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Aging and Individual Differences in Binding During Sentence Understanding: Evidence from Temporary and Global Syntactic Attachment Ambiguities

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Abstract

We report an investigation of aging and individual differences in binding information during sentence understanding. An age-continuous sample of adults (N = 91), ranging from 18 to 81 years of age, read sentences in which a relative clause could be attached high to a head noun NP1, attached low to its modifying prepositional phrase NP2 (e.g., The son of the princess who scratched himself / herself in public was humiliated), or in which the attachment site of the relative clause was ultimately indeterminate (e.g., The maid of the princess who scratched herself in public was humiliated). Word-by-word reading times and comprehension (e.g., *who scratched?*) were measured. A series of mixed-effects models were fit to the data, revealing: (1) that, on average, NP1-attached sentences were harder to process and comprehend than NP2-attached sentences; (2) that these average effects were independently moderated by verbal working memory capacity and reading experience, with effects that were most pronounced in the oldest participants and; (3) that readers on average did not allocate extra time to resolve global ambiguities, though older adults with higher working memory span did. Findings are discussed in relation to current models of lifespan cognitive development, working memory, language experience, and the role of prosodic segmentation strategies in reading. Collectively, these data suggest that aging brings differences in sentence understanding, and these differences may depend on independent influences of verbal working memory capacity and reading experience.

Keywords

Aging; Relative Clause Attachment; Working Memory; Print Exposure

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1. Introduction

One of the most fundamental processes of language comprehension is the binding of concepts into a single coherent representation. There is some controversy with respect to whether this process is compromised with advancing age (Caplan, DeDe, Waters, Michaud & Tripodis, 2011; Stine-Morrow, Miller, Gagne, & Hertzog, 2008; Payne & Stine-Morrow, 2012), and whether this process is dependent upon working memory resources (Smiler, Gagne, & Stine-Morrow, 2003; Swets, Desmet, Hambrick, & Ferreira, 2007; Traxler, 2007, 2009). Aging is characterized by declines in cognitive capacities including working memory (Bopp & Verhaeghen, 2005) and attentional control (Hasher, Lustig, & Zacks, 2007), but at the same time, an increased probability of growth in verbal ability as a consequence of literacy activity (Stanovich, West, & Harrington, 1995; Verhaeghen, 2003). It is not clear how this balance of gain and loss with age contributes to the binding of information in sentence comprehension.

In order to investigate whether aging impacts binding in on-line sentence comprehension, we had participants read a series of sentences with relative clauses that present certain challenges to conceptual binding (Traxler, Pickering, & Clifton, 1998), such as:

1. NP1: The son of the princess who scratched himself in public was humiliated.
2. NP2: The son of the princess who scratched herself in public was humiliated.
3. Ambig: The maid of the princess who scratched herself in public was humiliated.

Sentences (1) and (2) introduce temporary syntactic attachment ambiguities that are resolved at the reflexive pronoun. The reflexive pronoun in (1) refers to the head noun (NP1, *son*), and in (2) the reflexive pronoun refers to the object of the modifying prepositional phrase (NP2, *princess*). So any difference between these sentences in comprehension accuracy or reading time at or beyond the reflexive pronoun would indicate difficulty in binding the anaphor, *himself/herself*, to either NP1 or NP2. By contrast, sentence (3) is globally ambiguous in that a definitive attachment is never specified in the sentence (i.e., herself may refer to either the maid or the princess).

1.1. Working Memory and Attachment Resolution

A number of studies have recently investigated the role of individual differences in working memory in relative clause attachment (Swets et al., 2007; Traxler, 2007, 2009; Felser, Marinis, & Clahsen, 2003). Results have been mixed. Findings from an eye-tracking study by Traxler (2007) indicated that college-aged adults with better working memory showed a greater on-line NP1 preference (i.e., facilitated processing for NP1 versus NP2 attachments)[1], while low-span adults showed a greater preference for the more local NP2-attached sentences (see also Felser et al., 2003 for similar results in children). These findings are consistent with distance-based parsing models, in which the long-distance dependency introduced in NP1 sentences results in a greater integration cost at the point of disambiguation (Gibson, 1998; Grodner & Gibson, 2005), which would presumably be more demanding for low-span adults (cf. Wingfield & Grossman, 2006).

However, this pattern is not always found. For example, Swets, Desmet, Hambrick, and Ferreira (2007) tested a large cross-linguistic sample of 246 English and Dutch speaking young adults on their off-line attachment preferences for globally ambiguous relative clauses. High-span individuals showed a greater preference for NP2-attached sentences

[1]We use the term “preference” here and throughout to indicate evidence for facilitated on-line processing or comprehension performance for one syntactic construction relative to another (Traxler, 2007; 2009; Swets et al., 2008).

while lower span individuals, perhaps counterintuitively, showed a stronger preference for the distal NP1 attachment. An appealing interpretation of the findings from Swets et al. (2007) centers on how working memory may constrain segmentation strategies during silent reading. That is, there may be differences in where individuals segment language for semantic analysis, as reflected in implicit prosody (Carlson, Clifton & Frazier, 2001; Fodor, 2002; Frazier, Carlson, & Clifton, 2006). For example, some readers may insert an implicit intonational phrase boundary directly before the relative clause (i.e., The son of the princess # who scratched himself/herself…) while others may not impose this implicit break, perhaps delaying segmentation until after the entire relative clause (i.e., The son of the princess who scratched himself/herself in public #…). When a prosodic break occurs directly after NP2, the head noun of the complex noun phrase becomes more salient as a potential attachment site (Fodor, 2002; e.g., an example of an advantage of first-mention (Gernsbacher, 1990)). This is supported by studies that have directly manipulated segmentation with prosodic breaks in speech (Carlson, Clifton, & Frazier, 2001) and have found that placing a larger phrase boundary before a relative clause results in a higher probability of NP1 attachment. Swets and colleagues (2007) argued that low-span readers may "chunk" more frequently during reading, and thus, would be expected to show greater evidence for high (NP1) attachment relative to high-span readers, who are more likely to process the entire complex noun phrase and relative clause together, leading to a low (NP2) attachment. Consistent with this interpretation, Swets and colleagues (2007) presented experimental evidence that when readers were presented text segment-by-segment, with a structural break between NP2 and the relative clause, high-span readers increased NP1 attachment so that their preferences mirrored those of low-span readers (see also Traxler, 2009 for evidence consistent with this from eye-tracking).

