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Spoken Sentence Processing in Young and Older Adults Modulated by Task Demands: Evidence From Self-Paced Listening

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Young and older adult listeners paced themselves through recorded sentences, under instructions to recall the sentence verbatim or to respond to comprehension probes. Sentences varied in syntactic complexity and speech rate. Young and older adults paused longer after major syntactic boundaries, an effect that was constant across speech rates but became more pronounced with increasing syntactic complexity. These effects were moderated by listeners' expectations of what they were to do with the linguistic input and by their recent experience with particular tasks. Older adults tended to pause longer in the recall condition, especially when it preceded the comprehension condition. Young adults paused differentially longer at major syntactic boundaries in the comprehension condition, but only when the comprehension condition preceded the recall condition. These findings are discussed in the context of two competing theories of syntactic processing.

AS WE listen to speech, we automatically decode rapidly changing acoustic patterns and associate them with meaning. Success with this task requires, in part, the ability to correctly interpret the syntax of the speech input (i.e., how speech elements relate to one another). However, complex syntactic constructions place high demands on working memory resources associated with speech processing. Because of this, declines in working memory associated with normal aging (e.g., Salthouse, 1991) are thought to underlie age-related comprehension failures, especially when speech is syntactically complex (Carpenter, Miyaki, & Just, 1994; Kemper, 1992; Wingfield, Peelle, & Grossman, 2003). Less clear, however, is whether the working memory deficits thought to contribute to older adults' poorer performance reflect declines in a general working memory resource or one that is specialized for language comprehension.

According to the single-resource account (e.g., Just & Carpenter, 1992), various processes involved in language comprehension, which include operations at the semantic, syntactic, and discourse levels of analysis, operate in concert and draw on a single, limited pool of resources, or "computation space." If this pool of resources is depleted, as may be the case in adult aging, or the allocation of resources requires great effort, then language comprehension will suffer (Carpenter et al., 1994).

By contrast, the separate-sentence-interpretation resource theory posits that syntactic processing is a rapid and obligatory operation governed by a language-specific capsule of working memory (Caplan & Waters, 1999). According to this view, syntactic processing is so highly practiced and specialized that it does not draw on generalized resources, and thus is relatively unaffected by individual differences in overall working memory (Waters & Caplan, 2001, 2002; Waters, Caplan, & Yampolsky, 2003). Thus, comprehension difficulty would not arise directly from problems with syntactic parsing—which is online, or "interpretive"—but rather from demands of the "postinterpretive" processes carried out after the meaning of a sentence has been established (e.g., answering questions regarding the plausibility of the sentence or organizing and maintaining the material for recall).

One method that has been used in an attempt to distinguish between these two accounts is an *auditory moving window* (AMW) task, in which participants pace themselves through linguistic material that has been divided into individual words or longer constituents such as phrases or clauses (Ferreira, Anes, & Horine, 1996; Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996). After processing each segment, listeners initiate successive segments with a keypress, thereby controlling the flow of incoming information. It is presumed that when listeners require extra time to process information, they will exhibit correspondingly longer pause durations before initiating subsequent segments, reflecting participants' responsiveness to particular linguistic features. This technique is thought to capture patterns of resource allocation during online obligatory linguistic processing (Waters & Caplan, 2001, 2002).

If the single-resource theory (Just & Carpenter, 1992) holds, then older adults should not only show decrements on post-interpretive measures that tap working memory (e.g., verbatim recall, being prepared to respond to comprehension probes), but they should also display different patterns of pause durations while listening to sentences as compared with young adults. In other words, as a result of age-related working memory declines, young and older adults would be differentially responsive to constructions varying in syntactic complexity. By contrast, the separate-sentence-interpretation resource theory (Caplan & Waters, 1999) would predict that the older adults' pattern of pause durations should mirror that of the young adults.

Waters and Caplan (2001), using the AMW technique for spoken sentences, reported that although AMW pause durations of older adults were generally longer than those of young adults, young and older listeners produced comparable patterns of pause durations across different levels of syntactic complexity. In addition, this pattern of presumed resource allocation as a function of syntactic complexity remained stable for young

Table 1. Example of Sentence Segmentation Across Three Levels of Syntactic Complexity

Sentence Type	Segment 1	2	3	4	5	6
Active conjoined	The author / (NP1)	insulted / (V1)	the critic // (NP2)	and / (C)	hired / (V2)	a lawyer. (NP3)
Subject relative	The author / (NP1)	that / (C)	insulted / (V1)	the critic // (NP2)	hired / (V2)	a lawyer. (NP3)
Object relative	The author / (NP1)	that / (C)	the critic / (NP2)	insulted // (V1)	hired / (V2)	a lawyer. (NP3)

Notes: The double-slashes demarcate the end of the initial clause (i.e., the major internal linguistic constituent). The information in parentheses indicate the linguistic function of the segment (NP = noun phrase; V = verb; C = conjunction or complementizer).

listeners who were tested under memory loads tapping general working memory resources (Waters et al., 2003), supporting the notion of a language-specific working memory resource.

There may be situations, however, in which age differences in pacing patterns across a sentence do occur. Evidence from reading research using a moving window technique suggests that pause durations can be differentially affected by task demands. For example, one group of researchers observed slower reading times when participants were instructed to read for recall versus reading for comprehension (Stine-Morrow, Milinder, Pullara, & Herman, 2001). Although recall and comprehension are thought to engender a common set of basic processes, text recall demands additional effort to encode the specific words into memory over and above that needed for simple comprehension (Kieras, 1981; Stine-Morrow et al.).

