Cognitive Mediators of Age-Related Differences in Language Comprehension and Verbal Memory Performance

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ABSTRACT

The present study tried to specify how much processing speed, working memory capacity, and inhibition capability contribute to the effects of aging on language performance. An individual-differences approach was used to examine the component processes that predict performance in language comprehension and verbal long-term memory tasks. A total of 151 participants aged 31-80 completed language processing tasks and a battery of tasks designed to assess processing speed, working memory, and resistance to interference. Latent-construct structural equation modeling was used to examine the relationships of these factors and age to different types of language tasks. The best fit model showed first that all the significant relationships between age and language performance are mediated through reductions in speed, resistance to interference, and working memory; this confirms the validity of the general factor approach of age-related differences in cognitive performance. The best fit model, however, also showed that the contribution of speed and resistance to interference is indirect and mediated by working memory, which appears to play a crucial role in explaining age-related differences in language performance.

In the last decade, a number of interpretations have been proposed for age-related differences in cognitive functioning. According to analytical approaches, these changes can be explained in terms of the efficiency of task-specific structural or processing components. In contrast, global approaches suggest that they can be attributed to age-related differences in a few general factors.

Currently, the global approach dominates the cognitive aging literature. A large part of the recent research tries to identify age differences in some of these general factors and specify the contribution of these differences in various aspects of cognition. In recent years, several such general factors or mechanisms have received much attention: a decline in the speed of processing, a decline in working memory capability, and a decline in inhibitory efficiency. First, the processing speed hypothesis states that a reduction in the speed with which cognitive operations can be executed strongly contributes to age-related differences observed with many measures of cognition (Birren & Fisher, 1995; Salthouse, 1996). Second, the working memory hypothesis postulates that age-related cognitive deficits are due to a reduction in the amount of...
cognitive resources that are needed for temporarily storing new information while simultaneously performing mental operations on incoming or recently accessed information (Baddeley, 1986). Third, the inhibition hypothesis proposes that age-related differences in cognitive function occur because older adults have a deficit in those inhibitory attentional mechanisms which ordinarily prevent irrelevant information from gaining access to working memory (Hasher & Zacks, 1988; Zacks & Hasher, 1994). Finally, some recent works clearly identify a strong age-based relationship between sensorimotor functioning (vision, hearing, and balance/gait) and cognitive performance (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994). According to Baltes and Lindenberger (1997), this connection between the sensory and cognitive domains might be the outcome of a fourth common (global) factor, namely, the integrity of brain structure and functions (the “common cause” hypothesis).

In the language domain, numerous studies in the last decade were specifically aimed at relating differences in the efficiency of one or several of these general mechanisms to the wide range of age differences that have been identified (for reviews, see Hupet & Nef, 1994; Kemper, 1992; Light, 1990; Stine, 1995).

In most models of language processing, working memory represents “the critical bottleneck in which signals are decoded, concepts are activated, linguistic constituents are parsed, thematic roles are assigned and coherence among text-based ideas is sought” (Stine, Cheung, & Henderson, 1995, p. 1). It is therefore not surprising that adult age differences in language performance are often attributed to declines in the efficiency of this basic processing component. Older adults do show significantly poorer working memory (e.g., Van der Linden, Beerten, & Pesenti, 1998; Van der Linden, Brédart, & Beerten, 1994), and there is much evidence that age-related variance in many verbal tasks is largely mediated by working memory differences. Actually, various studies have found older adults to have smaller spans, and span measures correlate with both language comprehension and language production (see, e.g., Norman, Kemper, Kynette, Cheung, & Anagnostopulos, 1991; Stine & Wingfield, 1990; Tun, Wingfield, & Stine, 1991).

Similarly, since in all models of language processing the operations involved in the construction of a discourse representation are assumed to be time-consuming, age-related slowing may also account for age differences in language performance. The slowing hypothesis has much support in the literature. For example, memory for text and inference generation in older adults are specifically impaired by fast presentation (Cohen, 1979; Tun, Wingfield, Stine, & Mechsas, 1992; Wingfield, Poon, Lombardi, & Lowe, 1985). A study by Hartley, Stojacj, Mushaney, Kiku Annon, and Lee (1994) further showed that the minimum amount of time required to read a proposition in the context of a sentence is significantly longer for older than for younger adults. Detailed analyses of reading times also indicate that older adults need more time to integrate ideas which are conveyed by sentences that have a higher propositional density (Stine & Hindman, 1994). In another study by Stine et al. (1995), older adults who showed high levels of text recall were found to pause more frequently than young adults to organize new information during reading. It is worth noting that these findings are also consistent with a working memory explanation.

The inhibition deficit is supposed to limit both the ability of older participants to prevent irrelevant information from entering working memory during the processing of target information and their ability to deactivate contextually related but less relevant information, or information that is no longer relevant. Both types of failure are thought to impair comprehension processes if activation of off-goal information is sustained during the construction of a coherent text-based representation. Findings from various studies by Hasher, Zacks, and coworkers support this explanation (for a review, see Zacks & Hasher, 1994). However, in a recent critical assessment of the inhibition deficit theory as applied to language processing, Burke (1997) pointed out that many other inconsistent data have been reported and that alternative explanations can also be proposed in any cases in which...
data seem to support the inhibition view (for a reply, see Zacks & Hasher, 1997).

In the long-term verbal memory domain, a contribution of the same three general factors has also been postulated to account for the age-related differences on explicit (or direct) measures of episodic memory. More specifically, it has been frequently suggested that age differences in episodic memory are due to a limitation of processing speed and/or working memory capacity (for reviews, see Craik, Morris, & Gick, 1990; Salthouse, 1992). As a consequence of this limitation, older participants would carry out memory operations less efficiently or would select less effective encoding and/or retrieval strategies. In this perspective, it appears that various measures of processing speed do account for sizable amounts of age-related variance in memory performance. For instance, Hultsch, Hertzog, and Dixon (1990) showed that age-related differences in text and word recall can be substantially accounted for by individual differences in both verbal speed and working memory. In a subsequent longitudinal study, Hultsch, Hertzog, Small, McDonald-Miszczak, and Dixon (1992) observed age-related declines (over the 3-year interval of the study) in working memory, processing speed, verbal fluency and world knowledge, but not in word and text recall. Interestingly, they also found that the age-related differences observed in working memory (as well as in semantic abilities) remained even after statistical control of processing time variables. Likewise, Dunlosky and Salthouse (1996) found that slower processing speed mediates a substantial proportion of the age-related decline in multitrial free recall. However, 25% of the age-related variance was not accounted for by their measure of processing speed; therefore, other factors are required to fully account for age-related differences in verbal list learning. By means of regression analyses, Bryan and Luszcz (1996) also confirmed that speed of information processing mediates the relationship between age and free recall, but also observed that this relationship is itself mediated by working memory.

In conclusion, evidence suggests that processing speed, working memory, and inhibition capability play a role in the effects of aging on language and long-term verbal memory functioning, but there is much debate as to which hypothesis best accounts for age differences in language and memory performance. Most researchers, however, agree that these three indexes of processing efficiency are interdependent. Therefore, the current debate addresses the question of how much each factor contributes to aging effects.

