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The Contribution of Set Switching and Working Memory to Sentence Processing in Older Adults

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Abstract

This study evaluates the involvement of switching skills and working memory capacity in auditory sentence processing in older adults. We examined 241 healthy participants, aged 55 to 88 years, who completed four neuropsychological tasks and two sentence-processing tasks. In addition to age and the expected contribution of working memory, switching ability, as measured by the number of perseverative errors on the Wisconsin Card Sorting Test, emerged as a strong predictor of performance on both sentence processing tasks. Individuals with both low working-memory spans and more perseverative errors achieved the lowest accuracy scores. Our findings are consistent with compensatory accounts of successful performance in older age.

Introduction

Our goal in this study was to examine the extent to which working memory, inhibition, and switching control contribute to age-related language processing difficulties. Researchers who study language changes associated with healthy aging have reported that whereas language skills are generally preserved across the adult lifespan, language-comprehension skills, and specifically those associated with sentence processing, show decline in older age (e.g., DeDe et al., 2004; Wingfield, Peelle, & Grossman, 2003; Wingfield & Stine-Morrow, 2000).

Evidence for this decline comes predominantly from cross-sectional comparisons of young and old adults. In such studies, older adults have been found to be less accurate in judging the plausibility of spoken sentences or answering verification questions after they listen to spoken sentences, but not under all conditions. For example, Obler, Fein, Nicholas, and Albert (1991) employing a sentence verification task (“was the bureaucrat dishonest?”) found that older individuals made more errors than younger adults on complex sentences,

such as those containing two negatives (e.g., “The bureaucrat who was not dishonest refused the bribe”). The authors compared four age groups (30–39, 50–59, 60–69, and 70–79) and found main effects of age and of sentence structure, with older people making more errors than younger participants. Obler et al. also found a significant interaction between age and sentence structure for error rate (but no significant age by sentence structure interaction for response times). The findings showed that older adults were slower than younger adults on all sentence types – with no observed specific slowing on selected sentence structures – but made proportionately more errors on the more complex sentences. Waters & Caplan (2005) also found that older persons (mean age = 71) were less accurate at making plausibility judgments than younger participants (mean age = 21) in responding to cleft-object sentences (e.g., “It was the child that the movie terrified because it showed a monster.”) but not to other sentence structures included in their study (e.g., subject-relatives: “It was the movie that terrified the child because it showed a monster.”). This was confirmed by a significant main effect of sentence type and of age group, as well as significant sentence-type by age-group interaction. In that study, the sentences that proved particularly difficult were those whose structure is hypothesized to impose greater working memory demands during processing. Specifically, object-relative embedded sentences require that the listeners hold in memory the first portion of the sentence until they resolve whether the action is attributed to the first noun phrase (the subject of the main clause but the object of the embedded clause) or to the second noun phrase (the subject of the embedded clause) (see more on the cognitive demands of object-relative sentences below).

Age-related accuracy differences in sentence processing are not consistently found. Wingfield et al. (2003) employed sentences with structures similar to those used in the studies mentioned above (e.g., subject and object relatives) but found that older adults (mean age = 72) were slower, but no less accurate, than younger adults (mean age = 19). The task was to judge whether the actor of the action in the sentence was male or female; for example, the participants heard the sentence: “Boys that help girls are caring” and were asked to respond with the appropriate button press. But when Wingfield et al. presented the sentences at faster-than-normal speech rates, the older participants were less accurate than the younger ones. As in the RT results in Obler et al. (1991) (but unlike their error rate data), sentence structure did not interact with age, suggesting that all participants had more difficulty with the more demanding sentence structures (e.g., object relatives) and that it was not the case that the older participants had proportionally lower accuracy with demanding sentence structures. In sum, older participants have been reported, under some circumstances, to be less accurate than their younger peers on tests of spoken-language sentence processing, particularly with complex sentence structures.

Results from such studies lead to the following question: What, precisely, is the role of age in sentence-processing difficulties? That is, the finding of group differences in performance when 20-year-olds and 70-year-olds are compared could be interpreted as age-related differences in language processing, but could also be accounted for by other variables. For example, processing speed could contribute to age differences in sentence processing. It has been repeatedly demonstrated that information processing slows with age (e.g., Boyle et al., 2008; Salthouse, 1996); performance on experimental tasks such as listening to sentences and making plausibility judgments is likely to be affected by the speed with which the information presented is processed and a decision for a response is made. In addition to age-related reduced speed of processing, differences that are more specific to the task of sentence processing may explain variability in performance as follows.