Varying such task demands may differentially affect young and older adults' pacing times when listening to speech. To the extent that listeners may pace themselves through speech more slowly when their goal is to provide verbatim recall than to respond to comprehension probes, one could postulate that listeners who are less confident in their memory ability might show an especially strong difference in this regard. Thus, older adults might pace the speech input differentially slower to compensate for their perceived (Erber, Prager, Williams, & Caiola, 1996; Hess, Auman, Colcombe, & Rahhal, 2003; Rahhal, Hasher, & Colcombe, 2001) and actual (Kausler, 1994; Wingfield & Kahana, 2002) age-related declines in verbatim memory (see also Cavanaugh & Green, 1990; Hertzog, Dixon, & Hultsch, 1990), and especially so for syntactically complex speech. Such findings would support the single-resource allocation position of Just and Carpenter (1992); however, a lack of such a differential effect on young and older listeners' AMW pacing times would lend additional support to the separate-sentence-interpretation resource theory of Caplan and Waters (1999). In the current study, we examine the effects of task demands and syntactic structure on young and older adults' self-paced listening times.

To manipulate syntactic complexity in the present study, we employed three types of sentences (see Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Stine-Morrow, Ryan & Leonard, 2000). The simplest sentence type, *active-conjoined sentences*, contained two clauses connected by the conjunction *and* (see Table 1 for an example). In this case there are two important thematic roles: the agent (*the author*) who performs both actions (*insulting* and *hiring*) and the receiver of the first action (*the lawyer*). A more complex sentence type consisted of sentences with a *subject-relative center-embedded clause*. In such sentences the agent and the receiver retain their thematic roles, but the main clause (*The author hired a lawyer*) is interrupted by a relative clause (*that insulted the critic*).

The most complex constructions we employed contained *object-relative center-embedded clauses*. In object-relative sentences, the embedded clause not only interrupts the main clause, but the head noun phrase (*the author*) functions as both the subject of the main clause (*hiring the lawyer*) and the object of the relative clause (*being insulted*). Because the thematic roles in object-relative sentences are not canonical and require extensive thematic integration (Gibson, 1998; Warren & Gibson, 2002), they are more difficult to process than subject-relative sentences. Moreover, to disambiguate these thematic roles, one must keep the subject of the sentence in mind for a longer time in object-relative than in subject-relative sentences (Cooke et al., 2001). Thus, processing object-relative sentences is more resource demanding than is processing subject-relative sentences (e.g., Ferreira, Henderson, et al., 1996; Cooke et al.). As a result, object-relative sentences produce more comprehension errors (Just & Carpenter, 1992; Wingfield et al., 2003), increased patterns of neural activity in functional imaging studies (Cooke et al.; Just et al., 1996; Peelle, McMillan, Moore, Grossman, & Wingfield, 2004), and slower pacing patterns for both written (Stine-Morrow et al., 2000) and spoken (Waters & Caplan, 2001; Waters et al., 2003) contexts.

There is another potential load factor operative when young and older adults listen to speech. Speech rates in everyday communication range from as "slow" as 90 words per minute (wpm) in thoughtful conversation to as fast as 210 wpm for a TV or radio newsreader speaking from a prepared script (Stine, Wingfield, & Meyers, 1990). Although rapid speech rates are known to have a negative effect on recall (Wingfield, Tun, Koh & Rosen, 1999) and comprehension (Chodorow, 1979; Wingfield et al., 2003), particularly for older adults (Wingfield et al., 1999, 2003), as long as the speech remains intelligible there is no principled reason to expect speech rate to affect syntactic parsing operations at the interpretive level. Indeed, from prior results (Wingfield & Lindfield, 1995; Wingfield & Stine, 1986) one might expect speech rate to have minimal effects on young and older adults' AMW pacing patterns, in contrast to potentially prominent age effects on recall and comprehension outcome measures. Because of the natural variability in everyday speech rates (e.g., Lane & Grosjean, 1973), we presented our test materials at three different speech rates. Our goal in doing this was to ensure that any syntactically determined patterns of pacing times that might be related to age, task demands, or both would generalize across the range of speech-rate variability encountered in everyday discourse.

Our purpose in the present experiment was to examine online speech processing as a function of syntactic complexity, age, and task demands (recalling something verbatim vs responding to comprehension probes). To the extent that online interpretive sentence processing is carried by a language-specific resource not significantly diminished in normal aging (Caplan & Waters, 1999), we should observe comparable patterns of self-pacing regardless of age, speech rate, or task demands. Any interactions among these factors, however, would support the position of a single age-sensitive working memory resource that carries online sentence processing as well as higher level downstream operations (Just & Carpenter, 1992).

Methods

Participants

Participants were 24 young (8 men, 16 women) and 24 older (9 men, 15 women) adults. The young adults were university undergraduates and staff with ages ranging from 17 to 23 years (M = 19.4, SD = 1.9). The older adults were healthy, community-dwelling volunteers with ages ranging from 67 to 83 years ($M = 75.0$, $SD = 4.6$). Both groups' audiometric pure-tone thresholds (averaged across 500, 1000, and 2000 Hz) fell within the range considered to be clinically normal for speech (Hall & Mueller, 1997). Both groups were well educated, with the older adults having an average of 1.3 more years of formal education at time of testing ($M = 15.4$ years, $SD = 2.1$) than the young adults ($M = 14.1$ years, $SD = 1.9$), $t(46) = 2.20$, $p < .05$. In addition, participants were administered forward and backward word and digit spans as well as the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1997) vocabulary test. None of these variables significantly covaried with pause durations.