Within the language domain, a recent study by Kwong See and Ryan (1995) clearly illustrates this debate. Their study aimed at: (a) determining whether measures of working memory and inhibition would still significantly correlate with language performance when age differences in speed of processing are controlled; and (b) determining whether the age-related variance mediated by working memory capability and by inhibitory efficiency is unique or shared. In their study, young (M = 20 years) and old (M = 68 years) adults completed language processing tasks (reading comprehension, sentence recognition, text recall), and measures of working memory capacity (backward span and N-back lag task), inhibitory efficiency (Stroop interference), and processing speed (color naming). Regression analyses revealed that each of these measures significantly predicted language per-
formance and attenuated variance in language performance that would otherwise be attributed to age. When speed was entered first into the equation, the mediating influence of the inhibition and working memory measures remained significant. However, when speed and inhibition differences were controlled, the working memory measures no longer predicted language performance. According to Kwong See and Ryan, these results bring into question the theoretical uniqueness of the working memory hypothesis as an explanatory principle; they suggest, rather, that previous evidence for this hypothesis may have been a by-product of the fact that working memory capacity measures are sensitive to age differences in processing speed and inhibitory efficiency.

However, such a strong conclusion may be premature. So many studies support the idea that working memory mediates age-related variance in various verbal tasks that we cannot avoid questioning a conclusion which seems to deny the existence of any specific role of the working memory capability in age-related effects on language performance. Actually, several methodological aspects of the Kwong See and Ryan (1995) study might be evoked to qualify such a strong conclusion. First, Kwong See and Ryan only compared two extreme age groups and it is somewhat surprising to note that age 55 was old enough to be included in the old age group, particularly if one takes into account that the incidence of significant decrement for verbal abilities is quite limited until age 60 (Schaie, 1990). On the other hand, Kwong See and Ryan’s reliance on hierarchical regressions did not permit them to consider direct relationships between mediating factors. Furthermore, the influence of the two working memory measures on the composite language performance score was tested separately; Kwong See and Ryan did not attempt to construct a single working memory factor. Another point concerns the verbal tasks they used to assess language performance. Actually, their “language” construct is clearly limited to reading comprehension, and the tasks they used emphasize immediate comprehension rather than delayed memory for what was comprehended. Differences of this type between language processing tasks, along with differences in the complexity of the verbal material to be processed in both types of task, might affect the extent to which working memory accounts for age variance.

Other recent studies suggest that the relative contributions of processing speed, working memory, and inhibition actually depend on the type of cognitive task or the type of information to be remembered. For example, Mayr and Kliegl (1993) and Kliegl, Mayr, and Krampe (1994) propose a two-factor model of age differences that includes speed (which is associated with sequential processing complexity) and working memory (which is associated with coordinative processing complexity). More recently, Park et al. (1996) confirmed that speed is a central construct in explaining age-related variance in different types of memory performance. In addition, they found that working memory helped to explain variance in some memory tests (especially verbal free and cued recall) but not in others (such as spatial memory). More generally, Park et al.’s findings suggest that the contribution of working memory increases as memory becomes more effortful (see also Whiting & Smith, 1997, for similar conclusions). In addition to working memory and speed measures, the authors also collected measures of the inhibitory function; unfortunately, none of these measures could be included in the models because they were not reliable and did not correlate with any other measures in the study. Finally, Kirasic, Allen, Dobson, and Binder (1996) found that working memory was a more important mediating factor than processing speed in declarative learning when assessed by means of tasks that resemble those in daily learning situations (such as learning a menu, a round-trip bus schedule, or a spatial arrangement). More specifically, with this set of memory tasks they showed that the contribution of processing speed was small and mediated by working memory capacity.

In conclusion, it appears that these various studies lead to divergent or even contradictory conclusions, especially regarding the contribution of working memory. As suggested by Park
et al. (1996), this is probably because the extent to which different general factors (especially speed and working memory) contribute to cognitive performance is likely to be determined by the specific demands of the task under investigation.

In this context, it is particularly interesting to reexamine how the three general factors (processing speed, working memory, and inhibition) contribute to performance on a subset of tasks. The purpose of the present study is to examine the extent to which the three factors mediate age-related differences on language comprehension and verbal memory by using the latent-construct, structural equation modeling technique. This technique appears to be particularly adequate to assess, within a single study, the relative contribution of different factors to performance in a particular domain. This study constitutes the first attempt to simultaneously investigate the three factors by means of structural equation modeling.

METHOD

Participants
One hundred and fifty-one community dwelling adults spanning five age categories (from 30 to 80 years) volunteered to participate in the study. Table 1 summarizes their characteristics by age group.

All participants were native speakers of French with a high level of education (twelve years or more, except two participants who had nine years of education and four participants who had eleven years of education). The older participants were highly active in the Louvain-la-Neuve Senior Citizen University. They did not check any items on a medical screening questionnaire designed to detect neurological conditions, sensory defects, and use of medications susceptible to alter cognitive functioning (a French translation of the questionnaire published by Christensen, Moye, Armson, and Kern, 1992). In addition, to be eligible for the study participants had to pass a visual and auditory acuity test and obtain a score superior to the cutoff score established by Schmidt et al. (1994) as indicative of cognitive dysfunctioning. The participants aged 50 to 80 were also administered the Mattis Dementia Rating Scale (Coblentz et al., 1973), which is widely used to screen for dementia.

Finally, to assess crystallized verbal ability, each participant was administered the Mill-Hill Vocabulary Scale (multiple-choice form; a French language adaptation by Deltour, 1993). An analysis of variance (ANOVA) computed on the number of correct responses out of 44 revealed a significant age effect, $F(4, 146) = 3.57, p < .01$. The post hoc analysis (Newman-Keuls tests, $p < .05$) only showed a significant increase of performance between the 30–39 and 60–69 age groups.

Procedure
The present study was part of a broader research program about the effects of aging on different aspects of cognition: language, verbal memory, mental imagery, face recognition, and calculation. On the whole, participants were administered 17 tasks. They were tested individually in three 2-hr sessions on separate days. Each participant completed all the testing within one month. Most tasks were presented on a microcomputer. The order of tasks, as well as testing sessions, was constant across participants. The order was chosen to prevent the presentation of consecutive tasks of the

Table 1. Participant Characteristics by Age Group.

<table>
<thead>
<tr>
<th>Age group</th>
<th>n$^a$</th>
<th>Age (years)</th>
<th>Years of education</th>
<th>Mill-Hill (total correct out of 44)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30–39</td>
<td>30</td>
<td>33.30 (2.53)</td>
<td>16.57 (2.78)</td>
<td>28.90 (2.75)</td>
</tr>
<tr>
<td>40–49</td>
<td>30</td>
<td>44.63 (2.44)</td>
<td>16.17 (3.54)</td>
<td>29.80 (2.67)</td>
</tr>
<tr>
<td>50–59</td>
<td>30</td>
<td>55.23 (2.70)</td>
<td>15.60 (2.90)</td>
<td>30.33 (3.01)</td>
</tr>
<tr>
<td>60–69</td>
<td>31</td>
<td>64.03 (2.55)</td>
<td>14.29 (2.34)</td>
<td>31.19 (1.25)</td>
</tr>
<tr>
<td>70–80</td>
<td>30</td>
<td>72.87 (2.91)</td>
<td>14.97 (3.61)</td>
<td>30.23 (2.16)</td>
</tr>
</tbody>
</table>

$^a$ In each age group there were 15 males and 15 females, except in the 60-69 group in which there were 16 females.
same domain while considering motivational factors, especially by alternating difficult and easy tasks within each session.