In studies of young adults, differences in sentence processing have been associated with both linguistically-based and cognitively-based accounts. For example, King and Just (1991) demonstrated that for healthy, younger individuals processing embedded sentences, object-

relative (OR) embedded sentences (e.g., “The reporter that the senator attacked admitted the error”) are more difficult to process than subject-relative (SR) sentences (e.g., “The reporter that attacked the senator admitted the error”) and sentences without embedding. Linguistically, OR sentences are considered syntactically more complex than SR sentences for at least two reasons. First, the embedded clause (“that the senator attacked” in the example above) interrupts the main clause (“the reporter admitted the error”) in OR sentences but not in SR sentences; second, in OR sentences, there are two different nouns that carry the thematic role of *agent* (“the reporter” in the main clause, “the senator” in the embedded clause), whereas it is the same noun that is the *agent* of both clauses in SR sentences (“the reporter”).

From a cognitive perspective, one might argue that OR sentences would yield lower accuracy scores than SR sentences because the two sentence structures differ in the amount of cognitive resources (such as working memory) they demand (see Real & Christiansen, 2007). Perhaps the most prominent cognitive explanation of complex sentence processing difficulties is the dependency locality theory (DLT; Gibson, 1998; 2000). Gibson and others have argued that the added cognitive burden of the long-distance dependency in OR embedded sentences results from the cost of carrying the dependency in working memory over the distance (e.g., from the first to the second clause of the embedded sentence) and from the cost of integrating it into the sentence.

In the cognitive aging literature, some researchers have employed a working memory (WM) explanation for sentence processing difficulty (e.g., Just & Carpenter, 1992). WM has been defined as the ability to simultaneously store and process information (Baddeley, 2003). Just and colleagues have suggested that older adults’ difficulty in processing complex sentences (such as those containing embedded clauses and those containing negation) is the result of reduced WM span, as this has been shown to decline with advancing age (Salthouse, 1994; Wingfield et al., 1998). Others (e.g., Waters & Caplan, 2001), by contrast, have argued for a more limited role of WM in sentence processing. Their separate-sentence-interpretation resource theory suggests that resources used for language processing are distinct from general working-memory capacity and in this their theory stands in contrast to single-resource accounts (such as working memory or speed of processing) (e.g., Just & Carpenter, 1992; Salthouse, 1988a, 1988b, 1991). To date, the role of working memory in complex-sentence processing remains undetermined, and there is evidence that additional cognitive abilities contribute to successful language processing (e.g., Kane & Engle, 2002). For example, inhibition efficiency may be required to clear previously processed information out of the listeners’ WM; switching mechanisms may be required to allow efficient shifting from one sentence structure to another (e.g., Lustig et al., 2001; Kane et al., 2001). Inhibition and switching skills have been shown to decline with advancing age (e.g., Moscovitch & Winocur, 1992; Rhodes, 2004; Wecker et al., 2000); however, limited data are available, to our knowledge, to illustrate how these changes interact with language processing. Hasher, Zacks, and colleagues have proposed that impaired inhibition skills explain older adults’ relatively poor performance on spoken-language comprehension (e.g., Hasher & Zacks, 1988), but their inhibition-deficit hypothesis has been rejected by others (at least for naming performance, e.g., Cross & Burke, 2004; Paul, 1996).

In this paper we ask whether inhibition and switching control skills assist in sentence processing performance in older age beyond the contribution of working-memory abilities. These skills can be hypothesized to directly facilitate aspects of the sentence-processing tasks we used. Specifically, in both our sentence tasks, lexical items are rearranged in three sentence structures to examine the role of sentence structure on performance. In the Embedded Sentences Task we used, similar lexical items appear in an object-relative sentence, a subject-relative sentence, and a coordinate sentence (see examples in Methods

below). Therefore, the participants need to inhibit their previous judgment of a similar sentence when listening to another variation of a sentence previously heard. Furthermore, because the sentences are presented in mixed, rather than blocked conditions, the participants need to switch among three syntactic structures in their processing of the presented stimuli.