Stimulus Sentences

We constructed 54 active-conjoined sentences consisting of an agent, an action, a receiver, and an additional outcome (see Table 1 for an example). From each of these active-conjoined sentences we devised subject-relative and object-relative counterparts, for a total of 162 sentences. In all cases the doer and the receiver could be plausibly interchanged.

We used 6 sentence sets for a practice phase, leaving 48 sets (144 sentences) for the main experiment. All of the sentences were nine words in length. Each sentence was divided into six segments, which could consist of noun phrases (e.g., *the author*), verbs (e.g., *insulted*), or important functional elements (e.g., *that, and*). Table 1 presents the segmentation scheme for examples of the three sentence types that we employed.

All sentences were recorded by a female speaker of American English at an average speaking rate of 124 wpm. The speaker used normal intonation and paused slightly at segmentation points to minimize coarticulation effects that could render some segments unintelligible. Once the sentences were recorded, we time compressed them to 155 and 207 wpm by using SoundEdit software (Macromedia, Inc., San Francisco, CA). This method of time compression involves periodically removing small portions of the speech signal and abutting the remaining segments in time. The resulting speech thus maintains the overall intonation and relative temporal pattern of the original, but it is reproduced in less time.

Procedure

Experimenters tested participants individually in a sound-attenuated room. The experimenters told participants that as they listened to a sentence it would periodically stop. When they were ready to hear the next segment, they were to press the space bar on the computer keyboard. The experimenters instructed the participants to pace themselves through the sentence, segment by segment, until the sentence ended, and to refrain from pressing the initiation key until the current segment had finished playing and they were ready to continue. We programmed the scripting software such that accidentally pressing the key while a segment was being presented did not affect that segment or initiate the following segment.

Because word recognition processes occur as speech unfolds in time, with individual words often being recognized before their full acoustic duration has been heard (Grosjean, 1996; Marslen-Wilson, 1984; Wingfield, Lindfield, & Goodglass, 2000), the initiation point for processing time cannot be known exactly. The same argument might be made for semantic integration processes. In our procedures, we follow the approach used by Waters and Caplan (2001) by measuring pause durations from the physical offset of the segment to the keypress initiating the subsequent segment.

Experimenters informed participants that sentences would vary in "complexity" (i.e., syntax) and speech rate. A visual prompt indicated the speed of the sentence (normal, fast, or very fast) prior to each trial. Experimenters told participants that, after pacing their way through a sentence, a tone would signal them to recall the sentence aloud or to respond to a comprehension probe.

Following each sentence in the comprehension condition, participants encountered one of four types of true–false comprehension probes that appeared visually on the computer monitor. The questions tapped the thematic roles of the two characters in each sentence (e.g., *The author insulted the critic*; *The critic insulted the author*) and the characters' relation to the additional outcome (e.g., *The critic hired a lawyer*; *The author hired a lawyer*). We balanced these questions such that each type of comprehension probe was encountered an equal number of times for each syntactic type at every speech rate. We also equated the number of "true" and "false" responses. Participants responded to these questions by pressing keys on the computer keyboard labeled "true" or "false."

We blocked the sentences by task (recall vs comprehension), with half of the 144 sentences presented in each condition. Half of the young and older adults received the recall condition first, whereas the other half encountered the comprehension condition first.

We blocked the presentations by speech rate within each instruction condition, with the order of speech rates counterbalanced across young and older participants. We ensured that a quasi-random presentation of order of sentence types occurred within each rate, with the constraint that no more than three sentences of the same syntactic type could occur consecutively. We counterbalanced the stimuli such that, by the end of the experiment, each sentence was heard an equal number of times at each speech rate, in each instruction condition, and in each order of instruction condition (listening for comprehension condition first or listening for verbatim recall condition first). Prior to each task demand condition, the participants received nine practice sentences representing the three speech rates and three syntactic types, with relevant condition instructions. We did not use these sentences in the main experiment.

Experimenters presented stimuli binaurally over headphones at a comfortable listening level determined by the participants, which, once selected, remained constant throughout the experiment. A PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) computer script controlled the presentation of the stimuli

Table 2. Mean Recall and Comprehension Accuracy (% correct) for Young and Older Adults for Sentences with Three Degrees of Syntactic Complexity Heard at Each of Three Speech Rates

	Young Adults			Older Adults		
Speech Rate (wpm)	Active Conjoined	Subject Relative	Object Relative	Active Conjoined	Subject Relative	Object Relative
Recall						
124	97.8 (0.9)	99.4 (0.3)	99.0 (0.6)	97.9 (0.4)	96.9 (0.7)	96.4 (0.9)
155	98.7 (0.6)	99.3 (0.4)	99.4 (0.2)	96.9 (0.6)	97.3 (0.7)	96.3 (1.0)
207	99.0 (0.3)	99.2 (0.2)	99.1 (0.3)	93.3 (2.1)	94.8 (1.3)	93.0 (1.5)
Comprehension						
124	97.4 (1.3)	97.9 (1.2)	88.8 (3.2)	91.7 (2.8)	92.2 (2.0)	78.6 (3.2)
155	95.3 (1.6)	95.8 (1.4)	93.2 (3.1)	93.2 (2.0)	90.1 (3.0)	80.7 (3.0)
207	95.8 (1.6)	97.9 (1.0)	86.5 (3.3)	93.2 (1.7)	94.3 (1.5)	80.7 (3.0)

Notes: wpm = words per minute. Standard deviations are shown parenthetically.

and recorded the durations between the offset of a segment and the subsequent keypress for the next segment. We had responses in the recall condition recorded onto audiotape for later scoring.

