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The relationship between age, processing speed, working memory capacity, and language comprehension

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A total of 50 elderly individuals and 48 college students were tested on several measures of processing speed and of working memory capacity. Language processing was tested with an on-line measure of sentence processing efficiency, an end-of-sentence acceptability judgement task, and a paragraph comprehension test. Elderly individuals performed more poorly than college students on the speed of processing and working memory measures and had longer listening times overall on the sentence processing measures. Elderly individuals did not, however, have overall longer listening times at the most capacity-demanding regions of the harder sentence types. Correlational analyses failed to establish a relationship between the increase in syntactic processing load at the capacity-demanding region of the harder sentence type and the measures of working memory capacity, but did establish a relationship between paragraph comprehension and working memory capacity. The data are argued to provide evidence that the WM system used to structure sentences syntactically is separate from that used in other aspects of language comprehension.

Regardless of whether language is written or spoken, the input to the comprehender becomes available over time and temporally discontinuous parts of the input must be related to one another for language to be understood. Thus, language comprehension must involve a temporary store or working memory (WM) system.

Working memory capacity declines with age (see Carpenter, Miyake, & Just, 1994; Salthouse, 1991, for reviews) and some decrements in language comprehension have been hypothesised to be related to this decline. However, the decline in working memory capacity has in turn been related to reductions in other cognitive capacities, in particular the speed with which cognitive operations can be carried out (Salthouse, 1996). This finding has led some researchers to argue that a single common factor, processing speed, mediates the age-related influence on all cognitive variables, including both working memory capacity and language (e.g., Kliegel & Mayr, 1992; Verhaeghen & Salthouse, 1997).

While WM, processing speed, and language comprehension are certainly related in some way, the exact nature of the connections between them is not fully understood. A basic question is the extent to which changes in language processing, WM, and speed of processing are unitary vs the extent to which they can dissociate. Some theorists (e.g., Just & Carpenter, 1992) have postulated that there is a general verbal WM system, measured by tasks such as the Daneman and Carpenter (1980) reading span task, and that decrements in this system result in decrements in all verbally mediated tasks. Others (e.g., Caplan & Waters, 1999a, 1999b; Waters & Caplan, 1996) have argued that there is a specialised WM system that supports the initial, on-line, obligatory, unconscious processes

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that assign the structure and the literal, preferred, discourse-congruent meaning of sentences. On this view, decrements in working memory capacity as measured by the reading span task, do not results in comparable changes on all tasks.

Elderly participants appear to perform more poorly overall than younger participants in many tests of sentence comprehension (e.g., Feier & Gerstman, 1980). Moreover, some studies have reported a correlation between measures of WM capacity and off-line measures (i.e., measures that are taken at the end of the sentence after the sentence has been understood) of sentence comprehension in ageing (e.g., Kemper, 1986). However, when factorial designs are used, effects of group (i.e., of participants who differ in age or WM) on an overall comprehension measure do not necessarily imply that the different groups of participants differ in their abilities to assign structure and meaning. Older participants and those with lower WM may be less able to accomplish many aspects of a task, leading to overall lower performance levels (Waters & Caplan, 1996). Evidence that a group of participants has difficulty with structuring and assigning meaning to sentences requires the demonstration that group differences increase when the demands made by structure building and interpretive operations increase; i.e., that older or low WM participants perform disproportionately worse on more syntactically complex structures. In addition, off-line tasks do not measure syntactic complexity effects as they occur and thus give only an indirect view of syntactic processing abilities. End-of-sentence measures are likely to include effects of syntactic complexity associated with reviewing sentences to satisfy task requirements, such as making plausibility or grammaticality judgements, or matching sentences to pictures.

For these reasons, most researchers believe that on-line tasks that capture the effects of syntactic complexity as they occur in capacity-demanding portions of sentences are necessary to characterise first-pass syntactic processing. An extensive empirical literature has shown that on-line tasks are sensitive to the time-course of syntactic processing (see MacDonald, Pearlmutter, & Seidenberg, 1994, for a review). However, the results of studies to date have been equivocal in terms of the question of whether older or low WM participants perform disproportionately worse on more syntactically complex structures. Some studies have failed to find increased effects of syntactic complexity in elderly subjects using on-line measures (e.g., Kemtes & Kemper, 1997; Stine-Morrow, Loveless, & Soederberg, 1996; Waldstein & Baum, 1992; Waters & Caplan, 2001) and others have claimed to find such effects (e.g., Stine-Morrow, Ryan & Leonard, 2000; Zurif, Swinney, Prather, Wingfield, & Brownell, 1995). However, there are many methodological problems with existing studies (see Waters & Caplan, 2001, for a review).