In our analyses, we examined working memory, inhibition, and switching abilities – in addition to age, gender, education, and hearing acuity – as predictors of accuracy on spoken-language sentence processing to answer two questions: 1) Can we detect age-related accuracy differences in sentence processing among participants sampled from middle-aged and older adults (rather than two extreme age groups)? From the current literature it is unclear when in the adult lifespan sentence-processing differences might become evident and whether age differences can be found between less extreme ages, for which cohort effects might be reduced (e.g., between individuals in their 50s or 60s and those in their 70s or 80s). And, 2) Do differences in cognitive abilities, specifically inhibition and switching abilities, in addition to those of WM, account for age-related differences in sentence processing skills? We predicted that not only WM span, but also switching and inhibition control, contribute to age-related differences in performance.

Method

Participants

The sample included 241 native speakers of English from the greater Boston area, aged 55 to 88, with a mean age of 71. Exclusion criteria comprised history of stroke, loss of consciousness for over two hours, multiple concussions, neurodegenerative disorders, schizophrenia or bipolar disorder, electroconvulsive therapy, dialysis or interferon treatment at time of testing, general anesthesia within six months, chemotherapy or radiation treatment within one year, non-native knowledge of English, and a Mini-Mental State Exam score lower than 28 (out of 30)¹. Participant information is presented in Table 1.

Procedures

As part of a larger ongoing study (Language in the Aging Brain, [LAB]), we administered two sentence-processing tasks – an Embedded Sentences Task and a Multiple Negatives Task – and a selection of cognitive tests. We also tested participants' hearing thresholds. Each participant was tested individually in two sessions that included the tests listed below (as well as additional tests, not reported here²).

Sentence processing

Two sentence processing tasks (Embedded Sentences and Multiple Negatives), developed in our laboratory, were administered auditorily, through headphones, with output levels adjusted for each participant to a comfortable listening level. In both tasks, participants listened to pre-recorded sentences spoken in normal speech rate and were asked to judge whether each sentence was “likely to be true” or “unlikely to be true.” Half of the sentences were plausible sentences and half were implausible³. E-Prime software (Psychology Software Tools, Inc.) was used to record accuracy (and response time⁴) data. Correct and incorrect responses for each individual for each item in each task were recorded. We then

¹We selected individuals who performed high on the MMSE to assure a sample of healthy aging. It is possible, albeit less likely, that individuals with mild cognitive impairment will perform high on the MMSE. When we repeated the analyses including individuals with lower MMSE scores (26–30), the results were largely unchanged.

²The tests reported here are part of a larger battery administered to these participants in the Language in the Aging Brain project. Additional tests include naming and memory test. In this paper, we chose to focus only on the relations between sentence processing and three cognitive domains: working memory, inhibition, and switching, and so we report data from relevant tests.

computed the percent correct responses (number of correct responses of the correctly administered items) for each participant.

Embedded Sentences Task—The participants listened to 96 sentences varying in length from 9 to 12 words, divided into three blocks of 32 sentences each. The sentence list contained four types of sentences. There were 72 experimental sentences of three types: 24 subject-relative (e.g., “The firefighter that rescued the toddler broke the window.”), 24 object-relative (e.g., “The toddler that the firefighter rescued broke the window.”), and 24 control sentences with no center-embedding (e.g., “The firefighter rescued the toddler after the toddler broke the window.”). The list included also 24 fillers, in which the embedded clause appeared at the end of the sentence (e.g., “The agent represented the actor that the director dated.”). The sentences in the different sentence structures did not differ in mean word length.

Multiple Negatives Task—The sentence list comprised 50 sentences: Ten 10-word sentences had no negatives (e.g., “Because the ceiling light is off, the room is dark.”), 10–11-word sentences had one negative (e.g., “Because the ceiling light is not on, the room is dark.”), and 10–12-word sentences contained two negatives (e.g., “Because the ceiling light is not off, the room is not dark.”). Because the sentences that included one and two negatives were longer than those that did not include any negatives we added two conditions: ten 11-word and 10–12-word sentences with no negatives, to control for sentence length (“e.g., “Because the knife was sharp, it could cut the large turkey.”).

Cognitive abilities

Performance on four neuropsychological tests that assess working memory, inhibitory, and switching abilities was examined. As described above, these abilities are hypothesized to contribute to successful performance on sentence processing and have been documented to change with aging.