Results

Recall and Comprehension Accuracy

Recall levels were high for both age groups, ranging from 93.0% to 99.4% correct across all conditions. We submitted the recall data shown in the upper portion of Table 2 to a $2 \times 2 \times 3 \times 3$ mixed-design analysis of variance (ANOVA), with age (young, older) and task order (recall condition followed by comprehension condition and vice versa) as between-participants variables and speech rate (124, 155, and 207 wpm) and sentence type (active-conjoined, subject-relative, and object-relative) as within-participant variables. To correct for heterogeneity of variance between some conditions, we adjusted all F values using the Greenhouse–Geisser correction for degrees of freedom.

As seen in the upper portion of Table 2, the recall accuracy (the percentage of words correctly recalled) of older adults was poorer than that of young adults, $F(1, 44) = 16.77$, $MSE = 0.51$, $p < .001$, $\eta^2 = .28$. As is commonly found in the aging literature (e.g., Wingfield et al., 1999), there was a significant main effect of speech rate on recall accuracy, $F(1.41, 61.94) = 4.08$, $MSE = 0.32$, $p < .05$, $\eta^2 = .08$. This effect was differentially greater for the older than for the young adults, as supported by an Age $\times$ Rate interaction, $F(1.41, 61.94) = 5.30$, $MSE = 0.32$, $p < .05$, $\eta^2 = .11$. There was no main effect of syntactic complexity on recall accuracy, $F(1.60, 70.47) = 2.20$, *ns*, nor was there an effect of task order, $F(1, 44) < 1$. With the exception of the Age $\times$ Rate interaction, no two-way or three-way interactions achieved significance (in all cases, $p > .09$). Despite their congruence with previous research, these effects should be interpreted with caution as performance was at or near ceiling in several conditions.

Although comprehension accuracy is typically expected to be higher than recall accuracy, a reverse of this trend is possible when comprehension probes are challenging, as in the present case. As one can see in the lower portion of Table 2, the percentage of comprehension probes with correct responses ranged from 78.6% to 97.4%. An ANOVA confirmed that young adults outperformed older adults, $F(1, 44) = 8.67$, $p < .01$, $MSE = 0.05$, $\eta^2 = .16$. We also observed a main effect of syntactic type, $F(1.28, 56.53) = 25.54$, $MSE = 0.03$, $p < .001$, $\eta^2 = .37$, reflecting the finding, confirmed by paired-comparison testing, that accuracy was disproportionately poorer for object-relative sentences than for the other two sentence types ($p < .05$). Neither the main effect of speech rate nor task order, nor any of the interactions, reached significance (in all cases, $p \geq .14$).

Pause Durations

Figure 1 shows the older and young adults' mean pause durations for each segment of active-conjoined, subject-relative, and object-relative sentences for the recall and comprehension conditions. Also indicated in each figure is the order in which the orienting tasks (recall or comprehension) were experienced. (Because speech rate, as we subsequently indicate, did not produce reliable effects in either subject or item analyses, we collapsed the data across the three speech-rate conditions.)

We determined data inclusion by use of three criteria. First, following Waters and Caplan (2001), we included only those trials on which listeners provided accurate comprehension responses. For the recall condition, we defined an accurate response as correct recall of at least six of the nine words in the sentence. Thus, the pause duration data focus only on the pattern observed for successful performance. Second, we discarded trials on which the overall pause duration (i.e., the sum of all pause durations per trial) exceeded 12 s. Finally, if the pause duration for a particular segment exceeded 2.5 *SD* from the mean of that segment for any given condition, then we discarded the trial. A total of 9.5% of comprehension trials and 3.5% of recall trials did not meet these criteria, and we excluded them from pause duration analyses.

We submitted the data to a $2 \times 2 \times 6 \times 3 \times 3 \times 2$ mixed-model ANOVA, with task order (recall followed by comprehension and vice versa) and age (young, older) as between-participants variables, and segment (NP1, NP2, NP3, V1, V2, C), syntax (syntactic complexity: active-conjoined, subject-relative, and object-relative), speech rate (124, 155, and 207 wpm), and task demands (recall, comprehension) as within-participants variables. As in the accuracy analysis, we adjusted all F values using the Greenhouse–Geisser correction. All reported post hoc results are Bonferroni corrected.

Responsiveness to variations in sentence structure.—Our first task in this analysis was to confirm that our procedures reproduced an effect of syntactic structure on participants' pacing times within sentences, and that the patterns obtained were consistent across age groups (Waters & Caplan, 2001). As would have been expected from this prior work, pause durations varied across the segments, $F(1.69, 74.47) = 55.21$, $MSE = 1{,}458, 412.73$, $p < .001$, $\eta^2 = .56$, with pause times generally increasing with syntactic complexity, $F(1.57, 68.95) = 41.26$, $MSE = 77, 679.75$, $p < .001$, $\eta^2 = .48$. As expected, object-relative sentences required more processing time than did active-conjoined sentences ($p < .001$) or subject-relative sentences ($p < .001$).