This study investigated the relationship between language comprehension, WM, and speed of processing by characterising and relating language comprehension (at the levels of sentences and discourse), WM, and processing speed in young and elderly participants.

METHOD

Participants

A total of 48 university students and 50 elderly individuals, recruited through advertisements and paid for their participation, participated in the study.[1] All were required to have English as their mother tongue and at least a high-school education. Elderly participants were required to report that they were ageing normally and living independently.

Procedures and materials

All participants were pre-tested on a battery of neuropsychological tests, to rule out any evidence of cognitive decline or dementia (see Table 1).

Assessment of working memory

Working memory capacity and speed of processing were assessed using tasks that are commonly used to measure these constructs in studies of aging and that have been shown to have good internal consistency and test–retest reliability (Earles, Connor, Frieske, Park, Smith, & Zwahr, 1997; Salthouse & Babcock, 1991; Waters & Caplan, 1996; Waters & Caplan, 2003).

Working memory capacity was tested using the alphabet span (Craik, 1986), subtract 2 span

[1] The on-line data for the 48 university students are also presented in Waters & Caplan (2004). The focus of that paper is on language processing in college students and none of the analyses include a comparison with elderly participants.

TABLE 1
Subject characteristics

		Young	*Elderly*	
Age*	x	21.4	70.7	
	SD	2.7	4.8	
	Range	17–29	65–80	
Education (yrs)*	x	14.7	14.5	$t(1,96) = 0.09$, NS
	SD	1.5	3.0	
	Range	12–18	8–20	
Mini-mental State Exam[1] (/32)*	x	N/A	27.7	N/A
	SD	N/A	1.8	
	Range	N/A	23–30	
Wechsler Memory Scale Revised[2]				
Logical Memory I***	x	52.3	55.1	$t(1,96) = 0.22$, NS
	SD	25.5	33.2	
	Range	7–97	2–99	
Logical Memory II***	x	55.0	56.5	$t(1,96) = 0.06$, NS
	SD	3.7	4.7	
	Range	8–97	1–99	
Wechsler Adult Intelligence Scale[3]	x	76.4	79.7	
Vocabulary subtest***	SD	20.2	22.4	
	Range	16–99	14–99	
Boston Naming Test [4](/60)*	x	54.3	53.7	
	SD	4.1	4.7	
	Range	43–60	38–60	
Nelson-Denny Reading Test[5]**	x	70.2	86.8	
Vocabulary subtest	SD	21.2	18.9	
	Range	21–99	34–99	

*Mean scores. **Mean percentiles. ***Age-adjusted percentiles using Mayo's Older American Studies norms.

[1] Folstein, Folstein, & McHugh, 1975. [2] Wechsler, 1987. [3] Wechsler, 1981. [4] Nelson & Denny, 1960. [5] Goodglass & Kaplan, 1972.

(Salthouse, 1988), and two versions of the reading span (Waters & Caplan, 1996) tasks. In the alphabet and subtract 2 span tasks, participants heard random sequences of items (monosyllabic unrelated words in the former and numbers in the latter) and were required to repeat them back in alphabetic and numerical order, respectively. In the reading span tasks, participants were presented with mixed blocks of acceptable and unacceptable sentences in syntactically simple (cleft subject) and syntactically complex (subject object) form and were required to decide whether each sentence was acceptable. After seeing all of the sentences in a block, they were required to recall the final words of all of the sentences. For all tasks, span was defined as the longest list length at which participants repeated all of the items in a trial in the correct serial order on three of five trials. An additional .5 was given if two of five trials were correct at the next span size. A composite WM span measure was calculated for each participant by averaging across the four WM tasks.

Speed of processing was measured using the digit symbol substitution task (Wechsler, 1981) and a variant of this task—the digit letter task (Lindenberger, Mayr, & Kliegl, 1993). In the digit symbol task, participants were shown a display of nine symbols, each of which had a number written above it, and an array of pairs of boxes with a symbol in the top box and nothing in the box below it. They were required to write the number corresponding to the symbol in each bottom box. The number of items correctly completed in 90 s is measured. In the digit letter task, subjects named letters instead of writing symbols. The template with the digit letter mapping task was visible for the entire test period. The test consisted of a total of 21 sheets. Each sheet contained six digits with a question mark under each. Moving from left to right, subjects had to name the letters that corresponded to the digits. The total number of correct responses after 3 minutes was scored. A composite processing speed measure was calculated by converting the scores for each task to z scores and then averaging the two scores.

Assessment of on-line sentence processing efficiency

The auditory moving windows paradigm (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996) with an end-of-sentence plausibility judgement task was used as the on-line sentence processing task. The end-of-sentence plausibility judgement was used as an off-line measure of sentence comprehension.