During normal reading, individuals pause after major syntactic constituents, such as at clause and sentence boundaries (i.e., wrap-up effects; Rayner et al., 2000; Kuperman, Dambacher, Nuthmann, & Kliegl, 2010). This effect is increased with advancing age (Miller & Stine-Morrow, 1998; Stine, 1990; Stine-Morrow, Noh, & Shake, 2010), which is consistent with the idea that age-related reductions in working memory result in a greater likelihood of "chunking" longer syntactic constituents into smaller units (see Stine-Morrow & Miller, 2009 for a discussion), an effect that may be compensatory in nature (Payne & Stine-Morrow, 2012; Stine-Morrow et al., 2010). Given that, on average, aging is associated with reduced working memory capacity (and more frequent segmentation), older adults as a group would be expected to show a systematic preference for NP1 attachment, according to Swets et al.'s (2007) implicit segmentation account. In contrast, distance-based theories (Gibson, 1998) predict that older adults would have particular difficulty for NP1 attachments and would thus show a preference in comprehension or on-line processing towards NP2 attachments.

1.2. Reading Experience and Language Comprehension

Another factor that may contribute to syntactic attachment is the influence of experience on readers' syntactic expectations (Levy, 2008; MacDonald & Christensen, 2002; Staub & Clifton, 2006). In English, there does appear to be a preference towards sentences with low attachment (Frazier, 1978; Frazier & Clifton, 1996; Gilboy, Sopena, Clifton, & Frazier, 1995; Mitchell, 1994), consistent with the late closure principle (Frazier, 1979; Frazier & Clifton, 1996). These attachment preferences differ substantially across languages. Spanish, for example, has a strong NP1-attachment bias (Carreiras & Clifton, 1999; Carreiras, Salillas, & Barber, 2004; Cuetos & Mitchell, 1988). Moreover, there is evidence that reliable cross-linguistic differences in attachment preferences correspond with the "default" prosodic phrasing of that language (Jun, 2003).

Language experience has been influential in recent conceptualizations of the role of WM in language understanding (MacDonald & Christiansen, 2002; Wells, Christiansen, Race, Acheson, & MacDonald, 2009). Some models hypothesize that a domain-general verbal WM system (Fedorenko, Gibson & Rohde, 2006; King & Just, 1991; Just & Carpenter, 1992; Just & Varma, 2002; 2007) plays a central role in the ability to interpret and comprehend complex language, while others have argued that there is a language-specific verbal WM system for on-line processing that is unaffected by conditions, such as aging, that deplete general verbal WM (Caplanc & Waters, 1999; Caplan, Waters & DeDe, 2007; Caplan et al., 2011; DeDe, Caplan, Kemtes, & Waters, 2004). However, MacDonald and Christiansen (2002) have argued that individual differences in verbal WM may be epiphenomenal, reflecting a broader efficiency of the language system that arises from the interaction between language experience and biological constraints. One of MacDonald and Christiansen's stronger claims is that, because the majority of tasks assessing verbal working memory (such as the commonly used reading span task) are linguistically mediated, individual differences in these tasks largely reflect individual differences in linguistic competency, which are driven by differences in language exposure. However, very little research has empirically assessed individual differences in both verbal working memory and language experience simultaneously (but see Payne et al., 2012).

A considerable literature has amassed examining individual differences in reading experience and exposure. Within literate populations, there still exists substantial variability in how much people read in everyday life. Stanovich and colleagues (Stanovich & Cunningham, 1992; Stanovich & West, 1989) have coined the term *print exposure* to describe individuals' habitual engagement in reading and literacy activities. Individual differences in print exposure have been shown to play an important role in vocabulary development, lexical processing, and language comprehension in developing readers, dyslexic and atypical readers, and highly literate college-aged adults (Cunningham & Stanovich, 2003; Long, Johns, & Morris, 2006). Objective performance-based measures of print exposure, such as the Author Recognition Test (see Methods for more detail), have been shown to be reliable and valid indicators of print exposure among such diverse populations (Acheson et al., 2008; Cunningham & Stanovich, 1990), including older adults (Stanovich et al., 1995; Payne et al., 2012). More recently, print exposure has been investigated as a potential moderator of on-line language processing. For example, adults with high levels of print exposure show facilitated effects of word frequency in lexical decision (Chateau & Jared, 2000; Unsworth & Pexman, 2003) and word-by-word reading tasks (Payne et al., 2012). Although some studies have recently examined whether print exposure modulates higher-order sentence comprehension (Acheson et al., 2008; Metusalem, Kutas, Urbach, Hare, McRae, & Elman, 2012; Payne et al., 2012), to our knowledge, no such study has examined whether print exposure contributes to syntactic ambiguity resolution, despite clear theoretical reasons to believe that experience may influence parsing (MacDonald & Christensen, 2002).