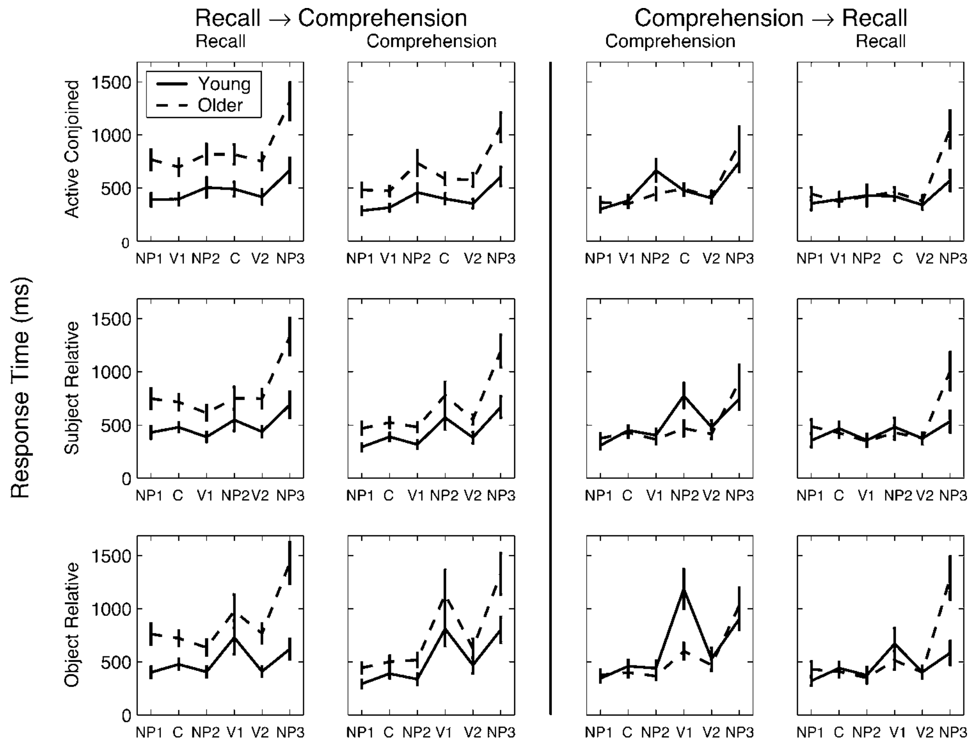

Figure 1. Pause durations across segment positions as a function of orienting task, age, order of tasks, and syntactic complexity. Arrows indicate when recall preceded comprehension or comprehension preceded recall, as shown in left and right panels, respectively. (Note: NP = noun phrase; *V* = verb; *C* = conjunction or complementizer).

In addition, pause durations interacted with syntactic complexity, $F(2.14, 94.26) = 32.76$, $MSE = 558, 443.65$, $p < .001$, $\eta^2 = .43$. Figure 1 shows the typical "scalloping" pattern of longer pause times following major internal linguistic boundaries, which occur at NP2 in active-conjoined and subject-relative sentences and at V1 in object-relative sentences (see Table 1). This pattern, along with increased pause times at the ends of sentences (sentence "wrap up" effects), replicates the commonly found patterns in both AMW listening-time and reading-time studies (cf. Waters & Caplan, 2001; also see Stine, 1990). We confirmed this interpretation by post hoc analyses.

As found by Waters and Caplan (2001), although older adults were generally slower in pause times than their younger counterparts were, $F(1, 44) = 7.20$, $MSE = 4{,}774, 750.02$, $p < .05$, $\eta^2 = .14$, this effect was moderated by an Age × Segment interaction, $F(1.69, 74.47) = 11.28$, $MSE = 1{,}458, 412.73$, $p < .001$, $\eta^2 = .20$. This interaction occurred primarily because older adults paused longer after final segments than did young adults ($p < .001$), a finding consistent with Waters and Caplan.

The argument in favor of an age-independent sentence-specific resource as proposed by Waters and Caplan (2001; also see Caplan & Waters, 1999) was supported by the similarity in the pattern of young and older adults' AMW pause times across syntactic types. There was no significant interaction between age and syntax, $F(1.57, 68.95) = 2.57$, *ns*, nor did we observe an Age × Syntax × Segment interaction, $F(1.97, 86.66) = 1.47$, *ns*. Thus, the young and older participants' patterns of pause durations displayed comparable responsiveness to variations in syntactic structure.

Effects of speech rate.—Speech rate did not exert a significant effect on pause durations, $F(1.79, 78.90) = 1.70$, *ns*, and no interactions with speech rate achieved significance.

Effects of task demands.—Given this general demonstration of age invariance in response to internal syntactic structure of sentences, our questions of interest were whether these effects would be moderated by the task demands imposed on the listeners and whether task demands might affect pacing times differently for the two age groups. Although the main effect of task demand was not significant, $F(1, 44) = 1.14$, *ns*, task demands interacted with a number of other variables, including age, $F(1, 44) = 6.81$, $MSE = 806, 395.53$, $p < .05$, $\eta^2 = .13$; syntactic complexity, $F(1.71, 75.01) = 12.18$, $MSE = 47, 128.03$, $p < .001$, $\eta^2 = .22$; and segment position, $F(1.54, 67.76) = 5.56$, $MSE = 498, 165.28$, $p < .05$, $\eta^2 = .11$. There was also a significant Task × Syntax × Segment interaction, $F(3.99, 175.47) = 8.11$, $MSE = 115, 768.42$, $p < .001$, $\eta^2 = .16$. As we indicated earlier, one would not expect to see these main effects and interactions on patterns of pause times if these pause times were governed by an independent language-specific resource.

An inspection of Figure 1 reveals the prominent effects of task demands that gave rise to the aforementioned interactions. Segment V1 (clause boundary for object-relative sentences) elicited longer pause durations for object-relative sentences than it did for active-conjoined or subject-relative sentences in the recall condition (in both cases, $p < .01$); this pattern was more marked when participants were listening for comprehension (in both cases, $p < .001$). In the comprehension condition, segment NP2 (the clause boundary for active-conjoined and subject-relative sentences) elicited shorter pause durations for object-relative sentences than for active-conjoined and subject-relative sentences (in both cases, $p < .001$).

