required to complete pairs of patterns and strings of letters, respectively, across two pages for each test, was calculated.

Text comprehension task.—Participants were presented with six short narrative texts selected from a standardized French battery (Aubert & Blanchard, 1988) and from Van der Linden and colleagues (1999) study (see Borella, 2006). The texts were grouped into two sets of three texts, each graded in difficulty, and presented in two experimental conditions. (The two sets of texts did not differ in terms of number of words [$M = 125.67$, $SD = 29.26$; $M = 126.67$, $SD = 32.32$], lexical density [$M = 88.23$, $SD = 5.02$; $M = 91.17$, $SD = 5.61$], number of propositions [$M = 18$, $SD = 6.08$; $M = 18.67$, $SD = 5.51$], or sentence count [$M = 7$, $SD = 3$; $M = 7.67$, $SD = 4.73$]. Furthermore, a pilot study, in which participants read each text, answered questions, and then rated text difficulty, confirmed the equivalence of the two sets of texts.) In the first condition (TP), each text was available to the participants during the response phase. In the second condition (TA), the texts were no longer available in the question-answering phase. Each text was followed by six questions of which three addressed details (facts explicitly stated, surface level) and three were inferential (i.e., relating to inferences the participant must make

for text coherence, to allow an understanding of the links between sentences [anaphoric reference], but which did not imply world knowledge or construction of a situation model; see Appendix).

Each text was presented in full on a computer screen. Participants were instructed to read each text carefully to understand it and then answer a series of questions appearing one at time; when ready, participants had to press the space bar to bring up the first question below the text at the bottom of the screen. Before starting the test, they were previously informed that, in the answering phase for the first series of texts, the text would remain available with each question. They were also explicitly alerted when only questions would be displayed and the text would disappear. A practice phase was given for each condition.

The order of text presentation and questions was fixed across participants; the two sets of texts were counterbalanced across participants. Detail and inferential questions were alternated. The task always started with the TP condition, as it is more similar to everyday reading habits (De Beni et al., 2007).

Each response was scored 0 (incorrect answer), 0.5 (partially correct—used for some detail questions), or 1 (fully correct) (see Appendix). Four judges independently classified the accuracy of the participants' answers. Interjudge agreement was larger than 95%. The correct response scores were considered. Performance in this task correlated moderately with the Nelson–Denny test performance ($r = .45$, $p < .001$) and with vocabulary score ($r = .32$, $p < .001$).

Procedure

Tests were administered individually during five test sessions at least 1 week apart. Test presentation involved the following—Session 1: test of visual accuracy, the pattern comparison, and the Stroop color tests; Session 2: Df and vocabulary tests; Session 3: letter comparison, matrices, and Hayling tests; Session 4: Rspan and the Nelson–Denny tasks; and Session 5: text comprehension task.

RESULTS

Preliminary analyses were run to assess the reliability of the measures; it was acceptable in all cases except for the Stroop color interference, NP, and Hayling indices (i.e., the relative difference scores controlled for speed). Due to the poor reliability of these measures, and their lack of correlation with other outcome measures, they were excluded from subsequent analyses. Measures of reliability, participants' performance, and age-related differences are shown in Table 1A. Focusing on the text comprehension task, results showed large age differences in TA. In contrast, in TP, age differences in accuracy were null for details and small for inferences.

Structural Equation Modeling

First, preliminary confirmatory factor analyses were carried out to assess the measurement qualities of each construct and of subsequent general alternative models, and to test the relations among the factors. LISREL 8.53 software (Jöreskog & Sörbom, 1999) was used; models quality was determined with different fit indices.

Each hypothesized latent variable was marked by at least two indicators. Furthermore, because intrusion errors in the Rspan test cannot be considered independent of the Rspan score, we added a correlated residual between the Rspan score, loading on the WM latent variable, and the intrusion errors in the Rspan task, loading on the inhibition latent variable. The measurement model based on the constructs of interest (see Figure 1) was good ($\chi^2 = 93.75$, $df = 50$, $p < .001$, Akaike's information criterion [AIC] = 176.55, goodness-of-fit index [GFI] = .93, normed fit index [NFI] = .95, comparative fit index [CFI] = .97, root mean square error of approximation [RMSEA] = .068, standardized root mean residual [SRMR] = .057), confirming that text processing can be reasonably represented by two distinct latent variables.