While some tasks were used to obtain measures of the three general factors (predictor variables), others provided measures of cognitive functioning. In the present study, we will exclusively examine the contribution of the three general factors on four language and verbal memory tasks.

Measures of General Factors
Three potentially important predictors were considered: working memory, sensitivity to interference (or lack of inhibition), and processing speed. Two measures were collected for each predictor. Except for the reading span task (see below), all the tasks designed to measure these predictors were presented via microcomputers.

Working memory
Working memory was measured by means of a reading span task and a working memory updating task. The reading span test is the most widely used measure of working memory in the study of cognitive aging (for recent examples, see Kirasic et al., 1996; Park et al., 1996). The task was originally designed by Daneman and Carpenter (1980) to assess working memory capability for verbal information. It requires the participants to read aloud a set of unrelated sentences and simultaneously memorize the final word of each sentence; the variable of interest is the number of final words the participant is able to recall. The updating task resembles the lag task of Kwong See and Ryan (1995). Participants are presented with strings of consonants of unpredictable length and prior to each string they are informed that they will have to recall a given number of consonants; this task requires maintaining considerable flexibility in information processing and shifting attention constantly (i.e., discarding some items while new ones are recorded). Morris and Jones (1990) showed that this task actually taps two independent working memory mechanisms. The updating process requires resources of the central executive, whereas the serial recall component involves the phonological loop. Recently, we successfully used the updating task to show that central executive resources decrease with age (Van der Linden et al., 1994).

For the present study, we designed a French version of the reading span test that consisted of 60 unrelated sentences distributed into three sets of 20 sentences; each set was composed of five lists of 2 to 6 sentences (Desmette, Hupet, Schelstraete, & Van der Linden, 1995). As an example, the first list of the first set consisted of the two following sentences: (a) Elle se leva très lentement et dit à son ami qu’il était un ivrogne [She stood up very slowly and said to her friend that he was a drunkard]; and (b) Ils se dirigèrent vers le balcon de l’appartement pour admirer les toits de la ville [They went to the terrace of the apartment to admire the roofs of the city]. Having read aloud these two sentences, the participant had to recall the final word of each sentence, in this case ivrogne and ville. The sentences were displayed on white cards, one at a time and centered. Immediately after the participant read a sentence, the experimenter turned over the next card to present the next sentence so that the opportunity to rehearse between sentences was minimized. Whenever a series of question marks appeared on a card, the participant had to report the last word of each of the preceding sentences; the order of recall was free except that the participants were not allowed to begin with the last word of the last sentence. Each participant was presented the first list of the first set (i.e., two sentences). If the two final words were correctly recalled, the list of 3 sentences was presented, and so on, until the recall was incomplete or incorrect. When this happened, the procedure restarted with a second set of lists, and finally with a third set. Two measures of reading span can be obtained from this task. The traditional span score is the sentence list size (from 2 to 6) for which at least two of the three sets of final words can be recalled successfully by the participant; a second score simply is the total number of final words correctly recalled (out of the maximum number, 60). For the analyses reported in the present study we used this second score of reading span, which has the advantage of offering considerably more variability than the traditional one (see, e.g., Kirasic et al., 1996, p. 660).

In the updating task participants were presented with strings of 6, 8, 10, and 12 consonants at a rate of one item per second, and asked to recall serially the last six items; strict forward serial recall was required (i.e., participants had to report serial position 1 before 2, etc.) and participants were asked to guess any consonant they could not recall before making the next response. Before the task started, participants were warned that they would be presented with lists of 6, 8, 10, and 12 consonants and that these lists would be presented in a random order. However, they were not informed of the length of each list before presentation. The various lists were presented in a standard randomized order with the restriction that no more than two lists of the same length were presented successively. The first eight trials were used as practice trials.
and were not included in the analyses. Experimental trials comprised eight trials for each list length. No consonant was repeated in the same list and sequences sounding like words and abbreviations were avoided. The dependent measure was the total number of correct recalls for each serial position and for the lists of 8, 10, and 12 consonants, that is, the lists that require updating operations.

Interference
Capacity to inhibit irrelevant information is often measured through variants of the Stroop color-word task (e.g., Kwong See & Ryan, 1995; Park et al., 1996). More recently, a conceptual distinction was made between interference (i.e., the observed difference between the incongruent color condition and the control condition) and underlying mechanisms like lack of inhibition (Earles et al., 1997; Kieley & Hartley, 1997).

In the present study, participants were administered a version of the Stroop task similar to that used by Tipper, Bourque, Anderson, and Brehaut (1989). The task included three conditions:

1. Control (hereafter CC): The stimuli consisted of series of juxtaposed Xs (e.g., XXXX) printed in different colors.
2. Stroop (ST): The stimuli were color names printed in incongruent ink colors.
3. Ignored repetition (IR, or negative priming): the color of the print was the same as the printed color name in the previous trial.

The conditions involved three cards for the control and Stroop conditions and four cards for the ignored repetition condition. There were 24 stimuli on each card, arranged in four rows of 6. The cards were actually presented on a computer screen. The stimuli consisted of the words blue, yellow, red, and green (in French), as well as rows of Xs, printed in four colors.

The participants were told that they would have to name the color in which each stimulus was printed, going from the leftmost to the rightmost column and from top to bottom in each column. They were asked to do so as quickly and as accurately as possible. The participants were instructed to correct their errors, but because errors were very few they were not recorded. For each condition, the participants pressed the space bar to make each card appear and activate the stopwatch; after each trial, the participant was asked to stop the watch by pressing the space bar. Two practice cards (one card with XXXs and one card illustrating the two other conditions) were administered. After that, participants processed 10 experimental lists. A single presentation order was used for all participants: ST, IR, CC, IR, ST, CC, IR, CC, IR, ST.

The reason for including the ignored repetition condition in the present study was the observation that negative priming declines with age (Hasher, Stoltzfus, Zacks, & Rypma, 1991; McDowd & Oseas-Kreger, 1991), which was interpreted as an indication of an impaired inhibitory mechanism. Negative priming is the mean reading times (in s) of cards in the ignored repetition condition (IR) minus the mean naming time in the Stroop condition (ST). We found a significant negative priming effect ($M = 1341; SD = 1833; t$ test against zero $= 8.99; df = 150; p < .001$) but no correlation with age. $R^2 = .01$, $F(1, 149) < 1$. It should be noted that such an absence of age effect on negative priming has also recently been observed by Vakil, Manovitch, Ramati, and Blachstein (1996) with a similar Stroop color-word procedure. This finding was interpreted in terms of the unique characteristics of the Stroop color-word task by comparison with the other negative priming tasks in which an age effect was observed (see also Kieley & Hartley, 1997).