Given that aging is associated with declines in working memory, but opportunities for increases in reading experience, a central goal of the current study was to understand how syntactic attachment resolution varies over the adult lifespan as a function of both working memory and reading experience. If indeed there is a statistical bias towards late closure in English, then it is possible that individuals with greater reading experience are sensitive to this bias and would thus show stronger NP2 attachment preferences.

1.3. Processing Globally Ambiguous Constructions

Another motivation for this study was to understand the impact of aging and individual differences on processing globally ambiguous attachments, such as sentence (3). Young

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adult readers are actually faster in reading such globally ambiguous sentences, compared to attachments that are ultimately disambiguated (Traxler et al., 1998; Swets et al., 2008; van Gompel, Pickering, Pearson, & Liversedge, 2005). A number of theories have been put forth to explain the finding that global ambiguity leads to facilitation, including theories based on serial analysis and re-analysis (Green & Mitchell, 2006), parallel race models (van Gompel et al., 2005), and "good-enough" models of language comprehension (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Ferreira, Bailey, & Ferraro, 2002), which explain such data in terms of syntactic underspecification (Swets et al., 2008); when faced with the irresolvable referent in sentence (3), readers do not come to a single syntactic solution, but rather neglect these computations, given that effort to construct a definitive binding will inevitably fail.

Indeed, recent findings have suggested that older adults may be more likely to adopt a strategy of underspecification in sentence comprehension (Christianson, Williams, Zacks, & Ferreira, 2006; Stine-Morrow et al., 2006). At the same time, it is unclear how individual differences in WM and language experience may moderate the processing of globally ambiguous constructions, especially given the findings from Swets et al., (2007), which were based on off-line assessments of globally ambiguous sentences only. A direct comparison of on-line relative clause attachment processing and off-line comprehension for both temporarily and globally ambiguous sentences is needed in order to fully understand the role that individual differences play in attachment resolution.

1.4. The Current Study

The overarching motivation for this study was to understand the implications for language comprehension of the shifting balance between age-related reductions in working memory and increases in reading experience. Specifically, our goals were three-fold. First, we aimed to test whether aging was associated with a systematically reduced preference for NP2 versus NP1 attachments, as predicted by Swets et al.'s (2007) implicit segmentation account, or if aging was associated with an increased preference for NP2 attachments over NP1 attachments, as predicted by both distance-based memory retrieval and experience-based accounts. Second, we wanted to know whether older readers would be differentially more likely to process globally ambiguous attachments less thoroughly than the young, given recent findings suggesting that older adults may adopt a strategy of underspecification (Christianson et al., 2006; McGinnis & Zelinski, 2003; Stine-Morrow et al., 2006). Our third and final goal was to investigate whether individual differences in WM moderated syntactic attachment processing over the lifespan, and moreover, whether individual differences in print exposure also impacted attachment.

A healthy lifespan sample provides a strong test for models of reading experience and verbal working memory (Stanovich et al., 1995), especially given the clear opposing trajectories of increased print exposure and reduced verbal WM with advancing age (see Figure 1 for data from the current study on this point). Our central questions with respect to this last goal were whether individual differences in WM and language experience operate similarly or differently in predicting language comprehension (cf. Just & Varma, 2002; MacDonald & Christiansen, 2002), and whether the impact of individual differences on attachment processing are exaggerated in older adulthood (cf. Kemtes & Kemper, 1997; Madden & Dijkstra, 2010). Critically, if individual differences in verbal working memory are a proxy for reading experience (MacDonald & Christiansen, 2002), we would expect performance on measures of print exposure and verbal working memory to have overlapping effects on on-line and off-line relative clause attachment. However, if individual differences in these measures show dissociable effects on attachment processing across the lifespan, this would suggest that WM capacity taps a resource separable from reading experience (cf. Caplan & Waters, 2002; Just & Varma, 2002; Payne et al., 2012).

2. Method

2.1. Participants

Participants included an adult lifespan sample (*N* = 91 adults; 59 female), ranging in age from 18 to 81 years (M_{age} = 43, SD = 20). Efforts were made to sample evenly across the following age ranges: younger (18-29), *N* = 33; middle-aged (30-59), *N* = 31; and older (60-81), *N* = 27. Table 1 presents sample characteristics and demographics. Older adults all had normal or corrected-to-normal vision, reported good health (*M* = 4.31 out of 5), were more highly educated than younger or middle-aged adults, and were all cognitively intact, scoring above the normal range (> 23) on the Mini Mental Status Exam.

2.2. Stimuli

Materials included 36 experimental sentences and an additional 36 filler sentences. Experimental items were presented in one of three relative clause conditions, as in examples (1) – (3) described earlier. These sentences were identical to those in Swets et al. (2008), which were modified from Traxler et al. (1998). An appendix of all items and questions is available in Swets et al. (2008). The gender of the reflexive pronoun was used to disambiguate the attachment to either the NP1 or NP2 site, in sentences (1) and (2). In (3), the gender did not disambiguate between the two NP's, resulting in a global ambiguity that was ultimately irresolvable. Stimuli were counterbalanced to create three lists and each participant viewed only one list, such that items were equally likely to belong to any condition across participants.

2.3. Measures

2.3.1. Working Memory—In order to provide the strongest test for MacDonald and Christiansen's (2002) experience-based parsing account, we measured complex WM performance via the reading span task, which MacDonald and Christiansen (2002) have critiqued because of its putative overlap with reading competency. The reading span task used in the current study was first described in Stine and Hindman (1994). Participants read a set of sentences silently, and were asked to immediately make true/false judgments after each sentence. After reading all of the sentences in a group, the participants were asked to recall all of the target words (the last words of each sentence in that group) in order. The number of sentences per set increased with progress through the task (until eight sentences per set or when the participant could no longer recall each of the target words in a set successfully).