The Wisconsin Card Sorting Test (WCST) computerized version (Heaton, 1993)—Participants were presented with cards and were instructed to sort them on the basis of a target criterion (color, shape, or number) but were not told what the criterion was. After ten successful trials, the sorting criterion changed without notice; the participants were required to adjust to the new sorting criterion and continue sorting the cards. Several outcome measures are associated with this test. In this study, we included in our analyses three of the most commonly used measures: number of categories completed, total correct responses, and the percent of perseverative errors (Berg, 1948; Miyake et al., 2000). In a meta-analytic review of studies examining age and performance on the WCST, percent perseverative errors was found to be particularly sensitive to age-related differences (Rhodes, 2004).

The Stroop Test (Stroop, 1935)—We used the written version of the Stroop test in which participants were shown a card with printed color words. The color of the ink and the name of the color word were incongruent (e.g., the color word “blue” was written in red ink). In the first condition (word), they were instructed to read aloud as many words as possible in two minutes. In the second (color) condition, they were instructed to name the color of the ink in which the words were printed. The number of items named correctly in

³ Half of the participants were instructed to press a response button with their right hand when they thought the sentence was plausible (“likely to be true”) and with the left hand when they thought the sentence was implausible (“unlikely to be true”); the other half pressed with the left hand for plausible sentences and the right hand for implausible ones. The data were collapsed for the analysis.

⁴Response time data are not reported in this paper.

each condition was recorded. The Stroop interference score was calculated as the difference between the number of words read in the first condition and number of colors named in the second condition. Such interference measure is associated with ability to inhibit automatically activated information.

The Trails Test (Spreen & Strauss, 1991)—In this paper-and-pen test, participants were asked to connect numbers (Trails A) and then numbers and letters in an alternating pattern (e.g., 1-A–2-B, etc.) (Trails B). The relative time to complete part B, i.e., the difference between the time it took to complete part A and part B, was measured. Better performance on this measure has been associated with good alternating attention skills.

Month Ordering Task—In this working memory task, modeled on MacDonald et al. (2001), participants listen to series of months and are instructed to repeat them back in order as they would be found on a calendar. The task continues with increasingly larger lists of months being read, until the participant no longer repeats them correctly. The highest level at which the participant's recall is correct is his or her span.

Hearing

Participants' hearing thresholds were tested using pure tone average (PTA) and speech recognition threshold (SRT). PTA values were obtained for four frequencies (500, 1000, 2000, and 4000 Hz.). SRTs were then tested using Spondee Word Lists (Auditec of St. Louis). The SRTs values⁵ for the better ear were used as the outcome measure.

Analyses

We employed a mixed logistic regression model (Molenberghs & Verbeke, 2005), analyzing item-level data for the two sentence tasks for each participant. Mixed logistic regression addresses two primary issues of this study: responses are skewed binary data, and they are repeated measures. Logistic regression permits the use of the binary response and the mixed component -- analogous to a hierarchical linear model for continuous normal responses

Missing data were addressed by multiple imputation (Graham, 2009). MI simulates values from the predictive distributions of the missing data, given the observed data, in multiple datasets, which are then analyzed in the usual way and averaged optimally. MI is substantially more efficient than listwise deletion/complete case analysis, especially for the present case because missingness on indicators typically requires that all of a participant's data be dropped if any of their covariates are missing⁶. Subsequent data analysis was done in Stata 10.1 (StataCorp, 2007) using the xtlogit program. No problems were observed with convergence in any of the MI replications.

Covariates were entered into the model predicting accuracy on the ES or MN tasks. These included, in addition to sentence structure, the following participant-level demographic – age, education, gender, MMSE scores, and hearing sensitivity – and cognitive – Month Ordering Task (WM span), Stroop interference (inhibition), Trails B relative time

⁵Hearing acuity was tested in a sound-treated booth for the majority of the participants; however a portion of the participants were tested in a quiet room. To adjust for this difference, we regressed each participant's speech thresholds on the type of room (booth or quiet room) in which they were tested. We adjusted for the use of a hearing aid and for whether the participant reported any of three hearing related issues: having a hearing loss in one or both ears, having trouble hearing even when wearing a hearing aid, and being treated for hearing problems. The predicted scores for each participant were then used as the hearing acuity measure.