Correlations between the latent variables are presented in Table 1.

The next step was to test several models specifying alternative explanatory theories of age differences in text processing. Latent variables were defined as described previously, and only the relationships between the latent variables were modified, according to five alternative models (Figure 2).

In Model 1, we expected all age differences in TP and TA to be mediated by WM, whereas processing speed and inhibition mediate age-related difference in WM and contribute only indirectly to text processing, as assumed by the literature (e.g., DeDe et al., 2004). In Model 2 (see Van der Linden et al., 1999), the effect of age on WM is mediated by processing speed and inhibition, but that age also exerts a direct influence on WM. WM also contributes directly to TP and TA. Model 3 was generated to test the presence of both direct and indirect effects of age on TP and TA. This latter model is similar to Model 1 but a direct path from age to both TP and TA was added, suggesting that not all age-related variance is directly mediated through WM on text processing. This model also assumes that age-related differences in TP and TA are explained by a reduction in WM capacity and by a direct and specific age effect on text processing abilities. Model 4 (see Kwong-See & Ryan, 1995) assumed that WM does not predict text processing, whereas inhibition and processing speed directly mediate the effect of age on TP and TA. Moreover, the effect of age on TP and TA is also expected to be direct. Finally, Model 5 was generated to test the hypothesis that age-related effects on TP and TA are directly mediated by both inhibition and WM. The effect of age on WM is mediated by processing speed and inhibition.
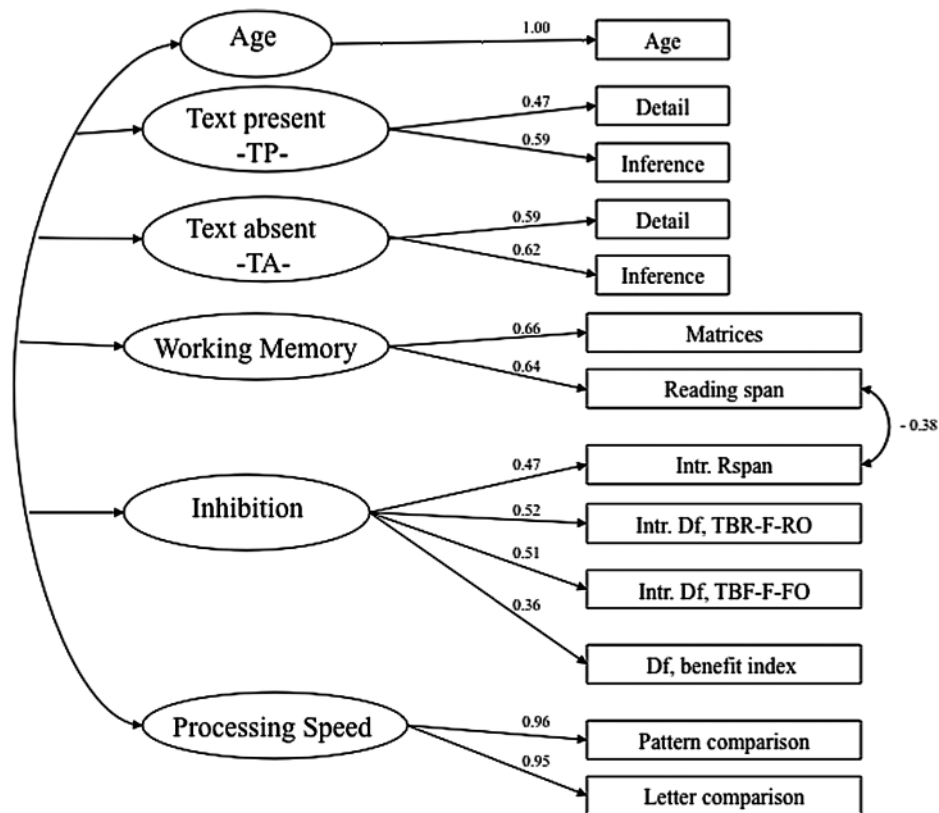
Figure 1. Measurement model that includes text processing -text present and text absent- working memory, inhibition-related mechanisms, and processing speed constructs. *Note*. Df = directed forgetting test; Intr. TBR-F-RO = items to be remembered (TBR) that are incorrectly recalled (F) in remember-only (RO) condition; Intr. TBF-F-FO = items to be forgotten (TBF) that are incorrectly recalled (F) in forgetting-only (FO) condition; Intr. Rspan = intrusion errors in the reading span test.