If the participant failed at a particular set size, they were given a second trial to successfully recall each of the target words within a set. If the participant failed at the second trial within that set, the test terminated (see also Waters & Caplan, 2003). A participants' final score was the number of target words recalled within the highest set in which they did not make an error, plus a fraction reflecting the proportion of correctly recalled words on the set in which they erred. In previous work, we have shown that this administration and scoring of the reading span task results in reliable estimates of verbal working memory (compared to estimates from other complex span tasks; see Waters & Caplan, 2003; Conway et al., 2005). For example, Stine-Morrow, Milinder, Pullara, and Herman (2001) tested reading and listening span among a large sample (*N* = 243) of younger and older adults at two time points, separated by a month. They obtained sentence span test-retest reliability of *r* = .76 (95% CI: [.70, .81]), illustrating that this measure of WM is reliable among younger and older adults. To enhance reliability in the current study, a continuous scoring of WM capacity was used, as described above, rather than a discrete "span level" scoring or a categorical grouping (e.g., classification into "high span" or "low span" groups based on median split)[2].

2.3.2. Print Exposure—Print exposure (PE) was measured with an adapted version of the Author Recognition Test (ART; MacDonald & Acheson, 2008; Stanovich & West, 1989), as described in detail by Payne et al. (2012). Participants completed a checklist in which they were instructed to select authors they knew from the checklist and to otherwise leave the item blank. Participants were discouraged from guessing. A discriminability score was calculated as hits minus false alarms. As addressed above, the ART has shown high reliability and validity among children (Cunningham & Stanovich, 1990), young adults (Acheson et al., 2008), and older adults (Stanovich & West, 1995; Payne et al., 2012). A Spearman-Brown split-half correlation was calculated between alternate columns of the ART in order to assess internal consistency. We found an estimate of $r = .85$, suggesting a high degree of internal consistency in the measure. Importantly, in the current study, ART scores correlated highly with years of education and an independent measure of vocabulary (see Table 1), attesting to its external validity (and, by extension, reliability[3]). Scores on the ART were also treated as continuous variables in all analyses.

2.3.3. Verbal Ability, Psychomotor Speed, and Fluency—A number of other individual difference measures were also collected in order to examine the specificity of the effects of WM and print exposure in the current study. Verbal ability was assessed with the Advanced and Extended Range Vocabulary subtests from the Educational Testing Service Kit of Factor Referenced Cognitive Tests ($\alpha = .79$ and .81, respectively; Ekstrom et al., 1976). Psychomotor speed was measured with the letter and pattern comparison tasks (Salthouse & Babcock, 1991; $\alpha = .94$ for both). Phonemic fluency was measured with the FAS task (Benton & Hamsher, 1978; Strauss, Sherman, & Spreen, 2006; $\alpha = .81$). To preview the results, while verbal ability, psychomotor speed, and fluency measures did significantly predict reading time and comprehension overall, none of these measures moderated any sentence condition effects, nor any Age × Condition interactions. Thus, the effects of WM and print exposure reported below cannot be accounted for by individual differences in fluency, speed, or vocabulary skill (cf. Payne et al., 2012).

2.4. Procedure

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Participants were first administered the self-paced reading task, followed by the administration of the individual difference measures. The self-paced reading experiment was conducted on a 19-inch (48.3 cm) Dell M782 monitor set to a resolution of 1024 × 768 pixels, controlled by a Dell 3.20-GHz computer. E-Prime software controlled experimental presentation and collected reading times (in milliseconds) for each word.

Participants read each sentence word-by-word, using a non-cumulative moving window method (Aaronson & Ferres, 1984). Each trial began with all punctuation intact, as well as a set of underscores representing each word in the sentence visible to the participant. The initial press of the space bar produced the first word of the sentence. Successive space bar presses produced the next word, while concurrently removing the prior word. After each sentence, participants were probed for comprehension with yes/no probes. Because the type of comprehension probe can affect interpretation of globally ambiguous sentences

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[2]Waters and Caplan (2003) showed that continuous scores of sentence reading span showed the highest test-retest reliability among a number of other complex WM span measures (in younger and older adults), but classification scores of the same sentence reading span measures resulted in very low reliability. One potential disadvantage of our administration of the reading span task is that simple estimates of internal consistency (e.g., split-half correlations; Cronbach's α) cannot be calculated, given that task continuation is contingent upon successful performance (cf. Anastasi & Urbina, 1997; see Waters & Caplan, 2003). However, our demonstration of high test-retest reliability in comparable samples is sufficient to establish reliability. Estimates of internal consistency are typically higher than test-retest correlations for the simple reason that internal consistency estimates reflect homogeneity of the test, which is a precondition for stability across time.

[3]The degree to which two measures are correlated sets a lower bound on the reliability of those estimates (Cohen et al., 2003). See Conway et al. (2005) for a discussion of this in the context of complex WM span tasks.

(Christianson & Luke, 2011; Swets et al., 2008), we only occasionally included comprehension questions that directly interrogated attachment interpretation, with six questions probing the first noun phrase (e.g., *Did the maid scratch in public?)* and six questions probing the second noun phrase (e.g., *Did the princess scratch in public?*). The remaining probes were directed to other elements of the sentence *(*e.g., *Was anyone humiliated?)* and were not analyzed. Materials were counterbalanced so that, across the experiment, the NP1 and NP2 probes were equally likely to probe comprehension of NP1-attached, NP2-attached, and ambiguous sentences.