Accordingly, the negative priming measure was not included in the analysis. Only two measures of interference were used: the mean reading times (in s) of cards in the Stroop condition (ST) minus the mean naming time in the control condition (CC; a measure similar to that used by Kwong See & Ryan, 1995), and the mean reading times in the ignored repetition condition (IR) minus the mean naming time in the control condition (CC).

Processing speed
Two speed tasks were administered: a letter comparison task and a color naming task. The letter comparison task is the most commonly used measure of processing speed in the analysis of cognitive aging and naming speed was the variable considered by Kwong See and Ryan (1995) in their study.

The letter comparison task was a computerized version of the task initially proposed by Salthouse and Babcock (1991). Participants were presented with pairs of letters. Their task was to decide as rapidly and accurately as possible whether the letters were the same or different and press the appropriate key. The test comprised 60 trials, 30 same and 30 different pairs. The selected measure was the mean correct latency for same responses.

The color naming task corresponded to the control condition of the Stroop color-word task (see the interference tasks): Participants were simply asked to name the ink in which strings of XXXs were printed. The dependent measure was the mean naming time (in s).
Measures of Language Comprehension and Verbal Long-Term Memory

Four language comprehension and verbal memory tasks were administered: a text comprehension task, a sentence reading and recall task, a story recall task, and a word list free recall task. Experimenters were given detailed coding forms and trained to achieve consistent assessment of performance. All the tasks required a great amount of self-initiated processing. It should be stressed here that the present study was already in progress when Kwong See and Ryan (1995) published their work; our language tasks therefore were not meant to test their theoretical propositions. A regrettable consequence of this is that our language battery is also narrowly defined and limited to tasks mainly involving reading comprehension. The tasks we used are in many ways different from the ones used by Kwong See and Ryan, however, and will therefore allow an interesting comparison between the two studies.

Text comprehension

The participants were presented with seven short expository texts similar to those used by Gernsbacher (1990) and Hamm and Hasher (1992). Each text had from 21 to 24 printed lines and a mean total length of about 160 words (see the Appendix for an example). Participants were instructed to read them carefully in order to be able to answer questions in a forthcoming test. The texts were presented on a computer screen one line at a time in a serial cumulative way allowing the simultaneous display of four lines maximum (i.e., when the fifth line of a text appeared on the screen, the first one disappeared and could not be recalled). The presentation duration of each successive line was the same for all the participants and depended on the length of the line (duration = constant of 1000 ms + 55 ms per character; cf. Experiment 4 of Gernsbacher, Varner, & Faust, 1990). It was chosen to impose a relatively fast reading (150 words per minute) and prevent a full rereading of preceding lines.

Following each text, four questions relating to its content were displayed on the screen. Two of the questions were simple ones requiring reproduction of the presented facts (though not necessarily verbatim). The other two questions were more complex and required inference drawn from the presented facts or anaphora resolution. The participant had to answer the four questions within 80 s. Each answer was scored 0 (no answer or erroneous answer), 1 (partially correct) or 2 (fully correct), and the measure of performance for this task was the total score obtained by each participant.

Sentence reading and recall

To assess reading performance and immediate memory for single sentences, we used a task adapted from Stine and Hindman (1994) in which younger and older adults read and immediately recalled a set of sentences. As Stine and Hindman pointed out, although such a task seems somewhat removed from spontaneous language processing, it arguably taps a fundamental component of discourse understanding (see also Jarvella, 1971).

Eighteen experimental sentences were created. They varied from 22 to 24 words in length, and had five to ten propositions (e.g., The fireman that the mayor had congratulated in front of everybody had rushed into the house which was in flames; The friends that we met last Saturday night at the end of the movie will go on holiday in Greece with their three oldest children). Five filler sentences were also added: They were shorter (12–14 words) and simpler than the experimental sentences, and were meant to encourage the participants. In addition, four practice sentences of various propositional density were presented.

The sentences were presented individually on a microcomputer. Reading was self-paced. Participants were asked to read each sentence carefully and immediately recall it aloud; their recall was taped for later transcription. Because we hoped to remain as close as possible to natural reading, we explicitly told participants not to study the sentences or try to memorize them verbatim. Each participant’s protocol was scored using a gist criterion (Turner & Greene, 1978). The measure of performance was the total number of propositions recalled.

Story recall

Participants were visually presented with a story adapted from Boccacio’s tales and asked to read it carefully because they would be asked to remember it later (Desmette, 1997). The story was 350 words in length and composed of 98 idea units (content units or propositions and interpropositional relationships, see Glosser & Deser, 1992) distributed over seven paragraphs varying from three to nine printed lines each. Due to the large number of different characters intervening in several episodes and many jumps backwards, this story was a rather complex one. It was presented on a computer screen one paragraph at a time, reading was self-paced, and the participants were allowed a second reading of the whole story in the same conditions before recall. After the second presentation the participants were asked to recall whatever they could remember from the story, either verbatim or in their own words. Recall was
oral and taped for later transcription. For each participant we computed the total number of idea units correctly recalled.

Verbal free recall
The California Verbal Learning Test (CVLT; Delis, Freeland, Kramer, & Kaplan, 1988; Delis, Kramer, Kaplan, & Ober, 1987; French adaptation by Deweer et al., 1997) was used to measure episodic memory performance. The CVLT consists of five learning trials of a 16-word “shopping” list comprising 4 words from 4 different semantic categories (fruits, spices, clothing, and tools). The list was read aloud by the examiner at the rate of one word per second. The items on the list were presented in the same order on all five of the trials. Participants were asked to recall all the items they could in any order they pleased, including those reported on previous trials. The total number of words recalled for the five learning trials was the only dependent measure actually used in the present study. However, it should be noted that participants were presented with the complete version of the CVLT which includes the presentation of an interference list of words after the five learning trials.

RESULTS

Age and Task Performance
Participants’ performance in the various tasks is reported in Table 2, which also presents the results of the regression analyses for each measure using age as predictor. In these analyses as throughout in this section, age was treated as a continuous independent variable. All dependent variables had significant linear relationship with age. Correlations with squared age were also computed, and no nonlinear effects were found in the sample.

Table 2 also presents the Cronbach estimates of measurement reliability for all of the measures. For the letter comparison measure of processing speed, we provide the reliability estimate collected by Salthouse and Babcock (1991). As Table 2 shows, all reliabilities were very good, equal to, or higher than reliability estimates for the same tasks in previous research (Graf & Uttl, 1995; Park et al., 1996, p. 626; see also Spreen & Strauss, 1991). More important, all of our measures met the general level of reliability that is recommended for structural equation modeling (Cohen, Cohen, Teresi, Marchi, & Velez, 1990).

Table 3 presents the correlations of variables used in the measurement and structural models. It also includes means and standard deviations for the variables.

Table 3 shows that (a) each variable was significantly correlated with age; and (b) a relatively high positive correlation was obtained between the two measures of speed, as well as between the two measures of working memory, the two measures of interference, and the four measures of language functioning.

Measurement and Structural Equation Models
The first step towards specifying and evaluating a structural model for determinants of language comprehension and verbal memory performance consists of establishing a measurement model which represents the correlated factors indexed by their observed variables (Anderson & Gerbing, 1988; James, Mulaik, & Brett, 1982). The initial measurement model based on the various constructs (speed, working memory, interference, language, and verbal memory) is presented in Figure 1. All the standardized path coefficients presented in Figure 1 are significant at $\alpha = .001$.