All models provided adequate fits (see Table 2).

Because Model 1 is statistically nested within both Models 2 and 3, a direct statistical comparison is possible with a change in chi-square ($\Delta\chi^2$) relative to the degrees of freedom (see Ullman, 1996). Comparing Model 1 with Model 2, a significant difference was found, $\Delta\chi^2 = 8.92$, for 1 *df*, $p < .01$, suggesting that Model 2, albeit less parsimonious, provided a better description of the data. Models 1 and 3 were not statistically different in fit, $\Delta\chi^2 = 4.30$, for 2 *df*, $p = .12$, so that the more parsimonious model-Model 1- was preferred. Moreover, in Model 1, in contrast with Models 2 and 3, all parameters were significant at $p < .05$. Thus, Model 1 is preferred over Models 2 and 3. As Model 1 is

not statistically nested within Model 4 or 5, we relied on AIC, CFI, and RMSEA indices to compare their fit. From a purely statistical perspective, the three models were equally efficient in describing the data. However, only Model 1 is without nonsignificant parameters; this provided one more reason to retain this model rather than Model 4 or 5. In conclusion, statistical evidence suggests that Model 1 is an adequate representation of the data best capturing the relationships among age, basic cognitive resources, and TP and TA (see Figure 3 for a detailed depiction).

To determine whether the relationships among the cognitive constructs found in Model 1 are qualitatively similar when TP and TA are considered separately, we tested two

Table 1. Correlations Between Age and Latent Constructs

	Age	TP	TA	WM	Inhibition-related mechanisms
Text present (TP), correct answers	.32	1			
Text absent (TA), correct answers	.54	−.71	1		
Working memory (WM)	−.71	.67	.67	1	
Inhibition-related mechanisms	.51	−.57	−.63	−.65	1
Processing speed	.86	−.26	−.42	−.66	.53

Note: A higher coefficient for inhibition-related measures (i.e., more errors and a higher cost for the directed forgetting) indicates less efficient inhibitory mechanisms. A higher score for processing speed indicates slower processing.
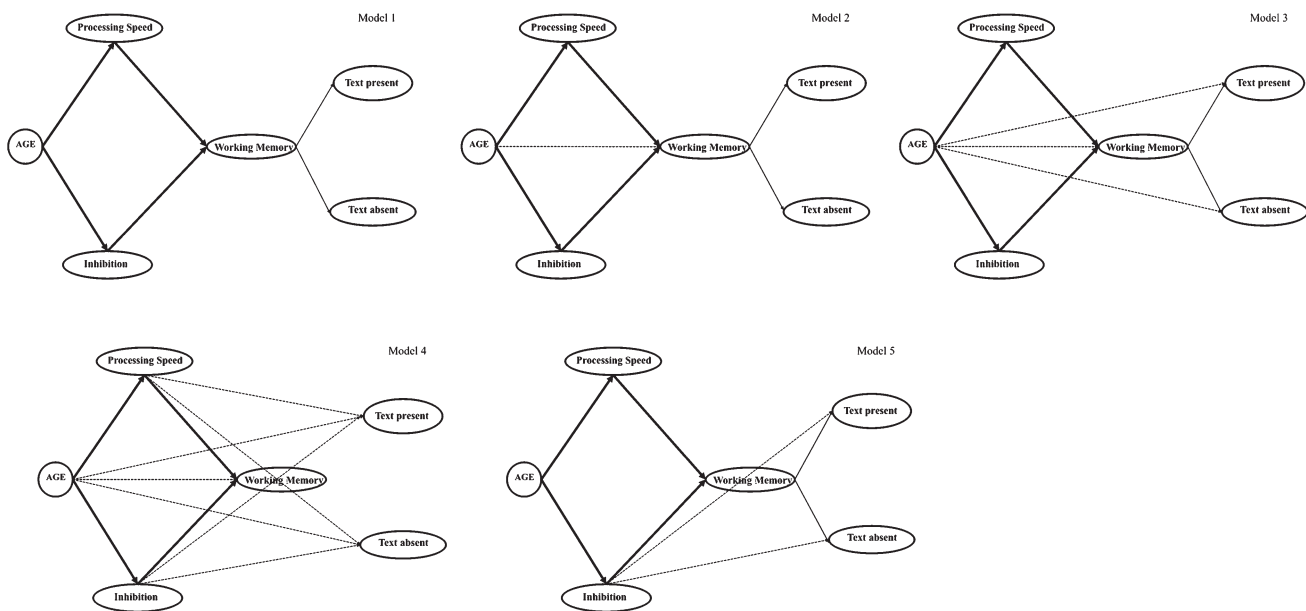
Figure 2. Hypothesized models for structural relationships among variables for the different models tested. *Note.* Black lines indicate the paths common to all models.