2.5. Data Analysis Plan

2.5.1. Reading Time Data—Self-paced reading times from two areas of interest were analyzed: the reflexive pronoun region, which disambiguates the NP1- and NP2-attached sentences (e.g., *himself/herself*), and the post-disambiguating region (e.g., *in public*). Reading times were trimmed for outliers at 3 SD above each individual's mean, based on a log-transformed distribution (<1% data excluded). For all models, subjects and items (individual words) were specified as completely crossed random effects (Baayen et al., 2008), and all continuous variables (age, working memory, print exposure) were treated as continuous predictors in all models[4]. For the reflexive pronoun region, linear mixed-effects models (Baayen, Davidson, & Bates, 2008; Snijders & Bosker, 2011) were fit, using SAS (Version 9.2) PROC MIXED based on restricted maximum likelihood estimation. The post-disambiguating region was defined as the region between the word following the reflexive pronoun and the following (final) verb phrase (also used by Swets et al., 2008)[5]. Traditional analyses of multiword regions involve some sort of initial averaging across words within a region of interest in order to accommodate the constraint of a univariate model (one observation per-subject per-item). To avoid having to initially average across items, which can lead to biased estimates of effects in unbalanced designs (see Baayen et al., 2008), we fit a multivariate linear mixed-effects model to reading times in the post-disambiguating region, using the same fixed effects structure as the models for the RPR, plus the addition of word position as a covariate[6]. The parameters reported for these models can be interpreted as the effect averaged across each word within the post-disambiguating region.

2.5.2. Comprehension Data—Analyses of comprehension accuracy were only conducted on questions probing NP1 and NP2 attachment; questions probing ambiguous sentences afforded a window into interpretation. Because accuracy was dichotomous, the

[4]Relatively minor choices in model specification can result in divergent results in mixed-effects models (Snijders & Bosker, 2011; Raudenbush & Byrk, 2002). Following the recommendations of Barr, Levy, Scheepers, and Tily (2013), we re-estimated all models with the maximal random effects structure allowable for the within-subject contrasts, in order to reduce the risk of potentially inflated Type I errors from an underspecified random-effects structure. That is, we re-estimated each model in a step-wise fashion, including the maximum number of random slopes and covariances among the random slopes for the C1 and C2 contrasts across subjects and items that resulted in a model that converged to a valid solution. Importantly, these models resulted in no changes in the pattern of results reported for any measures. Thus, for the sake of clarity and directness, we report the random-intercept models here. Conservative standard errors are reported, using empirical sandwich estimators based on generalized estimating equations (see Diggle et al., 1994; Harden & Hilbe, 2007). These estimators are robust against misspecifications of the random effects structure compared to model-based standard errors.

[5]For the majority of the sentences (83%), this region was a two or three-word prepositional phrase. Three sentences included a four-word prepositional phrase, two sentences included a five-word prepositional phrase and one sentence included a single word adverbial phrase (e.g., …who complimented himself/herself *constantly…*). Re-estimating the models after removing the single word adverbial phrase and the two 5-word prepositional phrases resulted in no change in the effects reported for the PDR models.

[6]See Snijders & Bosker (2011) for an introduction to the multivariate hierarchical linear model, see Schafer & Yucel, (2002) and Berridge & Crouchley (2011) for technical treatments of generalized multivariate mixed-effects models. In brief, this model has several advantages: (1) It accommodates the unbalanced design inherit in the post-disambiguating region, with some items (sentences) having more observations (individual words) in the post-disambiguating region than others without the use of some initial data reduction step such as averaging across word RTs. (2) We can control for correlations across word position, which results in improved power (i.e., smaller standard errors). (3) By including word as a factor in the model, nested within sentence (item), this allows us to perform a single analysis of the joint effects of item-level and subject-level predictors of RT on every word within the post-disambiguating region, rather than performing a number of single univariate analyses for each word.

comprehension data were analyzed using logit mixed-effects models (Jaeger, 2008; Snijders & Bosker, 2011). SAS (Version 9.2) PROC GLIMMIX, based on maximum likelihood estimation through the Laplace approximation, was used to fit these models. Models included crossed random effects for subjects and items.

3. Results

Table 2 presents the results of the mixed-effects models on reading time for the reflexive pronoun and post-disambiguating regions. Table 3 presents the results of the logit mixed-effects models on probe response accuracy[7]. Because sentence type has three levels, the NP2 condition was treated as a reference group to form two contrasts: Contrast 1 (C1): NP1 vs. NP2; Contrast 2 (C2): Ambiguous vs. NP2. These contrasts were used in all analyses. For all models, there was significant variability across subjects and items.

3.1. Online Relative Clause Attachment

The first set of models (Model 1), tested the effects of age on the on-line processing of temporary and global relative clause attachment ambiguities in the reflexive pronoun region and the post-disambiguating region[8]. The aim of these models was to test the effects of age on relative clause attachment processing, collapsing across potential individual differences in working memory and language experience. In the second (Model 2) and third sets (Model 3) of models, we tested the moderating influence of individual differences in verbal working memory and print exposure, respectively[9] (see Traxler, 2007; Rozek, Kemper, & McDowd, 2012; Payne et al., 2012 for similar analytical plans). Separate models were fit to reading times in the reflexive pronoun and post-disambiguating region in order to test for the effects of working memory and print exposure, by including these predictors in their respective models, and allowing them to moderate the sentence-type contrasts (i.e., two-way interactions) and the age × sentence-type contrast interactions (i.e., three-way interactions). In Model 2 (the WM-as-moderator model), print exposure was included as a covariate. Likewise, in Model 3 (the PE-as-moderator model), WM was included as a covariate. WM and PE were standardized (based on sample grand mean and standard deviation) in order to equate the magnitude of the parameter estimates for the interactions in Models 2 and 3. The key question of interest from these models was whether WM or PE moderated any age differences found in Model 1 (i.e., whether there were any three-way interactions with WM or PE).