⁶Handling missing data was particularly important because one of our covariates, the Wisconsin Card Sorting Task, had a great deal of missingness (if participants had already taken the WCST, it would not be meaningful to administer it to them again). MI allows us to make use of partially observed cases which would otherwise get thrown out but are often quite informative. Amelia II software (Honaker, King, & Blackwell, 2007) was used to generate ten imputations, in accordance with standard recommendations. A very mild prior was necessary to obtain good convergence and all recommended diagnostics were satisfactory.

(alternating attention), and percent perseverative errors on the WCST (set switching) – variables. In addition, planned interactions between age and sentence structure and between the cognitive measures and sentence structure were included in the analytic scheme.

Results

Table 2 reports accuracy scores for three age bands (based on summary measures per person per task) on the ES and MN tasks.

Sentence structure and age

It can be seen in Table 2 that sentence structure emerged as a strong predictor for both sentence tasks. Regardless of age, accuracy levels were lowest for the object relative sentences in the ES task and the 2-negative sentences in the MN task. Age predicted accuracy levels on the ES task, but not on the MN, and it did not interact with sentence structure on either task. Sentence length (in words) did not affect performance; that is, whereas the sentences with the added negative words on the MN task yielded lower accuracy, sentences that were matched to them in length but did not include negatives did not yield such a decline in performance.

Cognitive abilities

Performance on the four cognitive measures included in our study by three age bands is presented in Table 3. Correlations among these tasks are presented in Table 4. It can be seen in Tables 3 and 4 that performance on all cognitive measures was related to age.

Our regression analyses (see Table 5) revealed that when the cognitive variables were added to the regression equation, the amount of unexplained within-participant variance (level 2 variance, as measured by the ratio of intra-class correlation) decreased for both sentence tasks by of 30%–60%. The strongest predictor of sentence processing performance was percent perseverative errors such that lower perseverative error rate on the WCST, an indication of better set-switching ability, was associated with higher accuracy scores on both the ES and MN tasks. In addition, WM span predicted performance on both sentence tasks, with individuals with higher WM span performing at higher accuracy levels than those with lower spans.

Regardless of age, individuals with better set-switching ability and higher WM span performed at highest accuracy levels, whereas those with low performance on both cognitive abilities achieved lower accuracy. Figures 1 and 2 depict performance in the most difficult sentence structure of the ES (OR) and MN (2-negatives) tasks, respectively. By contrast, superior inhibitory performance on the Stroop did not predict performance on the either ES or MN, nor did performance on the Trails task. There was no interaction between any of the cognitive variables and sentence structure.

Gender, Education, and Hearing

Gender emerged as a significant predictor on both sentence tasks, with women performing at higher accuracy levels than men. Significantly more women were represented in the youngest age band, which might have contributed to the better performance of women than men and influenced the analysis of age differences. Years of formal education showed a trend toward being a significant predictor, in the direction of individuals with higher education performing more accurately than those with lower education levels. Our measure of hearing sensitivity did not predict performance on either task.

Discussion

Accuracy performance of participants between the ages of 55 and 88 on two auditory sentence processing tasks (embedded sentences, ES, and multiple negatives, MN) was found to be associated with a) the complexity of the sentence structures, with object-relative sentences and those with two negatives associated with lower accuracy; b) two cognitive abilities: WM span and switching control, with higher WM span and better switching abilities associated with higher accuracy; and c) three demographic variables: gender and education (predicting performance on both the ES and MN tasks), and age, predicting performance only on the ES task.

In answer to our first question – whether we can detect age-related accuracy differences in sentence processing among participants sampled from middle-aged and older adults – we found that whereas age predicted performance on the ES task, with older age predicting lower accuracy, age did not predict performance on the MN task. It is possible that the greater processing demands of the ES task, especially on the object-relative (OR) sentences, led to the difference in the age effect results between the two sentence processing tasks. It is also possible that some specific feature of the syntactic processing difference between the tasks contributed to this difference in the effect of age on performance. Namely, in the ES task we manipulated the syntactic component that is processed in the embedded clause of the sentence. By contrast, in the MN task, the manipulation concerns the number of negative elements in the otherwise structurally relatively simple sentence, adding to the computation burden needed to interpret the sentence without modifying the syntax *per se*. These results are consistent with a recent study also reporting that the presence of negation affected younger and older individuals' comprehension performance equally, with no increased difficulty associated with older age (Margolin & Abrams, 2009). These task differences and the role of syntactic processing of embedded clauses in the results obtained here warrant further examination, at a minimum by employing additional sentence structures.