The method and materials were taken from Waters and Caplan (2002). The stimuli consisted of 26 semantically plausible and 26 semantically implausible sentences of each of the five sentence types shown in Table 2. The sentences were segmented into phrases (see Table 2), and participants pressed a button on a box interfaced with the computer to hear each successive phrase. Reaction times for each phrase were recorded. Plausibility judgements were made by pressing a "yes" or "no" button on hearing the last word of the sentence, which was indicated by a tone, and judgement response time and judgement accuracy were recorded. The materials were constructed so that the plausibility judgement task could not be performed correctly unless the participants assigned the syntactic structure of the sentences and processed them for meaning (see Waters & Caplan, 2002).

The syntactically simple and complex sentences were developed in pairs with the same words in a different word order. The memory storage and computational requirements of processing the second, syntactically more complex, object-relativised member of each pair are greater than in the corresponding subject-relativised sentences. In object-relativised sentences, the head noun of the relative clause must be retained in memory over more words than in subject-relativised sentences. Also, at the embedded verb of cleft-object and subject-object sentences, the parser assigns two thematic roles—one to the agent and one to the theme of the verb—whereas at the embedded verb of cleft-subject, object-subject, and subject-subject sentences, the parser assigns only the thematic role of agent. Thus, the WM load at the embedded verb of object-relative sentences is greater than in subject-relative sentences for both memory and computational reasons (Caplan, Hildebrandt & Waters, 1994; Gibson, 1998). This load can spill over to the main verb of subject-object sentences (King & Just, 1991). Thus, the main data of interest in this study consisted of listening times for the verb in plausible cleft object compared to cleft-subject sentences, and on both verbs in plausible subject-object compared to object-subject and subject-subject sentences. Reading times have been found to be longer for words in sentence-final position (Balogh, Zurif, Prather, Swinney, & Finkel, 1998). To allow for a comparison of listening times on the verb of cleft-object sentences and the verb of cleft-subject sentences, which was not affected by sentence-final position, a short phrase was added to

TABLE 2
Examples of sentence stimuli

	Intro NP1 pro V NP2 AdjP
Cleft-Subject (CS)	*plausible:*/It was/ /the movie/ /that/ /terrified/ /the child/ /because it showed a monster/
Simple	*implausible:* /It was/ /the man/ /that/ /delighted/ /the camera in the film/
	Intro NP1 pro NP2 V AdjP
Cleft-Object (CO)	*plausible:* /It was/ /the child /that/ /the movie/ /terrified/ because it showed a monster/
Complex	*implausible*: /It was/ /the camera/ /that/ /the man/ /delighted/ /in the film/
	NP1 V1 NP2 pro V2 NP3
Object-Subject (OS)	*plausible:* /The scout/ / warmed/ / the cabin/ /that/ /contained/ /the firewood/
Simple	*implausible:* /The criminal/ /cursed/ /the judge/ /that/ /astonished/ /the verdict/
	NP1 pro V1 NP2 V2 NP3
Subject-Subject (SS)	*plausible:* /The cabin/ /that /warmed/ /the scout/ /contained/ /the firewood/
Simple	*implausible:* /The judge/ /who/ /cursed/ /the criminal/ /astonished/ /the verdict/
	NP1 pro NP2 V1 V2 NP3
Subject-Object (SO)	*plausible:* /The cabin/ /that /the scout/ /warmed/ /contained/ /the firewood/
Complex	*implausible:* /The judge/ /who/ /the criminal/ /cursed/ /astonished/ /the verdict/

each of these sentence types. Additional comparisons of interest that control for sentence position are between listening times for the first verb (the verb in the relative clause) of the object-relativised sentences (CO and SO) and the second noun-phrase (NP2) of the subject-relativised sentences (CS, SS, and OS), which occur in similar, clause-final, positions.

The sentences were recorded by a male speaker, digitised, and entered into PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh computer. They were played out over headphones. PsyScope recorded: (a) the time to play out and process each phrase, (b) the time from the end of the sentence to the participant's button press for plausibility judgements, and (c) the plausibility judgement response.

Assessment of discourse comprehension

All participants were tested on the reading comprehension subtest of the Nelson-Denny Reading Test Form A (Nelson & Denny, 1960) in which they were required to read short paragraphs and answer comprehension questions.

RESULTS

Table 1 shows the background characteristics of the subjects. Paired *t*-tests showed that the young and elderly participants did not differ in terms of education, performance on the Wechsler Memory Scale, the WAIS vocabulary test, or the Boston Naming test. They did differ on the Nelson-Denny reading vocabulary test. Although the scores of some of the elderly subjects fell in the impaired range on some tasks, none of the elderly participants showed a pattern of performance across tasks that was consistent with dementia.