3.1.1. Age Differences in Relative Clause Processing—The first column of Table 2 presents the results of the mixed-effects models on the reflexive pronoun region, and Figure 2 (Panel A) plots the regression lines for the Age × C1 and Age × C2 interactions corresponding to this analysis. Reading times were differentially longer in the NP1-attachment condition relative to the NP2-attachment condition with advancing age, as revealed by the reliable Age × C1 interaction. This finding suggests that older adults encountered greater processing difficulty for NP1 attachments relative to NP2 attachments.

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[7]Note that, in the presence of higher-order interactions, lower order parameters reflect conditional (or constitutive) effects and should not be interpreted as unconditional marginal effects (or "main effects" as in ANOVA models). See Cohen et al., 2003; Hayes, 2013 for discussions in the context of multiple linear regression models.

[8]Curvilinear trends of age effects were investigated by adding higher order polynomials (age^2 and age^3) but no significant trends were detected. Therefore, age was treated as a linear effect.

[9]WM and PE were entered as moderators in separate models. PE was entered as a covariate in the models where WM was treated as a moderator, and WM was entered as a covariate in the models where PE was treated as a moderator. A single "kitchen-sink" model that included all possible interactions (including each 3-way interaction with WM and PE, as well as the 4-way Age × WM × PE × sentence condition) results in a high degree of multicollinearity among the vectors specifying the 2- and 3-way interactions, despite the lack of correlation between PE and WM in the sample. The set of models presented here control for potential confounding effects of PE and WM, while avoiding multicollinearity and overfitting issues that would be present in a more complex "kitchen sink" model, thus leading to a clearer interpretation.

The Age × C2 interaction, on the other hand, was not reliable; that is, there were no age differences between the NP2 and globally ambiguous sentences, suggesting no age difference in underspecification of the globally ambiguous sentences. The second column of Table 2 presents the results of the mixed-effects models on the post-disambiguating region. The Age × C1 interaction was reliable, but in the opposite direction as in the reflexive pronoun analysis. As can be seen in Figure 2 (Panel B), reading times for the reflexive pronoun in the NP1 sentences were longer than those in the NP2 sentences among younger adults, but not among the old.

To summarize, generally readers showed on-line preferences for NP2 attachments, though there appeared to be adult age differences in attachment effects as they unfolded on-line. Older adults showed a stronger and more immediate reaction to NP1-attached sentences, at the reflexive pronoun. However, younger adults showed a unique effect in the post-disambiguating region, in part because older adults showed no apparent effects of sentence type within this region. Lastly, globally ambiguous sentences were processed similarly to the determinate NP2 attachments, but there did not appear to be age-related differences in processing the global ambiguity. Overall, in contrast to the predictions of the implicit segmentation account described above, these findings suggest that older adults allocated *more* time initially to resolve NP1 attachments at the point of disambiguation, indicating a potential preference for the local NP2 attachment (or relative difficulty with NP1 attachments) with advancing age. However, as we will show, these generalizations across the entire sample depended largely on individual differences in both verbal WM and reading experience in older adulthood.

3.1.2. Moderating Effects of Working Memory—The third and fourth columns in Table 2 show the parameter estimates for the models with WM as a moderator. At the reflexive pronoun, the Age × WM × C2 interaction was reliable. In order to visualize a 3-way interaction with age and WM as continuous predictors, we chose conditional levels of WM span (approximately M ± 1SD; lower span = 3; higher span = 6) and plotted regression lines for the effects of age on reading time in each of the three sentence conditions at these conditional levels of WM (see Hayes, 2013; Preacher, Curran, & Bauer, 2006). This plot is presented in Figure 3 (Panel A). The reliable three-way interaction can be characterized as the combination of non-significant Age × WM interactions in both the NP1 and NP2 conditions ($\|t\|$'s < 1), but a reliable Age × WM interaction in the globally ambiguous condition, $\gamma = 3.01$; 95% CI [.66, 5.32]. The plot shows that older adults with better working memory scores selectively increased reading time in the ambiguous condition, while low-span older adults did not, indicating that older high-span adults were the only group to show some sensitivity to the global ambiguity. In the post-disambiguating region, there were significant Age × WM × C1 and Age × WM × C2 interactions. These interactions were due to the Age × WM interaction reaching significance for NP2 sentences, $\gamma = -1.78$; 95% CI [-3.27, -.31], but not for NP1 or ambiguous sentences ($\|t\|$'s < 1). Figure 3 (Panel B) plots the regression lines for the effect of age on reading time at conditional levels of WM. In NP2 sentences, lower WM scores were related to longer reading times among the old, suggesting the older low-span individuals had more downstream processing difficulty in binding the reflexive pronoun to the NP2 phrase.

Collectively, these data show age-moderated WM effects along two lines. First, despite a general preference for low attachment (see Figure 1), low-span older adults showed evidence of a relative preference for higher attachment (Figure 3b). This finding is consistent with Swets et al.'s (2007) hypothesis that reduced working memory engenders more frequent segmentation, though this effect was not evident among the youngest readers. Second, even though readers tended not to allocate more time to the global ambiguity overall (cf. Swets et al., 2008), high-span older adults did allocate time to resolve to global ambiguity as soon as it was introduced.