We note that as in the present study, previous findings concerning the effect of age on language processing have been similarly inconsistent and that differences have been found most reliably when older adults were compared to young adults. Because we were particularly interested in age-related differences that might be detected in older adulthood, we selected an age range of 55 and up, rather than comparing our older participants to young individuals (e.g., in their 20s). Furthermore, the individuals included in our sample represent educated, community-dwelling, relatively healthy older adults, who achieved a score of 28–30 (of 30) on the MMSE. Our results confirm the finding that when a continuous range of older ages is examined, chronological age by itself is not a sufficiently strong predictor of performance. Indeed, even in the sentence task for which age was a significant predictor (ES), age alone accounted for some, but not a great deal, of the variability in performance (See Table 5). In this, our findings support previous studies arguing that chronological age may be a relatively weak predictor of behavior (e.g., Spiro & Brady, 2008). Instead, individual differences on a variety of language and cognitive skills characterize the abilities of older adults (e.g., Wingfield & Grossman, 2006). We therefore considered other factors that are likely to contribute to variability in performance.

To this end, and in answer to our second question – whether differences in cognitive abilities (specifically inhibition, switching control, and working memory) account for age-related differences in sentence processing skills – we found two cognitive variables that predicted performance on both sentence processing tasks: WM span and switching ability (as measured by the percent perseverative errors on the WCST). The effect of each of the two cognitive skills that emerged as predictors for the sentence tasks is consistent with existing theories of sentence processing. The role of WM has been associated with the processing of

syntactically complex sentences (e.g., Gibson, 2000; King & Just, 1991; Vos et al., 2001), particularly those that require computation and integration of components across different portions of the sentence. The role of switching control in sentence processing could be accounted for by the concept of processing load (Reali & Christiansen, 2007), particularly the need to integrate new information as the sentences are heard, and interpret each new sentence independently of previously presented sentences that share a number of components but differ in structure.

Whereas there is little research evidence concerning switching control and language processing in older age, a related specific cognitive domain that has been associated with age-related change is difficulty inhibiting previously activated materials (Hasher & Zacks, 1988; Hedden & Park, 2001; Murphy et al., 1999; Paul, 1996). Within our battery of tests, the test most directly measuring inhibition skills was the Stroop; however, we found that performance efficiency in the color-word interference condition on the Stroop test did not predict accuracy performance on either the ES task or the MN task. It is possible that the specific inhibition skills measured by the Stroop test do not play a critical role in the sentence processing tasks we employed. Specifically, whereas information from a previous sentence needs to be inhibited, the information processed within a sentence as the sentence is heard needs to be kept active – rather than inhibited – until a plausibility decision is made. Our findings are consistent with previous studies that have reported inconsistent age-group difference in performance on the Stroop test (e.g., Hull et al., 2008; Verhaeghen & De Meersman, 1998).

The other cognitive measure included in our study that did not emerge as a predictor for accurate performance on the sentence tasks was the Trail Making test. This can be a surprising finding at first glance – we had predicted that alternating attention and switching between numbers and letters could be associated with abilities needed to successfully perform the sentence tasks. We propose two possible explanations for the limited predictive value of the Trails task. One, performance on the Trails outcome measure correlated significantly with our two cognitive measures that emerged as significant predictors, which may have prevented us from finding its individual contribution in the regression model. Furthermore, we note that for both the Stroop and the Trails tasks – the two measures that did not predict accuracy performance on the sentence tasks – we used an outcome measure that depends on timing (time to complete Trails B relative to time to complete Trails A; Number of items read correctly in the Stroop conditions in a given time), whereas the outcome measure we used for our sentence tasks was accuracy. Indeed, previous findings demonstrated that speed accounted for a substantial variance in Stroop interference results (e.g., Bugg et al., 2007; c.f. Troyer, Leach & Strauss, 2006). The examination of the relation between these cognitive measures and timing performance on sentence processing tasks is fertile ground for future research.