additional models. In the first model, only TP was considered, and in the second one, only TA. The overall statistical fits were again quite reasonable: Age and general mechanisms explained 40% of the variance for TP and 45% for TA.

Finally, Model 1 was tested separately for young and older adults. An acceptable fit was found for older adults, $\chi^2 = 92.10$, $df = 59$, $p < .004$, AIC = 156.10, GFI = .89, NFI = .71, CFI = .86, RMSEA = .07, SRMR = .09. However, for young adults, the solution was poorer, $\chi^2 = 111.61$, $df = 62$, $p < .001$, AIC = 169.61, GFI = .84, NFI = .55, CFI = .71, RMSEA = .09, SRMR = .11. Although the measurement model was similar for the two groups, such a difference could be attributed to the nonsignificant inhibitory latent construct for the younger group. This is not too surprising that Model 1 was not very good in young adults, as the models were meant to explain age differences. No effect of age was expected in young adults; the same model should therefore not apply. Moreover, because the fit was not good in young adults, it was not possible to run a multigroup model.

DISCUSSION

The present study explored the relations among age and basic mechanisms (WM, inhibition, and processing speed) often called upon to explain text comprehension performance. It pursued three interrelated objectives. First, by testing text processing and focusing on the surface and text-based levels, in two conditions, we aimed at varying the demand placed on processing resources. Our hypothesis was that age differences would be larger when the text is absent because this condition taxes more processing resources and memory, both known to decline in aging. When the text was present, it amounted to providing an environmental support, which is known to help older adults (Craik & Byrd, 1982). Second, although these two conditions are very close, we hypothesized that they involve different processes and, consequently, represent two related but different constructs. SEM was used to test this hypothesis. Third, we assessed the influence of general basic mechanisms on text processing. Our hypothesis was that WM would account for most

Table 2. Model Fit Indices

Model	df	χ^2	χ^2/df	p	AIC	GFI	NFI	CFI	RMSEA	SRMR	Nonsignificant paths
1	59	119.28	2.02	<.001	179.48	.91	.94	.95	.070	.064	None
2	58	110.36	1.90	<.001	174.26	.92	.95	.96	.068	.068	From processing speed to working memory
3	57	114.98	2.01	<.001	180.05	.92	.94	.96	.071	.061	From age to: text present (TP) and text absent (TA)
4	54	105.28	1.94	<.001	177.31	.92	.94	.96	.069	.060	From processing speed to working memory; from age to TP, and to TA; from age to working memory
5	57	113.88	1.99	<.001	179.12	.92	.94	.96	.071	.062	From working memory to TP; from working memory to TA; from inhibition to TP