The correlations among age and the latent constructs are also significant at $\alpha = .001$ and presented in Table 4. Furthermore, we estimated the measurement error variances of the four factors, whereas error covariances among all indicators were fixed at zero.

Assuming that the observed variables accurately reflect the theoretical constructs of interest, the second step consisted of testing theoretical causal relationships specified between the factors, including those that are indirect or mediated as well as those that are direct. Figure 2 is a path diagram illustrating the relations among the factors of this study.

All measurement and structural modeling was done using the SAS CALIS Procedure (Version 6.09; Hartmann, 1990). The generalized least squares method was used to estimate the parameters in the presented models (factor loadings,
Table 2. Descriptive Statistics for the Indicators of Working Memory, Processing Speed, Resistance to Interference, and Language and Verbal Memory Performance in the Different Age Groups; and Results of the Linear Regression Analyses with Age as Predictor ($R^2$, $F$ values) and Reliability Estimates.

<table>
<thead>
<tr>
<th>Age group</th>
<th>30–39</th>
<th>40–49</th>
<th>50–59</th>
<th>60–69</th>
<th>70–80</th>
<th>$R^2$</th>
<th>$F(1, 149)$</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working Memory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Updating</td>
<td>$M$</td>
<td>89.6</td>
<td>79.7</td>
<td>74.3</td>
<td>65.6</td>
<td>57.0</td>
<td>0.22</td>
<td>40.25</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(21.3)</td>
<td>(22.7)</td>
<td>(24.7)</td>
<td>(20.0)</td>
<td>(19.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading span</td>
<td>$M$</td>
<td>31.63</td>
<td>28.57</td>
<td>28.40</td>
<td>26.32</td>
<td>21.27</td>
<td>0.12</td>
<td>19.41</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(12.28)</td>
<td>(8.51)</td>
<td>(8.83)</td>
<td>(8.02)</td>
<td>(9.32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Processing speed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Letter comparison</td>
<td>$M$</td>
<td>591</td>
<td>648</td>
<td>672</td>
<td>693</td>
<td>779</td>
<td>0.24</td>
<td>45.86</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(76.3)</td>
<td>(81.7)</td>
<td>(70.1)</td>
<td>(100.2)</td>
<td>(165.0)</td>
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</tr>
<tr>
<td>Color naming</td>
<td>$M$</td>
<td>15275</td>
<td>16672</td>
<td>16692</td>
<td>18069</td>
<td>18965</td>
<td>0.15</td>
<td>26.71</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(3089)</td>
<td>(2770)</td>
<td>(3090)</td>
<td>(2843)</td>
<td>(2785)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interference</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST-CC</td>
<td>$M$</td>
<td>6788</td>
<td>6551</td>
<td>8265</td>
<td>8741</td>
<td>10253</td>
<td>0.15</td>
<td>26.28</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(2446)</td>
<td>(2389)</td>
<td>(3558)</td>
<td>(4043)</td>
<td>(3697)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR-CC</td>
<td>$M$</td>
<td>7686</td>
<td>8348</td>
<td>9488</td>
<td>10465</td>
<td>11304</td>
<td>0.13</td>
<td>22.24</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(2925)</td>
<td>(3139)</td>
<td>(3775)</td>
<td>(4576)</td>
<td>(4116)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Language and verbal memory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CVLT</td>
<td>$M$</td>
<td>69.40</td>
<td>67.47</td>
<td>64.67</td>
<td>61.90</td>
<td>56.13</td>
<td>0.23</td>
<td>43.46</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(4.56)</td>
<td>(6.55)</td>
<td>(9.46)</td>
<td>(7.01)</td>
<td>(11.15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentence recall</td>
<td>$M$</td>
<td>90.59</td>
<td>86.37</td>
<td>83.41</td>
<td>81.14</td>
<td>74.63</td>
<td>0.19</td>
<td>35.81</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(8.13)</td>
<td>(10.96)</td>
<td>(11.72)</td>
<td>(10.65)</td>
<td>(12.63)</td>
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<td></td>
</tr>
<tr>
<td>Story recall</td>
<td>$M$</td>
<td>43.77</td>
<td>40.77</td>
<td>38.58</td>
<td>36.47</td>
<td>29.53</td>
<td>0.26</td>
<td>51.30</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(5.86)</td>
<td>(5.95)</td>
<td>(6.69)</td>
<td>(6.70)</td>
<td>(8.92)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Text comprehension</td>
<td>$M$</td>
<td>37.20</td>
<td>34.03</td>
<td>28.67</td>
<td>23.32</td>
<td>22.47</td>
<td>0.30</td>
<td>62.97</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(6.94)</td>
<td>(8.69)</td>
<td>(9.39)</td>
<td>(9.33)</td>
<td>(10.09)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Means, Standard Deviations, and Intercorrelations among Indicator Variables.

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
<th>10.</th>
<th>11.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Updating</td>
<td>-0.461</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. Reading span</td>
<td>-0.339</td>
<td>0.307</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Color naming time</td>
<td>0.390</td>
<td>-0.286</td>
<td>-0.184</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Letter comparison time</td>
<td>0.485</td>
<td>-0.354</td>
<td>-0.190</td>
<td>0.484</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Stroop minus control</td>
<td>0.387</td>
<td>-0.343</td>
<td>0.203</td>
<td>0.243</td>
<td>0.195</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Ignored repetition minus control</td>
<td>0.360</td>
<td>-0.354</td>
<td>0.230</td>
<td>0.320</td>
<td>0.230</td>
<td>0.885</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. California Verbal Learning Test</td>
<td>-0.475</td>
<td>0.289</td>
<td>0.294</td>
<td>-0.313</td>
<td>-0.235</td>
<td>-0.339</td>
<td>-0.285</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Sentence recall</td>
<td>-0.440</td>
<td>0.330</td>
<td>0.420</td>
<td>-0.196</td>
<td>-0.232</td>
<td>-0.237</td>
<td>-0.215</td>
<td>0.436</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Story recall</td>
<td>-0.506</td>
<td>0.298</td>
<td>0.350</td>
<td>-0.270</td>
<td>-0.309</td>
<td>-0.269</td>
<td>-0.195</td>
<td>0.429</td>
<td>0.602</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>11. Text comprehension</td>
<td>-0.545</td>
<td>0.445</td>
<td>0.436</td>
<td>-0.310</td>
<td>-0.271</td>
<td>-0.311</td>
<td>-0.313</td>
<td>0.538</td>
<td>0.612</td>
<td>0.538</td>
<td>1.000</td>
</tr>
</tbody>
</table>

M
(SD)
54.0
(14.2)
73.2
(24.1)
27.2
(10.0)
17141
(3149)
676.7
(120.1)
8124
(3530)
9465
(3943)
63.9
(9.2)
83.2
(12.0)
37.8
(8.3)
29.1
(10.6)