Speed of processing and working memory measures

As can be seen in Table 3, paired *t*-tests showed that the elderly subjects performed more poorly than the young subjects on the digit symbol test but not the digit letter test. Elderly subjects had significantly smaller working memory spans than younger subjects on all four of the WM measures. In addition, there were significant negative correlations between age and the two speed of

TABLE 3
Performance on the speed of processing and working memory measures

	Young	*Elderly*	
Digit Symbol*			
x	73.4	47.7	$t(1, 95) = 164.0, p < .001$
SD	10.1	9.5	
Digit Letter*			
x	95.5	94.2	$t(1, 96) = 2.9, p < .09$
SD	1.8	5.0	
Alphabet Span**			
x	4.5	3.9	$t(1, 96) = 15.3, p < .001$
SD	0.75	0.69	
Subtract 2 Span**			
x	6.0	5.1	$t(1, 96) = 15.9, p < .001$
SD	1.0	1.0	
Sentence Span (Simple)**			
x	4.2	3.1	$t(1, 96) = 17.3, p < .001$
SD	1.5	1.0	
Sentence Span (Complex)**			
x	3.5	2.4	$t(1, 96) = 16.9, p < .001$
SD	1.6	1.0	

* Indicates raw scores. ** Indicates span.

processing measures ($r = -.80$ Digit Symbol; $r = -.25$ Digit Letter) and the four WM measures ($r = -.49$ Alphabet Span; $r = -.38$ Subtract 2 Span; $r = -.41$ Reading Span Simple Sentences; $r = -.39$ Reading Span Complex Sentences).

On-line measure of sentence processing efficiency

The response time for each phrase on the auditory moving windows task was the dependent measure of on-line sentence processing efficiency in all conditions. Each segment's duration was subtracted from the response time to generate "listening times" that were independent of the duration of each segment. Listening times greater and less than 3 SDs from the mean for each condition for each subject were removed as outliers.

Listening times for plausible sentences for which participants made a correct plausibility judgement were analysed in ANOVAs using both subject (*F*1) and item (*F*2) means as units. CS and CO sentences were analysed in 2 (Group: Young vs Elderly) × 2 (Sentence Type) × 5 (Phrase: Intro, NP1, Pro, V, NP2) analyses. SO and SS, and SO and OS, sentences were analysed in 2 (Group: Young vs Elderly) × 2 (Sentence Type) × 5 (Phrase: NP1, Pro, V1, NP2, V2) analyses. Only those effects that were robust enough to be seen in both the analysis by subjects and items are discussed below, following Clark (1973).

The three panels of Figure 1 shows the mean listening times for the two groups at each phrase for the three sentence pairs—CS/CO, OS/SO, SS/SO. The pattern of performance was similar across the three sentence pairs.

As can be seen in the graphs, there was a main effect of Group for all three pairs of sentences, with the listening times of the elderly subjects being significantly longer than those of the younger subjects—CS/CO: $F1(1, 96) = 74.8$, $MSE = 352018.5$, $p < .0001$; $F2(1, 250) = 726.4$, $MSE = 19043.5$, $p < .0001$; OS/SO: $F1(1, 96) = 59.7$, $MSE = 426980.4$, $p < .001$; $F2(1, 250) = 1292.3$, $MSE = 10408.0$, $p < .001$; SS/SO: $F1(1, 96) = 59.4$, $MSE = 444248.7$, $p < .001$; $F2(1, 250) = 1352.5$, $MSE = 10368.9$, $p < .0001$. In addition, there was a significant Sentence Type × Phrase interaction for all three pairs of sentences—CS/CO: $F1(4, 384) = 111.2$, $MSE = 21682.6$, $p < .0001$; $F2(4, 250) = 15.9$, $MSE = 96078.8$, $p < .0001$; OS/SO: $F1(4, 384) = 47.0$, $MSE = 11774.4$, $p < .001$; $F2(4, 250) = 15.9$, $MSE = 22496.7$, $p < .001$; SS/SO: $F1(4, 384) = 43.1$, $MSE = 10038.0$, $p < .001$; $F2(4, 250) = 12.3$, $MSE = 22805.7$, $p < .001$.