Effects of task order.—Although the predictions of a sentence-specific resource account centered on the question of whether task demands would influence the patterns of pause durations, we also found significant effects related to task order. Although the main effect of task order was not significant, $F(1, 44) = 3.53$, *ns*, there was a significant interaction between task order and task demands, $F(1, 44) = 8.91$, $MSE = 806, 395.53$, $p < .01$, $\eta^2 = .17$, reflecting disproportionately long pause durations in the recall condition when recall preceded comprehension. A two-way interaction between task order and age, $F(1, 44) = 5.15$, $MSE = 4{,}774, 750.02$, $p < .05$, $\eta^2 = .10$, indicated that older adults exhibited significantly longer pause durations when recall preceded comprehension ($p < .01$). By contrast, young adults' pause durations did not differ as a function of task order.

In addition to the aforementioned main effects and interactions, there was also a five-way Task order × Task demands × Syntax × Age × Segment interaction, $F(3.99, 175.47) = 2.58$, $MSE = 115, 768.42$, $p < .05$, $\eta^2 = .06$. To clarify the meaning of this five-way interaction, we conducted two subsidiary ANOVAs, one isolating the condition in which recall preceded comprehension, and a second for the condition in which comprehension preceded recall.

For both orders, syntactic complexity, Fs > 20.10, ps $< .001$, η^2s $> .48$, and segmentation position, Fs > 27.77, ps $< .001$, η^2s $> .55$, affected pause durations in the manner described previously. We also observed several interactions across orders, including Segment × Age, Fs > 4.43, ps $< .05$, η^2s $> .16$; Task × Syntax, Fs > 3.89, ps $< .05$, η^2s $> .15$; Syntax × Segment, Fs > 11.32, ps $< .001$, η^2s $> .34$; and Task × Syntax × Segment, Fs > 3.51, ps $< .05$, η^2s $> .13$.

However, as we already described, main effects of age and task occurred only when the recall condition occurred first: older adults exhibited longer pause durations than did young adults $F(1, 22) = 10.59$, $MSE = 1{,}843, 305.42$, $p < .01$, $\eta^2 = .33$, and pause durations were generally longer in the recall condition than in the comprehension condition, $F(1, 22) = 9.26$, $MSE = 238, 405.24$, $p < .01$, $\eta^2 = .30$.

We observed several interactions only when the comprehension condition occurred first. Pause durations at major internal boundaries (i.e., segment NP2 in active-conjoined and subject-relative sentences, and segment V1 in object-relative sentences) were more pronounced in the comprehension condition than in the recall condition, as indicated by a Task × Segment interaction, $F(1.75, 38.50) = 3.35$, $MSE = 136, 787.97$, $p = .05$, $\eta^2 = .13$. This pattern was more pronounced for young adults than for older adults, as confirmed by a Task × Segment × Age interaction, $F(1.75, 38.50) = 4.06$, $MSE = 136, 787.97$, $p < .05$, $\eta^2 = .16$. This three-way interaction was also driven by older adults' disproportionately long wrap-up effects compared with those of young adults in the recall condition. There was a significant Task × Syntax × Age interaction, $F(1.50, 32.91) = 4.39$, $MSE = 16, 414.21$, $p < .05$, $\eta^2 = .17$, reflecting young adults' longer pause durations with increasing syntactic complexity, particularly in the comprehension condition. These interactions culminated in a Task × Syntax × Segment × Age interaction, $F(3.73, 82.01) = 2.78$, $MSE = 38, 674.50$, $p < .05$, $\eta^2 = .11$. The differential effects of syntax, age and task demands specific to each task order represent the significant interactions that would be expected according to a single-resource account.

Discussion

In the present study we adopted the position of Waters and Caplan (2001; also see Waters et al., 2003) that the pattern of pause durations observed when listeners pace themselves through recorded sentences is a valid assay of resource allocation in online sentence processing (also see Ferreira, Anes et al., 1996; Ferreira, Henderson et al., 1996). Consistent with Waters and Caplan's previous findings, we observed that young and older participants' patterns of pause durations displayed comparable responsiveness to variations in syntactic structure. Specifically, both young and older listeners paused differentially longer at clause boundaries than at points within clauses, resulting in a scalloped pattern of pause durations. Listeners also demonstrated a wrap-up effect, in the form of longer pause durations at the ends of sentences.

The similarity between young and older adults in this sensitivity to syntactic structure as reflected in AMW pause times has been taken as support for the hypothesis that online interpretive processing of spoken sentences draws not on a general age-sensitive working memory resource, but on a separate sentence-processing resource that is not significantly diminished by adult aging (Caplan & Waters, 1999). Consistent with this view is our additional finding that the pattern of pause durations across sentences was unaffected by moderate variations in speech rate for both age groups. A differential effect of speech rate did appear for recall accuracy, which would be consistent with the notion that age differences, when they occur, are primarily in postinterpretive operations such as recall performance.

An added factor in this present study, however, was a manipulation of the task demands imposed on participants. If online sentence processing is carried by a specialized resource independent of general working memory resources that constrain postinterpretive processes, then participants' online pacing patterns should be unaffected by the postinterpretive goals of sentence recall or responding to comprehension probes. The current data do not support the separate-sentence-interpretation resource theory (Caplan & Waters, 1999), as there were significant age differences in the patterns of pause durations when participants were listening for verbatim recall or for comprehension. The contrast to the separate-sentence-resource account, as indicated earlier, is a single-resource account (e.g., Just & Carpenter, 1992) that postulates that the various processes involved in language comprehension (semantic, syntactic, and discourse levels of analysis) all draw on a single, capacity-limited resource pool (Carpenter et al., 1994). Consistent with the single-resource account, the differences in global task demands, listening for comprehension or for verbatim recall, appeared to draw differentially on listeners' processing resources and hence affected their pacing.