Note: AIC = Akaike's information criterion; GFI = goodness-of-fit index; NFI = normed fit index; CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean residual.
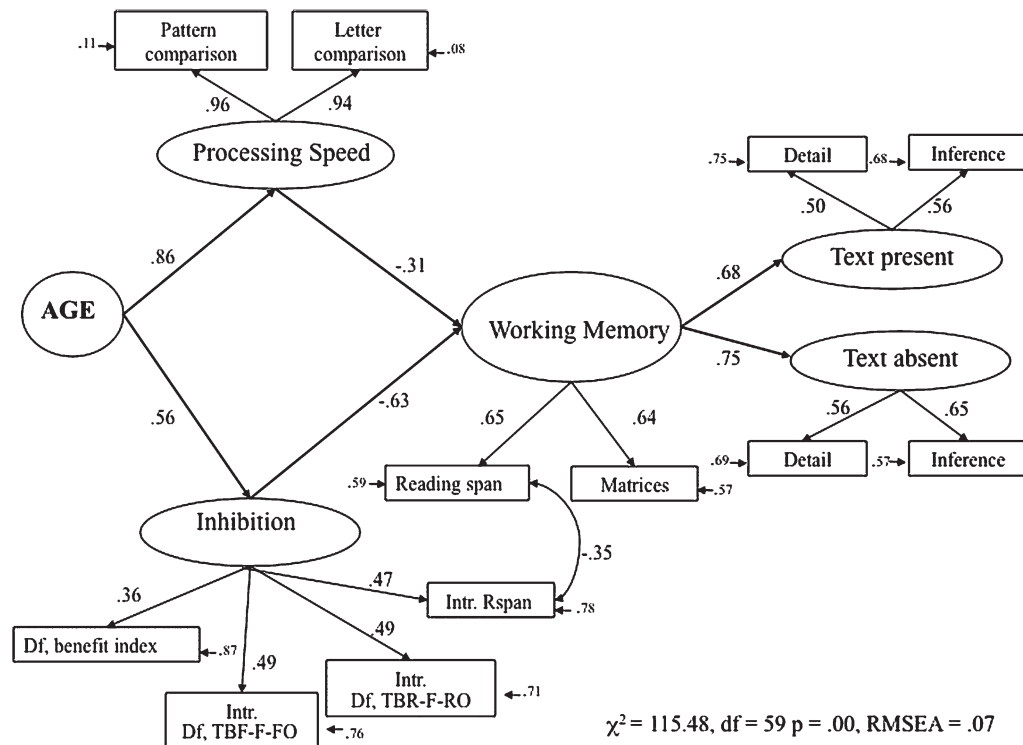
Figure 3. Structural model: best fitting measurement model. The completely standardized path coefficient is presented for each path in the model. *Note.* Df = directed forgetting test; Intr. TBR-F-RO = items to be remembered (TBR) that are incorrectly recalled (F) in remember-only (RO) condition; Intr. TBF-F-FO = items to be forgotten (TBF) that are incorreclty recalled (F) in forgetting-only (FO) condition; Intr. Rspan = intrusion errors in the reading span test.

age differences in text processing and that it would itself be explained by inhibition and processing speed.

A number of notable findings emerged.

First, as expected, age-related differences were larger in TA than in TP. Although both conditions require participants to understand and store text at the surface and text-based levels, participants' performance was lower in TA (when the text was not present in the retrieval phase) than in TP. TA is more resource consuming, impairing the effective regulation of processing resources (Stine-Morrow, Miller, Gagne, & Hertzog, 2008). In contrast, in TP, age differences were null for the surface-level measure, and attenuated for the text-based one (inferences related to the text), compared with TA. The TP condition offers a strong environmental support for retrieval; it therefore allows the participants to selectively allocate resources to meet task demands and/or to compensate for memory impairment. Minimizing the contribution of memory may, thus, contribute to a flexible processing that enhances accuracy, probably through a better regulating control (Stine-Morrow et al., 2008). These findings suggest that age differences may have been overestimated in the literature, at least when lower text representation levels are considered. Indeed, the paradigms proposed often imposed a memory burden in the retrieval phase, which taxes WM (Light & Burke, 1988; Verhaeghen et al., 1993). Younger adults still outperformed older adults in the TP condition when generation of inferences was considered,

showing this condition to be more sensitive to age-related decline (Zacks & Hasher, 1988). This indicates that the text-based level is still consuming processing resources, at least for older adults (Radvansky & Dijkstra, 2007) because it requires that critical information be available in their limited WM capacity.

Second, the interest of differentiating text processing according to the text presentation modality was confirmed: the two separate, but correlated, factors indicated that text processing is characterized by specific and related factors, which depend on the constraints on the level of processing capacity when retrieval of information from memory is requested.

In the subsequent models, we, therefore, considered TP and TA as separate but related variables to distinguish between the differential effects of age and the cognitive resources.