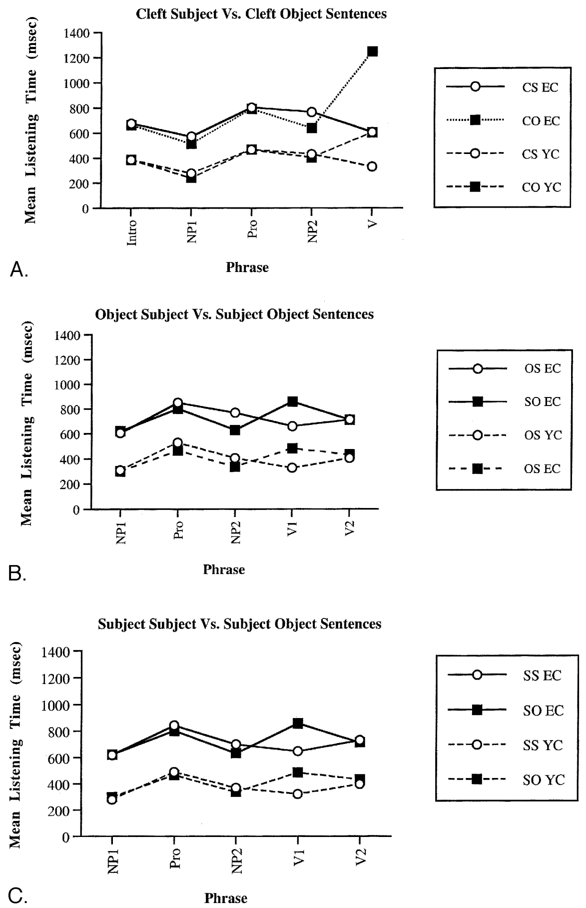

Figure 1. Mean listening times for the three subject groups. Panel A: Cleft-subject and cleft-object sentences. Panel B: Object-subject and subject-object sentences. Panel C: Subject-subject and subject-object sentences.

Post-hoc analysis of the Sentence Type × Phrase interaction using Tukey tests and a $p < .05$ criterion, showed that for the CS/CO comparison, listening times were longer at the verb in CO sentences than at both the verb and NP2 in CS sentences, indicating that there is the expected increase in processing time at the verb and that it is not simply due to its clause—final position. For both OS/SO and SS/SO sentences, listening times at V1 were longer for the syntactically more complex object-relativised than subject-relativised sentences. Listening times at V1 in object-relativised sentences were also longer than those at NP2 in subject-relativised sentences, indicating that the effect at V1 is not simply due to its clause-final position. Thus, the results for all three pairs of sentences showed that there was the expected increase in listening time at the verb of the more complex object-relativised sentences compared to the simpler subject-relativised sentences.

Finally, the three-way interaction between Group, Sentence Type, and Phrase was significant in both the subject and item analyses for the CS/CO comparison and was significant in the item but not subject analyses for the OS/SO and SS/SO sentence pairs—CS/CO: $F1(4, 384) = 19.2$, $MSE = 21682.6$, $p < .001$; $F2(4, 250) = 14.0$, $MSE = 19043.5$, $p < .001$; OS/SO: $F1(4, 383) = 2.0$, $MSE = 11774.4$, ns, $F2(4, 250) = 2.7$, $MSE = 10408.7$, $p < .05$; SS/SO: $F1(4, 383) = 1.8$, $MSE = 10038.0$, ns, $F2(4, 250) = 3.3$, $MSE = 10368.9$, $p < .01$. Post-hoc analysis of the subject means for the CS/CO comparison showed that, as can be seen in Figure 1, both young and elderly subjects had longer processing times on the verb of the object-relativised CO sentence. The interaction was due to the fact that for elderly subjects listening times were longer on NP2 in CS than in CO sentences, while there was no difference between these phrases for young subjects.

The data presented in Figure 1 suggest that although both groups of subjects showed an increase in listening time at the verb of syntactically more complex object-relativised sentences, this effect may be larger in the elderly than in the young subjects. In order to determine whether this was the case, we calculated difference scores for each subject that represented the difference in processing time between the syntactically simpler and complex sentence at each phrase for each of the three sentence comparisons. In addition, we calculated the difference between processing time at the verb of the object-relativised sentence and processing time at NP2 for the subject-relativised sentence in order to differentiate effects at the verb that were due to the processing load associated with its syntactic position and processing load associated with its position at the end of the clause. These difference scores were analysed in Group × Phrase ANOVAs. For the CS/CO comparison, there was a significant interaction between Group and Phrase, $F1(4, 364) = 19.5$, $MSE = 57048.2$, $p < .001$, however this interaction was not significant for the other two sentence comparisons—OS/SO: $F1(4, 364) = 1.8$, $MSE = 25328.7$, ns; SS/SO: $F1(4, 364) = 2.3$, $MSE = 22921.9$, ns. Post-hoc analysis of the Group × Phrase interaction in the CS/CO analysis showed that the increase in processing time at the verb in CO sentences compared to both the verb in CS sentences and NP2 in CS sentences was larger in elderly than in young subjects.