3.1.3. Moderating Effects of Print Exposure—Notably, there was no relationship between PE and WM across the full sample (r =-.05), nor within each age group (Young: r = .19; Middle-aged: r = -.10; Old: r =.10), suggesting that these measures are tapping independent individual differences (cf. Caplan & Waters, 2002; Payne et al., 2012; Stanovich et al., 1995). The fifth and sixth columns in Table 2 show the parameter estimates for the models with PE as a moderator, controlling for WM. Importantly, in the reflexive pronoun region, the Age × PE × C1 interaction was reliable, as seen in Figure 4. This was due to was a reliable Age × PE interaction in the NP1-attached sentences, $\gamma = 3.28$; 95% CI [.38, 6.18], but not in the NP2 or Ambiguous sentences ($\|t\|$'s < 1). There were no reliable moderating effects of print exposure on the post-disambiguating region for any sentence condition or age group. Older adults with higher levels of print exposure showed a differential disruption in processing the NP1 attachments, suggesting an increasing preference for low attachment. Importantly, the effects of PE operated independently of the effects of WM, with moderation occurring only for NP1 attachments in the reflexive pronoun. The earlier observed age-related costs in NP1 sentences (Figure 2) thus appeared to be largely driven by older adults with higher levels of print exposure, arguing against a pure memory-retrieval cost (Gibson, 1998; Traxler, 2007) explanation of such age differences. Thus, these data suggest that older adults with above-average literacy experience tend toward attachments that are more frequent in the language.

3.3. Probe Response Accuracy

Similar to the reading time data, models are first presented to demonstrate the effect of age on comprehension (Model 1), followed by the moderating effects of WM (Model 2) and PE (Model 3). In Model 2 (the WM-as-moderator model), print exposure was included as a covariate. Likewise, in Model 3 (the PE-as-moderator model), WM was included as a covariate.

3.3.1. Age Differences in Relative Clause Comprehension—Overall, participants' accuracy for the NP1- and NP2-attached sentences was only moderate, at 79%. In order to test for age and attachment differences in comprehension, we fit a logit mixed model including Age, C1, and the Age × C1 interaction as fixed effects. Table 3 presents the results from these models (parameter estimates are log odds scale). Comprehension for NP1 attachments (M = .75 SD = .43) was worse than for NP2 attachments (M = .83 SD = .38). However, this comprehension advantage for NP2 attachments was moderated by Age (column 1), such that older adults showed a smaller NP2 advantage than the young. For example, older adults (1 SD above the mean in age, 63 years) had an average of 88% accuracy for NP1 sentences and 90% for NP2 sentences, while younger adults (1 SD below the mean in age, 22 years) showed 82% accuracy for NP1 sentences and 92% for NP2 sentences. This reduced NP2 advantage with age in comprehension is consistent with the idea that, as a group, older readers may segment language input into smaller constituents, resulting in a greater preference for high attachment. Importantly, however, as detailed in the next section, these age-related effects were largely moderated by individual differences in both verbal working memory and language experience.

3.3.2. Moderating Effects of Working Memory—The second column of Table 3 presents the parameter estimates from the logit mixed model with WM included as a moderator. There was a substantial 3-way interaction between Age, WM, and C1. In order to decompose this interaction, we treated age as a categorical variable and examined the WM ×

C1 interaction conditionally within each group (i.e., testing the effect of WM on the NP2 comprehension advantage (the C1 contrast) within each age group).

The source of the three-way interaction was that the WM × C1 interaction was reliable among the younger adults, Odds Ratio (OR) = .76; 95% CI [.68, .87], and middle-aged adults, OR = .43; 95% CI [.36, .51], but the effect size was much larger among the older adult participants, OR =.15; 95% CI [.09, .22], with an effect size more than 2 times that of the middle-aged, and more than 5 times that of the young[10]. This can be seen in Figure 5, which plots the comprehension bias towards NP2 sentences (NP2 accuracy - NP1 accuracy) as a function of WM, for each age group. Values closer to 1 indicate a bias to answer all items as if they were NP2 attachments while values closer to -1 indicate a bias to answer all items as if they were NP1 attachments. WM was associated with a larger NP2 preference (e.g., better accuracy for NP2 over NP1, indicating that NP1-attached sentences were more likely to be responded to as if they were NP2 attachments), but that this effect of WM was much larger for older readers.

Overall, this suggests that lower WM span is associated with a relative disadvantage in comprehending NP2 (local) attachments, while higher WM span is associated with a comprehension bias towards NP2 attachments, an effect that is greatest among older adults. This supports the view that there are systematic effects of WM on the preference for relative clause attachment (Swets et al., 2007).

3.3.3. Moderating Effects of Print Exposure—The third column of Table 3 presents the parameter estimates from the logit model with PE as a moderator of comprehension for NP1- and NP2-attached sentences. There was a small but statistically significant Age × PE × C1 interaction, suggesting that print exposure moderated the effects of age on comprehension differences in NP1 and NP2 sentences. To understand the source of this interaction, we examined the lower order PE × C1 interactions within each age group. There was no significant interaction among middle-aged adults, OR = .97; 95% CI [.93, 1.02], and only a marginally significant effect among older adults, OR = .95; 95% CI [.91, .99], but there was a reliable PE × C1 effect among the younger adults, OR = .81; 95% CI [.75, .86], such that higher print exposure was associated with a greater advantage in comprehension for NP2-attached sentences vs. NP1-attached sentences. For example, low-PE (*M*− 1*SD*) younger adults' accuracy was 82% for NP1-attached sentences and 90% for NP2-attached sentences. However, high-PE (*M*+1*SD*) young adults' accuracy was 80% for NP1-attached sentences and 97% for NP2-attached sentences. Younger adults showed a greater sensitivity to PE in off-line comprehension such that higher levels of reading experience were associated with a larger NP2 advantage.