Of particular interest in the current study is that the combination of deficiency in the two domains, WM and switching ability, yielded added difficulty in sentence processing. That is, as can be seen in Figures 1 and 2 above, low performance on either variable decreases performance on the sentence tasks, but the combination of low abilities in both cognitive domains led to substantially lower accuracy on the sentence processing tasks. This finding, obtained for both sentence-processing tasks, is consistent with previous studies suggesting that a number of cognitive skills contribute to successful language performance and that those older individuals who perform better than might be predicted by their age are the ones who are better able to compensate for compromised skills in one cognitive domain by recruiting additional cognitive abilities (e.g., Goffaux et al., 2008; Wingfield & Grossman, 2006). Our results thus lend support to the compensation hypothesis (e.g., Cabeza et al., 2002; Boyle et al., 2008) in that better-performing older adults may rely on a number of

cognitive processes to successfully complete tasks such as sentence processing, whereas older individuals who experience decline in a number of cognitive domains are less able to compensate for any one impaired domain and thus demonstrated depressed performance.

One additional variable that significantly predicted performance on both sentence tasks was gender. Previous findings have been inconsistent concerning gender differences in language performance, with studies demonstrating that women outperform men (Capitani, Laiacona, & Basso, 1998; Kimura, 1999), others showing that this possible advantage does not hold in older age (Goral et al., 2007; Parsons et al., 2005), and still others reporting no gender-based difference at all (e.g., Wallentin, 2008). In our analyses of largely overlapping samples from the LAB project, we have previously found that women perform less well than men on lexical-retrieval tasks (Goral et al., 2007). In Clark-Cotton et al. (2007) we argued that gender differences on the Boston Naming Test can be explained by differences in performance on relatively few items. The contrast between these studies that report lower accuracy for women on lexical-retrieval tasks and the present findings of higher accuracy for women on the sentence-processing tasks suggest that to some extent gender difference may vary by task. Age differences related to gender in the current sample may have contributed here as well.

We also found that, as has been reported in previous studies of aging (e.g., Chodosh et al., 2002; Christensen et al., 1999; Neils et al., 1995; Verhaeghen, 2003), individuals with higher levels of education tended to perform with higher accuracy levels than those with fewer years of education. The vocabulary and sentence structures employed in our tasks may have contributed to this effect of education.

Finally, in contrast to some previous findings, we did not find that hearing sensitivity played a role in predicting accuracy performance. Hearing acuity has been hypothesized to explain age-related differences in abilities to perceive and comprehend spoken language. Age-related differences in language processing have been found particularly when the speech stimuli were modified, for example, when noise was introduced and when the speech rate was accelerated. However the degree to which hearing thresholds account for these effects has been controversial (Gordon-Salant & Fitzgibbons, 1997; Pichora-Fuller & Souza, 2003; Tun, 1998). We found that speech-recognition thresholds did not predict accuracy performance on either sentence processing task employed here. In our tasks, sentences were presented at a normal speech rate and at a comfortable listening level, suggesting, that under good listening conditions, it is cognitive processing rather than perceptual processing that contributes to performance on challenging linguistic structures.

In summary, the present study contributes to the explanations of individual variability in language skills among older adults. Specifically, we found that individuals with compromised skills in both WM (as measured by a verbal month ordering task) and switching ability (as measured by the perseverative errors on the WCST) demonstrated particular difficulty in processing complex sentences. By contrast, those who may have been able to compensate for one compromised domain with preserved abilities in other cognitive domains performed well on the sentence processing tasks. We consider for future investigation the contributions of additional factors, such as lexical processing, other aspects of executive and control resources, and health, to more fully understand sentence processing in older age.

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Figure 1.
Percent accuracy on the object-relative condition of the embedded sentences task as a function of age and cognitive performance

Figure 2.
Percent accuracy on the two-negative sentences of the multiple-negatives tasks as a function of age and cognitive performance

Table 1

Participant Demographics

Age band	N	Mean Age (SD)	Mean Education (SD)	Gender: % female	Hearing (SRT in best ear)
55–64	57	59.49 (2.80)	15.59 (1.70)	70.59	26.54 (14.57)
65–74	87	70.16 (2.86)	15.33 (1.63)	50.94	27.99 (15.82)
75–88	97	78.89 (3.04)	14.65 (2.11)	48.45	25.87 (14.84)
All	241	71.15 (8.08)	15.11 (1.89)	54.59	26.79 (15.10)