Note. N = 151. Critical values : .19 (α = .05); .25 (α = .01); .32 (α = .001).
Fig. 1. A hypothesized measurement model that includes speed, working memory, interference, and language/verbal memory constructs with coefficients obtained from a confirmatory factor analysis. ST = Stroop; CC = control condition; IR = ignored repetition; CVLT = California Verbal Learning Test.
Table 4. Correlations Between Latent Constructs.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Speed</th>
<th>Interference</th>
<th>Working memory</th>
<th>Language and verbal memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td></td>
<td>.639</td>
<td>.390</td>
<td>−.732</td>
<td>−.700</td>
</tr>
<tr>
<td>Interference</td>
<td>.390</td>
<td>.337</td>
<td>.695</td>
<td>−.547</td>
<td>.337</td>
</tr>
<tr>
<td>Working memory</td>
<td>−.732</td>
<td>−.695</td>
<td>−.547</td>
<td>1.000</td>
<td>−.547</td>
</tr>
<tr>
<td>Language</td>
<td>−.700</td>
<td>−.597</td>
<td>−.406</td>
<td>.880</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note. All the correlations are significant at least at $\alpha = .001$.

parameters into account. AIC equals zero when the model is unconstrained and it decreases when simpler models are tested. The smaller (i.e., the more negative) the AIC is, the better the model. Finally, a null model $\chi^2$ was used to test for the presence of a covariance structure among the observed variables.

Several structural models (SMs) were tested (Figure 3). In an initial step we compared two models, respectively derived from Kwong See and Ryan (1995) and Park et al. (1996). Kwong See and Ryan suggested that age-related variations in language and memory are partially and independently mediated by speed and inhibition but when these factors are controlled, the contribution of age remains significant. Working memory does not intervene. We represent this view with the SM1 model. The second model (SM2), following Park et al., also assumes that speed explains a significant part of variance in verbal memory but that working memory also contributes to performance. In this model, no direct link exists between age and verbal memory performance and the interference factor was not considered. In a second step, we merged these two models and proposed an integrated view (SM3). This model assumes links between all the latent constructs. In the fourth model (SM4) the direct paths from speed and interference to language comprehension and memory were removed, suggesting that these factors intervene indirectly through the mediation of
working memory. Finally, in the SM5 model, we eliminated the direct path from age to language comprehension and memory performance, and thus the part of age-related variance that remained unexplained by the three factors of speed, interference, and working memory.

A summary of fit indexes for the models tested is presented in Table 5. The $\chi^2$ statistics for the null model provide a test of the hypothesis that the observed items are uncorrelated. As Table 5 shows, this independence hypothesis must be rejected. Furthermore, it appears that the measurement model produced an adequate fit to the data.

Keeping the same constructs (age, speed, working memory, interference, and language/verbal memory), we tested the adequacy of the structural equation models SM1 to SM5. The first one (SM1), which assumes that the working memory measures do not reliably predict language performance when speed and interference differences are controlled, did not provide a good fit to the data (see Table 5: CFI inferior to .90 and significant $\chi^2$ indicate discrepancy between observations and the model). Furthermore, the three causal parameters explaining the working memory scores through direct influence of age (path b), speed (path d), and resistance to interference (path e) were not statistically significant (Table 6). Thus, the overall fit of this model was relatively poor. In the second structural model (SM2) language/verbal memory measures are influenced by speed, both directly and indirectly through the mediation of working memory. There is no direct link between age and working memory nor between age and language/verbal memory performance. As Table 5 shows, this model also provided a poor fit to the data (CFI < .90).
Table 5. Summary of Measurement and Structural Model Fitting (N = 151 for all models).

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$</th>
<th>df</th>
<th>$p$</th>
<th>GFI</th>
<th>CFI</th>
<th>RMSEA</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null Measurement</td>
<td>177.637</td>
<td>55</td>
<td>&lt; .001</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SM1</td>
<td>52.475</td>
<td>37</td>
<td>.047</td>
<td>.936</td>
<td>.874</td>
<td>.053</td>
<td>-21.525</td>
</tr>
<tr>
<td>SM2</td>
<td>35.802</td>
<td>24</td>
<td>.057</td>
<td>.947</td>
<td>.823</td>
<td>.057</td>
<td>-12.198</td>
</tr>
<tr>
<td>SM3</td>
<td>44.869</td>
<td>36</td>
<td>.148</td>
<td>.946</td>
<td>.928</td>
<td>.041</td>
<td>-27.131</td>
</tr>
<tr>
<td>SM4</td>
<td>45.260</td>
<td>38</td>
<td>.195</td>
<td>.945</td>
<td>.941</td>
<td>.036</td>
<td>-30.740</td>
</tr>
</tbody>
</table>

Note. SM = structural model (see Figure 3); GFI = Goodness of Fit Index; CFI = Bentler’s Comparative Fit Index; RMSEA = Steiger’s root mean square error of approximation; AIC = Akaike’s Information Criterion.

Because neither of the two models derived from the literature was individually satisfactory, we tested an alternate model that integrated them by assuming theoretical links between all factors (see Figure 3, SM3). As Table 5 indicates, this general model provided an adequate global fit to the data. The fit was significantly better than that of SM1, $\Delta \chi^2(1) = 52.48 - 44.87 = 7.61, p < .01$, showing that the direct link from working memory to language comprehension/verbal memory significantly improved the model fit. However, the model lacked parsimony and it clearly appears that two causal paths were nonsignificant. The link between speed and language comprehension/verbal memory and the link between interference and language comprehension/verbal memory (see Figure 2 and Table 6) had coefficients less than twice their standard errors. These paths can therefore be deleted, $\Delta \chi^2(2) = 45.27 - 44.87 = 0.4, ns$, and the analysis can be repeated with a simplified model.

Consequently, a model was examined in which the links going from speed and interference to language comprehension/verbal memory were set to zero (see Figure 3, SM4). In other words, this cascade model postulates that the contribution of speed and interference on language comprehension/verbal memory is completely mediated by working memory. Indicators of fit showed that this more parsimonious model remained very satisfactory (see Table 5).

As Figure 3 shows, SM4 includes a direct link between age and language comprehension and memory. However, this link is nonsignificant and can be deleted without loss. A more economical SM5 (see Figure 3), without such a direct link, postulates that the effect of age on language comprehension and verbal memory is completely mediated by speed, resistance to interference, and working memory. Indicators of fit showed that this more parsimonious structural model remains highly satisfactory (Table 5) and does not differ significantly from the previous one, $\Delta \chi^2(1) = 46.17 - 45.26 = 0.91, ns$.

An intriguing aspect of this most satisfactory SM5 is the extremely high value of the link between working memory and language comprehension/verbal memory (standardized path coefficient = .906). Actually, it could be argued that the working memory construct completely overlaps with the language component as defined by the verbal tasks used in the present study. More specifically, such an overlap could be attributed to the fact that the reading span task is highly likely to require cognitive processes very similar to those involved in at least some of the verbal tasks used here. However, it should be noted that the simple correlations between the reading span score and the language and verbal memory measures are not very high (see Table 3). Nevertheless, we decided to clarify this point in various ways. First, we tested an additional SM6, which was exactly the same as SM5, except that the link between the constructs of working memory and language was set to 1. It appeared that the fit of this model was lower than that of SM5, $\Delta \chi^2(1) = 49.256 - 46.173 = 3.08, p = .08$. 
Table 6. Standardized Path Coefficients for Various Structural Models.