We found further support for the single-resource account in the age differences arising from the order in which the two orienting tasks were experienced. When the young adults experienced the recall condition first, they exhibited comparable patterns of pause durations across both orienting conditions and levels of syntactic complexity. By contrast, when the comprehension condition occurred first, the young adults moved especially slowly at major linguistic boundaries under comprehension instructions. Their patterns of pacing in the proceeding recall condition, however, were reasonably fast paced. The order effects for the older adults were different. Older adults who received the comprehension condition before the recall condition exhibited comparable patterns of pause durations across both orienting tasks. However, when older adults received the recall condition first, they displayed longer pause durations in that condition than their counterparts experiencing the reverse order. In summary, although both young and older adults changed their pacing patterns in response to the perceived demands imposed by the task, the two age groups were affected differently by the order of the two tasks.

This demonstration of an age difference in resource allocation according to task and task order may have been driven by age differences in perceived self-efficacy. Considerable evidence suggests that older adults not only show declines in rote memory ability (Kausler, 1994; Wingfield & Kahana, 2002) but they typically have acute awareness and concern about this fact (Erber et al., 1996; Rahhal et al., 2001). Indeed, Hess and colleagues (2003) have suggested that simply participating in a laboratory experiment that is testing recall may activate or enhance older adults' negative beliefs about age decrements in memory. Such anxiety may be related to age differences in text comprehension in the sense that undergraduates may rely on verbatim memory to aid their text comprehension (presumably due to their honing of such skills to succeed academically), whereas older adults generally depend upon gist-based representations (Radvansky, 1999). Therefore, older adults may have experienced less anxiety over listening for comprehension than listening for recall. Under the present circumstances, older adults' memory concerns might have been exacerbated by our presenting the recall condition first, resulting in older adults' disproportionately slow pacing times when the recall condition preceded the comprehension condition. It should be noted, however, that this may be a reflection of intention, rather than necessarily having an effect on recall or comprehension performance, a phenomenon sometimes referred to as a *utilization deficiency* (Miller, 1990). Although age differences in perceived self-efficacy may shed light on older adults' resource allocation, it is unclear how our present understanding of young adults' self-efficacy can explain their greater sensitivity to syntactic complexity in the comprehension condition only when it preceded the recall condition.

Our suggestion that these data argue against an age-independent separate sentence-processing resource of the sort proposed by Caplan and Waters (1999) assumes that the pacing patterns observed in the AMW task are indeed a reflection of online sentence processing. To the extent that the measure itself is contaminated by postinterpretive operations and listening goals, one would need to reevaluate these findings and the suggestions in the literature that AMW patterns are uniquely reflective of online sentence-processing operations.

Whether the constraint is operating at the interpretive or postinterpretive level, however, it is clear that the young and older adults in the present study paced themselves through speech quite differently in response to task demands. In this case, the tasks demands were listening for verbatim recall versus listening for a later test of comprehension. Although this question was the initial focus of this study, one should not ignore the intriguing finding of the differential slowing in older adults' pacing times under comprehension instructions when this condition immediately followed the verbatim recall condition. As we have indicated, this recall-first ordering may have given salience to older adults' memory concerns, an indication of stereotype threat (Hess et al., 2003) or challenge to a sense of self-efficacy (Cavanaugh & Green, 1990; Lachman & Jelalian, 1984). If so, this would be a demonstration of such effects not only on outcome measures but on the way older adults allocate their attentional resources while listening to the speech itself. This interpretation points to the need for traditional studies of age, memory, and language processing to include considerations of differential effects of task demands and of age differences in real and perceived self-efficacy.

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REFERENCES

Caplan, D., & Waters, G. S. (1999). Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences, 22*, 77–126.

Carpenter, P. A., Miyaki, A., & Just, M. A. (1994). Working memory constraints in comprehension: Evidence from individual differences, aphasia, and aging. In M. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 1075–1122). San Diego, CA: Academic Press.

Cavanaugh, J. C., & Green, E. E. (1990). I believe, therefore I can: Self-efficacy beliefs in memory aging. In E. A. Lovelace (Ed.), *Aging and cognition: Mental processes, self-awareness, and interventions* (pp. 189–230). Oxford: North-Holland.

Chodorow, M. S. (1979). Time-compressed speech and the study of lexical and syntactic processing. In W. E. Cooper & E. C. T. Walker (Eds.), *Sentence processing: Psycholinguistics studies presented to Merrill Garrett* (pp. 87–111). Hillsdale, NJ: Erlbaum.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments and Computers, 25*, 257–271.

Cooke, A., Zurif, E. B., DeVita, C., Alsop, D., Koenig, P., Detre, J., et al. (2001). Neural basis for sentence comprehension: Grammatical and short-term memory components. *Human Brain Mapping, 15*, 80–94.

Erber, J. T., Prager, I. G., Williams, M., & Caiola, M. A. (1996). Age and forgetfulness: confidence in ability and attribution for memory failures. *Psychology and Aging, 11*, 310–315.

Ferreira, F., Anes, M. D., & Horine, M. D. (1996). Exploring the use of prosody during language comprehension using the auditory moving window technique. *Journal of Psycholinguistic Research, 25*, 273–290.