End-of-sentence plausibility judgements

Figure 2 shows the mean percent correct scores for the five sentence types (CS, CO, OS, SS, and SO) for the two subject groups. The data were analysed in 2 (Group) × 5 (Sentence Type) ANOVAs with subject and item means as units. There was a significant main effect of Sentence Type, $F1(4, 384) = 111.5$, $MSE = 21.8$, $p < .001$; $F2(4, 255) = 5.6$, $MSE = 460.2$, $p < .001$, and a Group × Sentence Type interaction, $F1(4, 384) = 3.5$, $MSE = 21.8$, $p < .01$; $F2(4, 255 = 2.7$, $MSE = 29.7)$ $p < .05$. Elderly subjects made significantly more errors than young subjects on CO sentences. The two groups did not differ on the other sentence types. Elderly subjects made more errors on CO than on CS sentences and on SO than on OS sentences. There was no difference between SS and SO sentences for this group. Young subjects only made more errors on CO than on CS sentences and there were no significant differences between the other sentence types.

Figure 2 also shows plausibility judgement reaction time data for plausible sentences correctly judged to be plausible. The data were analysed in a 2 (Group) × 5 (Sentence Type) ANOVA with both subject and item means as units. There was a significant main effect of Group, $F1(1, 96) = 18.3$, $MSE = 1443065.1$, $p < .001$; $F2(1, 255) = 356.1$, $MSE = 41793.1$, $p < .001$, and of Sentence Type, $F1(4, 96) = 55.6$, $MSE = 96468.2$, $p < .001$; $F2(4, 255) = 10.8$, $MSE = 218966.5$, $p < .001$. The Group × Sentence Type interaction was significant in the subject analysis and marginally significant in the item analyses, $F1(4, 97) = 3.5$, $MSE = 96468.2$, $p < .01$; $F2(4, 255) = 2.2$, $MSE = 41793.1$, $p < .07$. Post-hoc analysis of the subject means showed that the elderly subjects had longer reaction times than young subjects on all five types of sentences. In addition, both the elderly and young subjects had longer reaction times on CO than on CS sentences. Young subjects had longer reaction times on SO than on SS sentences but there was no significant difference for elderly subjects. In addition, reaction times for SO and OS sentences did not differ for either group.

Nelson-Denny comprehension

Mean percentile scores for the young and elderly subjects were 59.4 and 56.6, respectively, on the Nelson-Denny reading comprehension subtest and 57.8 and 51.1 on the reading rate measure.

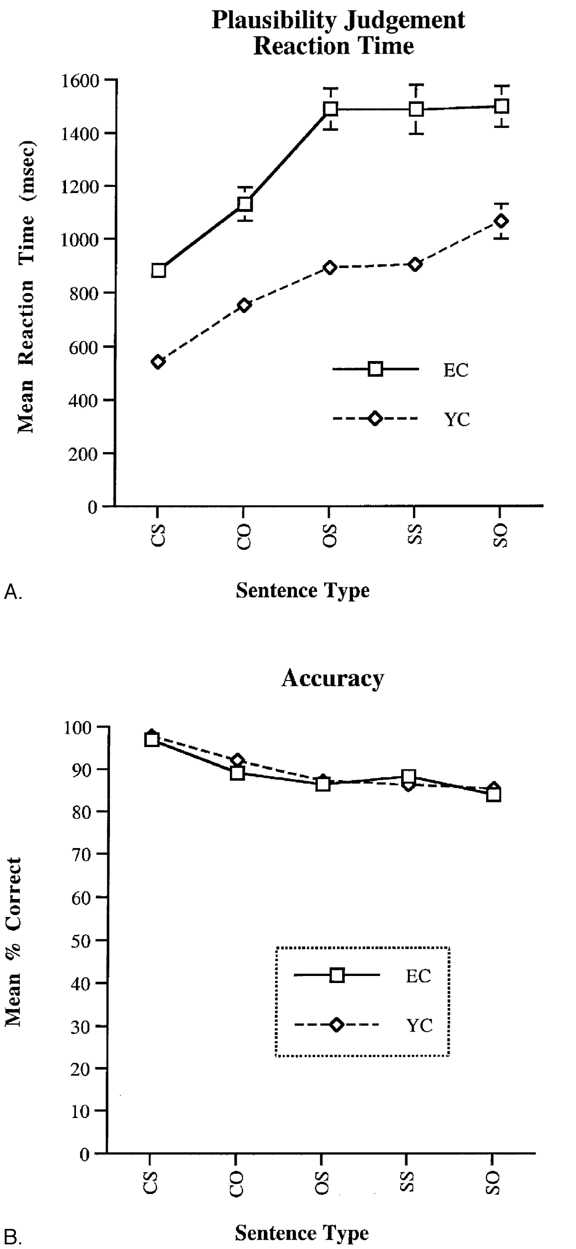

Figure 2. Panel A: Mean plausibility judgement reaction times. Panel B: Mean accuracy scores for plausibility judgements.