Third, SEM results indicated that the contribution of inhibition and speed of processing to both text processing conditions is indirect and mediated through WM. Age differences in both conditions were determined directly by one source of variation, WM, which accounted for most of the age-related variance in text comprehension latent variables (see Figure 2). A larger WM capacity reflects the availability of more attentional resources for processing text, independent of the presence of the text during the response phase (Caplan & Waters, 1999; Daneman & Merikle, 1996). This result confirms the role of WM in explaining age differ-

ences in text comprehension when lower levels of comprehension processing are assessed (Radvansky & Dijkstra, 2007).

In line with other studies (de Ribaupierre, 2001; Salthouse, 1996), WM itself was multidetermined by two independent sources of variation—inhibition and processing speed—at least with regard to age differences. However, although it was possible to define a latent variable for inhibition (but see Park et al., 1996; Salthouse & Meinz, 1995; Stine-Morrow et al., 2008), the reliability of measures was low, and it was almost wholly represented by intrusion errors rather than more classic measures (note, however, that all factor loadings were significantly different from zero).

Compared with the results of Van der Linden and colleagues (1999), a direct additional path between age and WM was not significant in our study (Model 2), even though the model was, overall, slightly better. It is worth mentioning that in the Van der Linden and colleagues study, the WM latent variable was constructed using a global score of the classic reading span test (Experiment 1 of Daneman & Carpenter, 1980) and an updating task score. In the reading span task we employed, participants had to retain the final word of the sentence but they also had (in contrast with the version used by Van der Linden et al. study) to process the meaning of the sentences; though the sentences were simple, this procedure may hinder the possibility of chunking the final words and confers no advantage to young strategic readers. The direct path between age and WM observed by Van der Linden and colleagues may, thus, be due to the version used, which might be to the advantage of strategic readers (i.e., young adults). Nevertheless, in line with Van der Linden and colleagues' results, and in contrast with those of Kwong-See and Ryan (1995)—who used composite scores for the measures of interest—the WM measures were found to be the main cognitive determinant of text processing.

Overall, the present results appear to be consistent with the hypothesis that age and individual differences in text comprehension performance can be attributed, at least partially, to inefficiencies in WM control mechanisms (e.g., Carretti et al., 2009). This confirms the assumption that the efficiency of inhibiting irrelevant information and the speed of processing information explain age differences in the amount of information that can be processed in view of a limited WM capacity (de Ribaupierre, 2001; Hasher et al., 2007; Park et al., 1996), affecting text processing only indirectly.

Because an extreme-group design was used, the best fitting model found was also run for young and older adults separately. The results yielded an acceptable solution only for the older sample. This may be due to the higher cognitive resources of the younger sample, which may have rendered some of the relationships tested nonsignificant. In particular, it appeared that the range of scores in the processing speed tasks was restricted in younger group. However, this is simply a hypothesis because no study has yet examined, using SEM, text comprehension mediators in young adults; there is, therefore, a need for a multivariate approach to validate mechanisms evoked in adult reading comprehension models. It could also be that the postulated relationship between the factors is unreliable and unstable because of the large number of parameters estimated relative to sample size. It would, therefore, be of interest to carry out an adult life-span study, to clarify the age differences in reading comprehension and the general factors involved.

Our study is somewhat limited, in that it uses only two indicators to define the WM and processing speed latent variables. Our conclusions would benefit from future studies using more measures to define these latent variables, to verify their role and generality; included here should be measures of verbal abilities that determine their potential compensatory role in explaining age-related differences in text processing (Kemper & Sumner, 2001).

While the present study casts light on the often-hypothesized relationships between basic cognitive mechanisms and text comprehension to account for age differences between young and older adults, a further factor to consider is whether such relationships explain text processing also when considering the highest level of representation: situation model processing, the creation of which is the primary goal of comprehension. A more refined analysis of the role of such mechanisms in explaining reading comprehension in a variety of tasks and comprehension requests would be of great interest and should be addressed in future research.

To summarize, the results of the present study highlight the role of the retrieval condition in determining text comprehension performance when lower processing levels are examined because this is likely to generate larger age differences, and of considering WM, inhibition, and processing speed as interdependent factors in explaining text processing, especially when older adults are considered. Moreover, our consideration of the two components of text processing demonstrates that presenting text in a way that is similar to everyday reading can attenuate age-related differences.