<table>
<thead>
<tr>
<th>Model</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM1</td>
<td>.703***</td>
<td>-.137 (ns)</td>
<td>.404***</td>
<td>-.733 (ns)</td>
<td>-.335 (ns)</td>
<td>-.494**</td>
<td>.000</td>
<td>-.179*</td>
<td>-.313*</td>
</tr>
<tr>
<td>SM2</td>
<td>.835</td>
<td>.000</td>
<td>.000</td>
<td>-.893</td>
<td>.000</td>
<td>-.165</td>
<td>.740</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>SM3</td>
<td>.641***</td>
<td>-.412**</td>
<td>.391***</td>
<td>-.340 (t)</td>
<td>-.286**</td>
<td>-.077 (ns)</td>
<td>.881 (t)</td>
<td>.094 (ns)</td>
<td>-.139 (ns)</td>
</tr>
<tr>
<td>SM4</td>
<td>.638***</td>
<td>-.416**</td>
<td>.389***</td>
<td>-.322*</td>
<td>-.252**</td>
<td>.000</td>
<td>.714**</td>
<td>.000</td>
<td>-.195 (ns)</td>
</tr>
<tr>
<td>SM5</td>
<td>.640***</td>
<td>-.512***</td>
<td>.393***</td>
<td>-.277*</td>
<td>-.212**</td>
<td>.000</td>
<td>.906**</td>
<td>.000</td>
<td>.000</td>
</tr>
</tbody>
</table>

*Note.* See Figure 3 illustrating the five structural models (SM1 to SM5).

*** significant at $\alpha = .001$. ** significant at $\alpha = .01$. * significant at $\alpha = .05$. $t$ significant at $\alpha = .10$.**
It should thus be concluded that the working memory measures and language/verbal memory measures did not constitute a unitary construct. In addition, we retested SM5 by indexing the working memory construct only by means of scores derived from the updating task, eliminating data from the reading span task. This model was tested in two conditions. In the first one, we used the measure of reliability of the global updating score (see Table 2) to fix the residual term of the working memory factor. In the second one, we used as indicators of working memory two measures of performance in the updating task, the number of correct recall when lists of 8 and 10 items were presented (these measures were selected on the basis of a factorial analysis which showed high loadings on the updating factor). In both cases, the fit of the revised SM5 was very poor, \( \chi^2(31) = 70.036, p < .001 \), GFI = .906, CFI = .698, RMSEA = .092 and \( \chi^2(39) = 70.675, p < .001 \), GFI = .914, CFI = .801, RMSEA = .074, respectively. Similarly, when the working memory latent construct was indexed only by the participants’ scores in the reading span test (with the reliability coefficient used to fix the residual term), the revised SM5 did not fit the data any more, \( \chi^2(31) = 52.606, p < .01 \), GFI = .930, CFI = .829, RMSEA = .068. These results suggest that the working memory construct has to be measured by both the reading span and the updating task to predict age-related changes in language and verbal memory performance.

Finally, because the unitary language and verbal memory factor is related more to verbal memory than to language comprehension, we attempted to construct two separate factors for language processing (indexed by sentence recall and text comprehension) and verbal memory (indexed by the CVLT and story recall). However, we found correlations near 1.00 between these factors and consequently did not assume that they represented independent aspects of performance.

DISCUSSION

The results of this study may be summarized as follows. First, the best fit model postulates that all significant relationships between age and measures of language comprehension/verbal memory are indirect and mediated through age-related reductions in speed, resistance to interference, and working memory; no direct links were kept. These findings indicate that the three general factors of cognitive functioning are useful constructs in explaining age-related differences in language comprehension and verbal long-term memory. More generally, they confirm the validity of the general factor approach of age-related differences in cognitive performance across a range of verbal tasks.

Furthermore, the specific set of tasks included in the present study clearly indicate that the contribution of speed and interference to language comprehension and verbal memory performance is indirect and mediated through working memory. With regard to the relationship between interference and working memory, our results are consistent with Zacks and Hasher’s (1994) view that the age-related decline in the ability to inhibit irrelevant information may result in an increase of the amount of irrelevant information in working memory, thus decreasing working memory efficiency. A general consequence of this view is that older adults have more dispersed interpretations and encoding of target material than do younger adults and also have difficulty focusing on target information at retrieval, which would partly explain their comprehension and memory problems. The findings are also consistent with the view that the speed of processing variable exerts part of its effect through working memory (Bryan & Luszcz, 1996; Park et al., 1996; Salthouse, 1992). However, in addition to the indirect contribution of age to working memory (via interference and speed), there was a direct and strong link between age and working memory. Thus, age-related differences in language memory and comprehension were explained by a reduction of the capacity of working memory, which was itself influenced by reduction of speed, increasing sensitivity to interference, and task-specific
age effects. This strong relationship between age, working memory, and verbal performance is similar to that observed in Kirasic et al.’s (1996) model, which describes the mediators of the age effects in declarative learning.

There may be some debate about our findings because of the apparent proximity of working memory and language tasks in the present study. On the one hand, the reading span task might be viewed as a language task and the story recall task as another memory task; on the other hand, if the reading span task is viewed as a verbal task, this is much less the case for the updating task. Whatever the surface dissimilarities between different tasks are, however, it must be admitted that they are not sufficient to demonstrate that these tasks measure different things. In the present study, because the models assuming that working memory and language tasks constitute a single factor had a relatively poor fit, we favored an interpretation in accordance with theoretical models of natural language processing that emphasize the role of working memory in information integration during discourse comprehension (Kintsch & Van Dijk, 1978; Light, 1990).

Our findings contradict Kwong See and Ryan’s (1995) final conclusion that working memory cannot be retained as a central explanatory principle accounting for older adults’ poorer performance in language tasks. Indeed, in Kwong See and Ryan’s study, which is exclusively based on hierarchical regression analyses contrasting young and old participants’ performances, the influence of working memory differences remained significant when speed was entered first into the regression equation. This indicated that the working memory measure was a significant predictor of language performance over and above its sensitivity to age differences in processing speed. However, after variability associated with speed and inhibition had been controlled, neither working memory measure significantly predicted language performances. In contrast, when speed and working memory were entered first, inhibition (measured by means of a Stroop interference task) remained a significant predictor and thus significantly mediated age variance in language performance.

It is worth noting that Kwong See and Ryan (1995) themselves declared that their conclusion might be somewhat too strong given the narrow assessment of the speed, inhibition, and working memory constructs. With regard to this latter construct, they suggested inter alia to examine the extent to which speed and inhibition are involved in various working memory tasks and then to reconsider studies that have used these measures to predict language performance. More generally, Kwong See and Ryan admitted that future research will need both to extend the range of predictor variables and to further sample the many facets of the language performance domain.