Ferreira, F., Henderson, J. M., Anes, M. D., Weeks, P. A., & McFarlane, D. K. (1996). Effects of lexical frequency and syntactic complexity in spoken-language comprehension: Evidence from the auditory moving-window technique. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 324–335.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition, 68*, 1–76.

Grosjean, F. (1996). Gating. *Language and Cognitive Processes, 11*, 597–604.

Hall, J., & Mueller, G. (1997). *Audiologist desk reference.* San Diego, CA: Singular Publishing.

Hertzog, C., Dixon, R. A., & Hultsch, D. F. (1990). Relationships between metamemory, memory predictions, and memory task performance in adults. *Psychology and Aging, 5*, 215–227.

Hess, T. M., Auman, C., Colcombe, S. J., & Rahhal, T. A. (2003). The impact of stereotype threat on age differences in memory performance. *Journal of Gerontology: Psychological Sciences, 58B*, P3–P11.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122–149.

Just, M. A., Carpenter, P. A., Keller, T. A., Eddy, W. F., & Thulborn, K. R. (1996). Brain activation modulated by sentence comprehension. *Science, 274*, 114–116.

Kausler, D. H. (1994). *Learning and memory in normal aging.* San Diego, CA: Academic Press.

Kemper, S. (1992). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *Handbook of aging and cognition* (pp. 213–270). Hillsdale, NJ: Erlbaum.

Kieras, D. E. (1981). Component processes in the comprehension of simple prose. *Journal of Verbal Learning and Verbal Behavior, 20*, 1–23.

Lachman, M. E., & Jelalian, E. (1984). Self-efficacy and attributions of intellectual performance in young and elderly adults. *Gerontology, 39*, 577–582.

Lane, H., & Grosjean, F. (1973). Perception of reading rate by speakers and listeners. *Journal of Experimental Psychology, 97*, 141–147.

Marslen-Wilson, W. D. (1984). Function and process in spoken word recognition: A tutorial review. In H. Bouma & D. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 125–148). Hillsdale, NJ: Erlbaum.

Miller, P. H. (1990). The development of strategies of selective attention. In D. F. Bjorkland (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 157–184). Hillsdale, NJ: Erlbaum.

Peelle, J. E., McMillan, C., Moore, P., Grossman, M., & Wingfield, A. (2004). Dissociable patterns of brain activity during comprehension of rapid and syntactically complex speech: Evidence from fMRI. *Brain and Language, 91*, 315–325.

Radvansky, G. A. (1999). Aging, memory, and comprehension. *Current Directions in Psychological Science, 8*, 49–53.

Rahhal, T. A., Hasher, L., & Colcombe, S. J. (2001). Instructional manipulations and age differences in memory: Now you see them, now you don't. *Psychology and Aging, 16*, 697–706.

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging.* Hillsdale, NJ: Erlbaum.

Stine, E. A. L. (1990) . On-line processing of written text by younger and older adults. *Psychology and Aging, 5*, 68–78.

Stine, E. A. L., Wingfield, A., & Meyers, S. D. (1990). Age differences in processing information from television news: The effects of bisensory augmentation. *Journal of Gerontology: Psychological Sciences, 45*, 1–8.

Stine-Morrow, E. A. L., Milinder, L. A., Pullara, O., & Herman, B. (2001). Patterns of resource allocation are reliable among younger and older readers. *Psychology and Aging, 16*, 69–84.

Stine-Morrow, E. A. L., Ryan, S., & Leonard, J. S. (2000). Age differences in on-line syntactic processing. *Experimental Aging Research, 26*, 315–322.

Warren, T., & Gibson, E. (2002). The influence of referential processing on sentence complexity. *Cognition, 85*, 79–112.

Waters, G. S., & Caplan, D. (2001). Age, working memory, and on-line syntactic processing in sentence comprehension. *Psychology and Aging, 16*, 128–144.

Waters, G. S., & Caplan, D. (2002). Working memory and online syntactic processing in Alzheimer's disease: Studies with auditory moving window presentation. *Journal of Gerontology: Psychological Sciences, 57B*, P298–P311.

Waters, G. S., Caplan, D., & Yampolsky, S. (2003). On-line syntactic processing under concurrent memory load. *Psychonomic Bulletin and Review, 10*, 88–95.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* (3rd ed.). New York: Psychological Corporation.

Wingfield, A., & Kahana, M. J. (2002). The dynamics of memory retrieval in older adulthood. *Canadian Journal of Experimental Psychology, 56*, 187–199.

Wingfield, A., & Lindfield, K. C. (1995). Multiple memory systems in the processing of speech: Evidence from aging. *Experimental Aging Research, 21*, 101–121.

Wingfield, A., Lindfield, K. C., & Goodglass, H. (2000). Effects of age and hearing sensitivity on the use of prosodic information in spoken word recognition. *Journal of Speech, Language, and Hearing Research, 43*, 915–925.

Wingfield, A., Peelle, J. E., & Grossman, M. (2003). Speech rate and syntactic complexity as multiplicative factors in speech comprehension by young and older adults. *Aging, Neuropsychology, and Cognition, 10*, 310–322.

Wingfield, A., & Stine, E. A. L. (1986). Organizational strategies in immediate recall of rapid speech by young and elderly adults. *Experimental Aging Research, 12*, 79–83.

Wingfield, A., Tun, P. A., Koh, C. K., & Rosen, M. J. (1999). Regaining lost time: Adult aging and the effect of time restoration on recall of time-compressed speech. *Psychology and Aging, 14*, 380–389.

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