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APPENDIX.

EXTRACT OF MATERIAL USED IN THE COMPREHENSION TASK (ALMOST LITERAL TRANSLATION FROM THE FRENCH)

TEXT

Leras, employee at the company Labuze and Cie, worked all day in the back of the shop that was opposite a backyard, as narrow and deep as a bottomless pit. The room was very dark, damp and cold. So damp and dark that it was hard for the ink to dry. Every morning he arrived at 7 am in this prison. He worked till 7 pm, bent over his book, writing with a pen that everyone envied. When he got out of the shop, with his case in his hand, he was sometimes blinded by the sunset. He put down the case to do up his mac. He then went slowly home. He walked like an automaton, without paying attention to people he met. He was thinking about the monotony of his life. The voice of the newsagent woke him from his melancholic daydream. "You've forgotten it again," she shouted. Leras made a quick half-turn.

DETAIL QUESTION

At what time does Leras arrive at work? At 7 am*

INFERENCE QUESTION

What does Leras forget at the end of the story? His case.

*If participants answered, "In the morning," 0.5 point was attributed.

Appendix Table 1. Descriptive Statistics and Analysis of Variance (ANOVA) Results on Group Differences Between Young and Older Adults, and Reliability Estimates on the Measures of Interest

| | Young, *M* (*SD*) | Older, *M* (*SD*) | Group comparison | | Reliability |
			Effect size, Cohen's *d*	ANOVA *F*(1, 189)	
Background					
Education	14.54 (1.33)	13.91 (2.99)	0.27	3.34	
Vocabulary, Mill-Hill	36.00 (3.73)	39.42 (3.46)	0.95	43.12***	.67
Nelson–Denny	19.04 (2.76)	18.20 (2.89)	0.30	4.29*	.54
Text processing, text present					
Detail, correct answers	0.93 (0.09)	0.90 (0.13)	0.26	3.33	.51
Inference, correct answers	0.77 (0.13)	0.72 (0.16)	0.34	6.02*	.56
Text processing, text absent					
Detail, correct answers	0.85 (0.13)	0.76 (0.16)	0.61	17.33***	.56
Inference, correct answers	0.75 (0.15)	0.63 (0.18)	0.72	23.42***	.65
Working memory					
Reading span	2.97 (0.36)	2.57 (0.47)	0.95	42.52***	.89
Matrices	2.53 (0.54)	2.01 (0.43)	1.07	56.07***	.89
Inhibition					
Stroop color interference[a]	0.21 (0.12)	0.22 (0.11)	0.09	0.36	.38
Stroop color NP[a]	0.02 (0.07)	0.02 (0.07)	0.00	0.17	.30
Hayling[a]	0.97 (0.10)	1.11 (0.40)	0.47	4.38*	.08
Df, index	0.26 (0.51)	0.43 (0.91)	0.23	2.29	.51
Intr. Df, TBF-F-FO	0.09 (0.27)	0.38 (0.53)	0.68	22.57***	.50
Intr. Df, TBR-F-RO	0.11 (0.24)	0.35 (0.55)	0.55	14.92***	.50
Intr. Rspan	0.04 (0.04)	0.07 (0.07)	0.52	14.84***	.50
Processing speed					
Pattern comparison	44.89 (10.43)	126.58 (38.55)	2.81	375.32***	.95
Letter comparison	54.15 (17.22)	151.47 (41.45)	2.99	426.14***	.95

Note: Df = directed forgetting test; Intr. TBR-F-RO = items to be remembered (TBR) that are incorrectly recalled (F) in remember-only (RO) condition; Intr. TBF-F-FO = items to be forgotten (TBF) that are incorrectly recalled (F) in forgetting-only (FO) condition; Intr. Rspan = intrusion errors in the reading span test.

[a] Index calculated on the basis of response times as follows: [(RT experimental condition − RT control condition)/RT control condition]. Reliability estimates were obtained by calculating either the true-to-total variance ratio (for the four text processing, matrices, and Df variables) or the odd–even split-half correlation (all other variables).

*$p < .05$; ***$p < .001$.