In this respect, a plausible interpretation of the discrepancy between their findings and ours is that the language and verbal memory tasks used in the two studies are of rather different types. They actually used three types of tasks: two sentence comprehension tasks, a discourse comprehension task, and a delayed text memory task. Sentence comprehension was tested for passive sentences (testing subject-object discrimination) and possessive ones (testing possessive relationships of reversible constructions); there was, however, little or no difference between the two age groups for these two measures (the possessive sentence measures had to be discarded), probably due to the fact that the memory and attentional load of these tasks were rather low. Discourse comprehension was tested for short narratives, the comprehension of which was indexed by a multiple-choice test after the reading of each story. However, each story remained in view and could be consulted in answering the questions, which undoubtedly reduced the memory and attentional demands of the task. Finally, delayed memory for text was assessed in a cued recall task and two recognition tasks. There was little or no age difference in recognition of true and false gist statements; in fact, important age differences only emerge from the two more demanding tasks: the cued recall task and the recognition task for statements which were consistent with the story presented but not actually stated. It is not unreasonable to assume that these two tasks were the only ones in which processing demands were
relatively high. On the other hand, comprehension tasks may vary along a continuum which contrasts immediate comprehension with delayed memory for what was comprehended. In this regard it can be argued that the language battery used by Kwong See and Ryan (1995) places greater emphasis on the former type of task. In contrast, the battery used in the present study not only required the participants to process verbal materials of a higher complexity, but emphasized the delayed memory component of comprehension. Taking these factors into account indicates that Kwong See and Ryan’s general conclusion about the irrelevance of working memory capability has to be qualified.

In Kwong See and Ryan’s (1995) study, it should be noted that after speed, inhibition, and working memory had been controlled, age still significantly predicted language performance. In contrast, in the present study, the best fit model does not involve any direct link between age and language/verbal memory performance. The data reported here are also inconsistent with the general model of Park et al. (1996) in which all age-related variance in general long-term memory ability (measured by means of the three types of memory tasks: free recall, cued recall, and spatial recall) is mediated by speed. Their model indeed predicts indirect effects of speed mediated by working memory (which is in agreement with our model), but also direct effects of speed (which is not in agreement with our model). Park et al. also suggested, however, that the contribution of working memory becomes more important to memory tasks (especially free recall) that are high in processing demands. Generally speaking, Kwong See and Ryan’s and Park et al.’s results, as well as the findings from Kirasic et al. (1996) and the present research, indicate that the extent to which different general factors contribute to cognitive performance depends on the type of cognitive task or the information to be processed. More specifically, working memory may be a particularly important mediator for tasks that require the elaboration in long-term memory of semantic representations integrating successive pieces of incoming information. The present results obtained by a cross-sectional analysis clearly need to be confirmed using other methods, namely longitudinal studies, in order to examine both individual trends and cohort effects (e.g., Hultsch et al., 1992). Whatever the discrepancies might be between the two types of approaches, it is worth noting that in their longitudinal study, Hultsch et al. (1992) also found a relationship between age and working memory which was not completely explained by processing speed differences. Similarly, in a more recent monograph, Hultsch, Dixon, Small, and Hertzog (1999) reported further longitudinal results much in line with our findings, showing that change in working memory drives changes in comprehension and memory and the influence of speed is mediated through changes in working memory.

To sum up, the present cross-sectional study showed that the working memory construct, as assessed by a composite measure that combines scores in a reading span task and an updating task, is a good predictor of performance in demanding verbal tasks. In the best fit model, speed and resistance to interference do not directly explain language comprehension and memory performance but these factors, along with age, influence working memory. These findings are neither trivial nor revolutionary. They are compatible with results of other studies but the model we proposed differs from suggestions made by other investigators. The use of structural equation modeling techniques elucidates the relative contributions of different factors predicting age-related differences in language performance. However, we do not think future research should compare various structural models combining different parameters in different ways. An agreement within the scientific community on the proper measurement of speed, inhibition, and working memory is more important, and such a measurement can only be validated by a thorough analysis of the underlying mechanisms.

There is convincing evidence that working memory is composed of distinct subsystems: a phonological loop, a visuospatial sketchpad, and a central executive which itself is a cluster of several control processes (Baddeley, 1996a, 1996b). Measures of working memory usually involve many of these components and this is
probably why they predict performance in complex tasks. This is particularly well illustrated in the present study, which showed that working memory constitutes a mediator of age effects when it is measured by both the updating and the reading span tasks, but not when it is measured by each task alone. Further research is needed to understand how long-term storage and use of verbal information depend on elementary operations performed on the input to the system, on the speed of their execution, and on the ability of the system to select the relevant information.

A more precise specification of the inhibitory construct and its relationships with interference and working memory, along with the development of multiple reliable measures of inhibition, are clearly needed. Because the measure of inhibition that we had chosen in this study (negative priming) did not decline with age, we only used a measure of resistance to interference in the testing of various structural models. This could be problematic if one refers to Zacks and Hasher’s work (1994) arguing that the mediator of theoretical importance is inhibition. Actually, the relationships between inhibition and interference are still unclear. The dissociation observed in the present study (age affects interference but not negative priming) suggests that interference and negative priming might result from independent inhibitory mechanisms (see Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). In the interference condition, inhibitory processes should intervene to reduce interference during concurrent response selection; in the negative priming condition, inhibitory processes should act to prevent recently rejected information to influence the current task. However, evidence for this interpretation is controversial (see Kieley & Hartley, 1997). Any further progress in our understanding of how inhibition capability contributes to age-related differences in cognition will require a better identification of the mechanisms that underlie the inhibitory function. The future of the global approaches to cognitive aging is likely to consist of more analytic investigations of the variables that hide within the general factors.

REFERENCES


APPENDIX

Example of Material Used in the Text Comprehension Task
(literally translated from the French)

Text Presentation

It is summer. The small town is quiet.\(^1\)
Mrs. Baker is not gone on holidays.\(^1\)
She doesn’t like traveling.\(^1\)
And she is so well at home.\(^1\)
All her life is spent through little habits.\(^1\)
Every morning, she goes out for shopping\(^1\)
at the corner grocery. There, she often meets/\(^1\)
two former colleagues, from the time she was teaching.\(^1\)
At noon, she takes lunch while listening to the radio.\(^1\)
Then, when there is sun, she sits in the park.\(^1\)
She gives ducks pieces of bread.\(^1\)
\(^2\)
She also likes looking at children playing/\(^2\)
on swings. She often pushes them/\(^2\)
but never strongly enough to their taste./\(^2\)
In the evening, she watches news on the television./\(^2\)
On that evening, three friends came/\(^2\)
to play cards. She interrupted/\(^2\)
the game to listen to weather information./\(^2\)
Unfortunately, a very cloudy sky is forecast/\(^2\)
until the end of the week. Then, the game went on/\(^2\)
but Mrs. Baker was no longer very attentive./\(^2\)
#\(^2\)

Questions

(1) Will Mrs. Baker go to feed the ducks tomorrow? Why?\(^2\)
(2) What does Mrs. Baker dislike?\(^2\)
#\(^2\)
(3) What does she do every morning?\(^2\)
(4) Do you think it is a tourist town? Why?\(^2\)

Response Coding

(1) No, because she only goes to the park when there is sun and a cloudy sky is announced = 2 points.
(2) She doesn’t like traveling = 2 points.
(3) She goes out for shopping = 2 points.
(4) No, because it is summer and the town is quiet = 2 points.

Appendix notes
\(^1\) /= end of a segment.
\(^2\) //= new screen.