One-way ANOVAs showed that the differences between the young and the elderly subjects were not significant for either the comprehension, $F(1, 96) = 0.25$, ns, or the rate, $F(1, 96) = 2.1$, ns, measures.

Relationship between speed, WM, and language processing measures

A more direct approach to investigating the question of the relationship between WM span and performance on the language processing measures is to examine the correlation between the WM and language measures. The contribution of differences in general processing speed can also be approached in this manner. To obtain an index of the increase in processing time at the most capacity-demanding portions of the more complex sentences, we used the difference scores that reflected the increase in listening time at the verb in the syntactically more complex object-relativised compared to subject-relativised sentences (COV–CSV; SO V1–OS V1; SO V2–OSV2; SO V1–SS V1; SO V2–SSV2). In addition, we computed the difference between listening times at COV and CS NP2, SOV1 and OSNP2, and SOV1 and SSNP2. These latter difference scores take into account the fact that V is at the end of a clause in CO sentences and that V1 is at the end of a clause in SO sentences.

We also examined the relationship between the two off-line measures of performance on the auditory moving windows task—reaction time and accuracy—and WM span and speed of processing. For these measures, we calculated difference scores that provide an index of the increased difficulty in making an acceptability judgement for the more complex sentence type. For the reaction time (RT) measures a positive score indicates a complexity effect, while for accuracy a negative score indicates a complexity effect. If WM is related to these off-line difference measures, one would expect to find a negative correlation with the RT difference scores and a positive correlation with the accuracy difference scores. Finally, we looked at the relationship between performance on the Nelson-Denny reading comprehension test, and speed of processing and WM span.

The left-hand column of Table 4 shows the correlation between the language measures and the WM composite score and the right-hand column shows the correlation with the composite speed measure. The only on-line measure to show a significant correlation with the WM measure was the COV–CSV measure. This correlation was negative, indicating that individuals with lower working memory scores take an increased amount of time to process the verb in CO sentences. However, the fact that the correlation was not significant with the COV–CSNP2 measure, and Fisher's r to z test showed that the correlation between WM and COV–CSV was significantly greater than that with COV–CSNP2, suggests that the effect at COV is primarily an end-of-clause effect and is not due to the increased syntactic

TABLE 4
Correlations between processing speed, working memory, and language processing measures

	WM	*Speed*
On-line measures		
CO V–CS V	−.23*	−.36*
CO V–CS NP2	−.11	−.25*
SO V1–SS V1	.02	−.09
SO V2–SS V2	.11	.24*
SO V1–SS NP2	.00	−.09
SO V1–OS V1	.01	−.07
SO V2–OS V2	.05	.01
SO V1–OS NP2	.11	.06
End-of-sentence measures		
CO–CS RT	.05	−.17
SO–OS RT	.11	.06
SO–SS RT	.07	.12
CO–CS Accuracy	.23*	.05
SO–OS Accuracy	.26*	.19
SO–SS Accuracy	.06	.11
Discourse measure		
Nelson-Denny Comprehension	.27*	.19
Nelson-Denny Rate	.25*	.23*

* $p < .05$

processing load at V, since it goes away when position is taken into account. The argument that the effect seen in CO sentences is not due to the increased syntactic processing load at this point is also supported by the fact that a similar effect was not seen for the verb in SO sentences.

Significant correlations were found between two of the off-line measures of syntactic processing and WM (CO-CS accuracy and SO-OS accuracy). These correlations suggest that WM is related to off-line measures of syntactic processing. In addition, a significant correlation was found between both the comprehension and rate measures on the Nelson Denny reading comprehension test and WM. This correlation supports the widely held view that standard measures of WM are related to global language comprehension measures.

The right-hand column of Table 4 shows the relationship between the language and the speed of processing measures. There was a significant negative correlation between the increase in processing time at the verb of CO sentences and subjects' rate of processing. There was also a significant relationship with the SOV2–SSV2 measure, however, this correlation is in the opposite direction to that expected. Finally, as might be expected, there was a significant correlation between reading rate and the general speed of processing measure.