Table 2
Percent Accuracy (SD) in the Embedded Sentences and the Multiple Negatives Tasks

Embedded Sentences				
Age	Coordinate	Subject Relative	Object Relative	Total
55–64	93.77 (6.25)	93.68 (6.28)	91.10 (9.18)	92.81 (6.11)
65–74	91.63 (7.04)	90.75 (8.63)	89.10 (9.46)	90.44 (6.73)
75–88	89.46 (8.66)	88.35 (8.82)	84.72 (10.50)	87.45 (7.69)
All	91.26 (7.73)	90.48 (8.45)	87.81 (10.14)	89.80 (7.29)
Multiple Negatives				
Age	0-negative	1-negative	2-negatives	Total
55–64	97.95 (4.61)	93.64 (11.22)	85.00 (14.05)	97.04 (5.09)
65–74	95.86 (7.24)	93.08 (9.96)	81.95 (15.76)	96.29 (7.70)
75–88	96.22 (6.10)	91.78 (9.67)	79.65 (15.52)	94.88 (7.83)
All	96.42 (6.35)	92.66 (10.09)	81.62 (15.40)	95.91 (7.27)

Table 3

Means (SD) Performance on the Neuropsychological Measures

Age	Month Ordering Span	Trails (sec.)	Stroop Interference (#)	WCST % Perseveration	MMSE
55–64	4.41 (1.04)	36.70 (17.23)	133.41 (33.52)	13.23 (8.38)	29.47 (.67)
65–74	4.44 (1.07)	39.96 (21.59)	148.63 (38.08)	14.52 (11.29)	29.23 (.75)
75–88	4.16 (.99)	49.36 (28.09)	159.75 (49.68)	17.51 (13.10)	29.09 (.74)
All	4.33 (1.04)	42.63 (23.81)	148.96 (42.81)	15.25 (11.38)	29.24 (.74)

Table 4

Correlations among Age and the Neuropsychological Measures*

	Age	Education	Month Ordering Span	Trails	Stroop Interference	MMSE	WCST % Perseveration
Age							
Education	-0.132						
Month Ordering Span	-0.152	0.101					
Trails	0.241	-0.138	-0.391				
Stroop Interference	0.189	0.013	0.027	0.002			
MMSE	-0.212	-0.024	0.119	-0.228	-0.059		
WCST % Perseveration	0.199	-0.089	-0.296	0.293	0.078	-0.154	

* Note: Bolded numbers represent significant correlations

Table 5

Results from a Mixed Logistic Regression*

<i>Embedded Sentences</i>	Coef.	Std. Err.	t	P
SR	−0.088	0.069	−1.27	0.205
OR	−0.410	0.065	−6.29	0.000
Age	−0.183	0.051	−3.60	0.000
Education	0.090	0.046	1.97	0.049
Female	0.180	0.093	1.94	0.053
Hearing	−0.035	0.047	−0.07	0.459
MMSE	0.151	0.068	2.21	0.028
Month Ordering	0.172	0.052	3.34	0.001
Trails	−0.054	0.060	−0.90	0.371
Stroop Interference	−0.066	0.047	−1.40	0.161
WCST % perseveration	−0.115	0.051	−2.27	0.026
Constant	2.401	0.081	29.61	0.000
<i>Multiple Negatives</i>	Coef.	Std. Err.	t	P
1-Negative	−0.779	0.147	−5.28	0.000
2-Negatives	−1.903	0.134	−14.25	0.000
11 words	−0.062	0.167	−0.37	0.708
12 words	−0.129	0.164	−0.79	0.433
Age	−0.038	0.069	−0.55	0.585
Education	0.112	0.060	1.90	0.058
Female	0.329	0.126	2.61	0.009
Hearing	−0.004	0.068	−0.06	0.951
MMSE	0.084	0.093	0.90	0.367
Month Ordering	0.201	0.069	2.93	0.003
Trails	−0.075	0.078	−0.95	0.341
Stroop Interference	0.010	0.061	0.17	0.869
WCST % perseveration	−0.134	0.068	−1.96	0.052
Constant	3.355	0.149	22.59	0.000

* Note: Bolded variables represent significant results; Measures are converted to z scores