DISCUSSION

The main goal of this study was to investigate the effects of age, working memory capacity, and speed of processing on on-line syntactic processing. Older individuals did have significantly lower working memory capacities than younger subjects and overall listening times became longer with age. However, for two of the three sentence comparisons, the effects of age were the same in the simple and complex versions of the sentences in each pair, since elderly subjects did not show a disproportionate increase in listening time on the capacity-demanding portion of the complex sentence. This suggests that the on-line syntactic operations that *differ* between the complex and simple sentences in these studies were not affected by age. These operations—processing of long distance dependencies—are highly demanding of working memory resources, while the syntactic operations that are shared between the sentence types contrasted here—constructing local phrase markers—are considerably less demanding of such resources.

The one on-line finding that could suggest that the elderly were more affected by syntactic complexity than the controls was the greater increase for these subjects in listening times at the verb of CO compared to CS sentences. However, a more likely interpretation of this finding is that it is due to non-syntactic processing that occurs when the thematic roles required by a verb are assigned, not syntactic processing *per se*. This conclusion seems warranted given that the elderly subjects did not show a greater effect of increased processing load compared to controls at the capacity-demanding region of SO sentences when compared to either SS or OS sentences. If the CO effect were a syntactic effect, a similar increase would be expected for elderly subjects with SO sentences. In addition, while both the difference in listening times for V in CO sentences compared to V in CS sentences, and the difference in listening times for V in CO sentences compared to NP2 in CS sentences, were significantly greater for elderly subjects, only the former difference was significantly related to the WM measure. However, adopting Gibson's (1998) model of syntactic processing, the difference in local syntactic processing load between V in CO sentences and V in CS sentences is the same as that between V in CO sentences and NP2 in CS sentences. If it were the increased load at V that accounted for this effect, then a comparable relationship with WM would be expected to be seen with the NP2 comparison.

One possible source of the increased load at V in CO sentences is related to discourse-level representations. In addition to constructing sentence-level semantic properties, such as thematic roles, listeners also construct discourse-level semantic properties, such as an inventory of entities in the universe of discourse, the entity in the focus of the discourse, etc. From the perspective of creating a discourse structure, sentences presented in isolation act as discourse-initial sentences (Altmann & Steedman, 1988). Clefting and other markers of discourse focus are usually inappropriate in discourse-initial sentences, and therefore in sentences presented in isolation. On this view, cleft-object sentences but not subject-object sentences presented in isolation make additional demands on the construction of discourse focus. The focus of a discourse usually is the subject of a sentence and the agent of a verb (Kintsch & Van Dijk, 1978). In a cleft-object sentence, this usual co-occurrence of agent and focus is violated, because the theme of the verb is put into the focused, clefted, position. The verb of CO sentences is the first point at which the dissociation of the usual combination of agent and focus can be recognised. All these factors increase the processing load at the V of CO sentences. Because of the unnaturalness of the clefted construction in discourse-initial sentences, constructing the discourse representations associated with clefted structures in single sentence presentations may lie outside the usual interpretive process and involve the putative "general purpose" pool of processing resources; the demands on this pool would be particularly high at the V of CO sentences. Increases in the processing load on the "general" pool of processing resources are expected to affect elderly subjects more than controls, due to their reduced "general" pool of such resources.

It is interesting to note that the only significant relationship between the on-line measures and speed of processing was with the effects outlined above at the verb of cleft-object sentences. If the effect at the verb is truly non-syntactic as we have argued above, and if it is related to the general verbal WM system, then the additional finding of a correlation between speed of processing and the increased processing time at V in CO sentences may provide support for the notion that this WM effect is related to a speed of processing limitation.

There was some suggestion in the data that age and WM capacity did have an effect on off-line measures. Plausibility judgement accuracy was lower for the syntactically more complex CO sentences than for simpler CS sentences, and elderly and young subjects only differed in terms of accuracy on the syntactically more complex CO sentences. In addition, elderly but not young subjects made more errors on SO than on OS sentences, although in the reaction time data young but not elderly subjects had longer listening times for SO compared to SS sentences. Most importantly, the decrease in accuracy seen on plausibility judgements for the syntactically complex CO and SO sentences compared to baseline CS and OS sentences was significantly correlated with WM. Thus, individuals with larger WM capacities were less affected in their end-of-sentence judgements by the syntactic complexity of a sentence. In addition, consistent with many previous studies, there was a significant correlation between performance on the Nelson-Denny reading comprehension test and WM scores. The fact that these effects were seen in the end-of sentence data and in the reading comprehension data, but not the on-line data, is consistent with the view that WM plays a role in review processes but not in the on-line construction of syntactic form.

Together, these results are consistent with the claim that WM capacity as measured by standard tests is not related to the on-line construction of syntactic form and meaning but is related to processes that occur after the meaning of sentences has been extracted. They thus provide evidence that the WM system used for assigning syntactic structure is a specialised resource system.

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