3.3.4. Offline Preferences for Ambiguous Sentences—We were underpowered to detect variance in attachment bias across items for the ambiguous sentences. The analyses reported here are between-subjects analyses, based on averaging responses to the ambiguous items, to yield an *NP2 preference score* (similar to the NP2 comprehension bias above), with higher values (closer to 1) indicating a greater preference for NP2 attachment, and lower values (closer to -1) indicating a preference for NP1 attachment. Overall, there was a slight bias for preferring an NP2 attachment in the globally ambiguous sentences (*M* = 60%, 95% CI [55%, 75%], *t* (90) = 4.06), regardless of age (*r* = .02, for the correlation between age and NP2 preference). Note that this aligns with the generally better comprehension for

[10]The odds ratio can be interpreted as an index of effect size for binary response data. In this case, this can be interpreted as the moderating effect of WM on the C1 contrast (NP1 vs. NP2). 95% confidence intervals containing 1 suggest no moderating influence of working memory; values closer to unity suggest weaker influences of WM while values further from unity reflect a larger moderating effect of WM.

NP2 attachments. In order to test whether individual differences in the NP2 comprehension bias predicted attachment preferences in the ambiguous condition, a multiple regression model was fit to the NP2 preference scores in the ambiguous condition. Age, WM, PE, and comprehension for the NP1- and NP2-attached sentences were included as predictors. There was only a reliable effect of NP2 comprehension, $\beta = .23$, t (90) = 2.21, such that those who had better comprehension of the NP2 sentences were also more likely to show an NP2 attachment bias in the ambiguous sentences.

4. Discussion

In the current study, we investigated the influence of adult developmental differences in working memory and reading experience on language comprehension. We focused specifically on attachment ambiguity resolution, given the growing interest in understanding the roles of age and working memory limitations on syntactic processing specifically (Kemper & Liu, 2007; Caplan et al., 2011), and associative binding more generally (Naveh-Benjamin, 2000). While our approach for investigating these issues was specific to the binding of reflexive pronouns to early or late anaphors in relative clauses, we believe that our findings have broad implications for understanding the adult development of language comprehension.

4.1. Binding in Attachment Resolution

We found an overall bias favoring NP2 attachments, as indicated by (a) better off-line comprehension for determinately attached sentences when they were resolved low, towards NP2, compared to sentences that were resolved high, towards NP1, (b) a bias towards answering questions about globally ambiguous sentences as NP2 attachments, and (c) an immediate disruption in online processing at the pronoun when it referred to NP1. This is consistent with a large literature suggesting a general preference for low attachments in English, perhaps reflecting statistical learning of their more frequent occurrence in the language (Cuetos & Mitchell, 1988; Frazier & Clifton, 1996).

However, this NP2 bias was moderated by working memory. In the temporarily ambiguous sentences, working memory moderated off-line comprehension biases towards NP2 attachments in younger, middle-aged, and older adults. Overall, higher span individuals showed a larger comprehension bias towards NP2 attachments, while lower span individuals showed a relative comprehension bias towards NP1 attachments, consistent with Swets et al.'s (2007) working memory and prosodic segmentation hypothesis. Critically, this effect was much larger among older adults. A similar effect was found in the on-line data as well, as poorer working memory was associated with an increased disruption in on-line processing time for NP2-attached sentences among older adults. This is consistent with the claim that low-span older adults are more likely to insert a prosodic boundary after the second NP, resulting in increased difficulty in recovering in the spillover region for low attachments.

4.2. Comprehension of Globally Ambiguous Attachments

We did not find evidence to support the claim that underspecification of the globally ambiguous attachments (Swets et al., 2008) increased with advancing age (cf. Christianson et al., 2006). Moreover, we did not find evidence in the off-line data that WM, on average, was associated with a greater NP2 preference for globally ambiguous sentences, as in Swets et al. (2007). One reason this may have occurred is that, in the current study, relative clause attachment was not explicitly probed for all experimental items, as in Swets et al. (2007). Indeed, Swets et al. (2008) has shown that the interpretation of globally ambiguous attachments is highly dependent upon the type of comprehension probes participants expect to answer. In the current study, comprehension probes cueing NP1 or NP2 attachment were only occasionally presented in order to reduce explicitly drawing individuals' attention to the relative clause. In fact, we found that only high-span older adults were sensitive to the global ambiguity, showing inflated reading times at the reflexive pronoun. As far as we know, this is the first demonstration of differential slowing for processing globally ambiguous syntactic attachments among a group of individuals (as opposed to the more common facilitation). We believe the most plausible explanation of this finding is that older adults, who have been found to weigh accuracy over speeded performance across a variety of cognitive tasks (Smith & Brewer, 1995; Forstmann et al., 2011; Starns & Ratcliff, 2010), were more sensitive to the small number of items explicitly probing attachment (Swets et al., 2008; see also Fallon, Peelle, & Wingfield, 2006; Stine-Morrow et al., 2006; for evidence of comprehension goals differentially affecting on-line processing for older adults). High-span adults may have allocated more time at the point of disambiguation in an attempt to reach a final interpretation, despite the fact that the meaning was ultimately indeterminate. That this effect happened uniquely for the older adults with high verbal working memory suggests that individual differences in WM do not simply mimic the effects of normative aging; that is, high-span older adults do not always behave like the young and low-span younger adults do not always behave like the old (cf. Jost, Byrk, Vogel, & Mayr, 2011). Indeed, a general finding was that the influence of WM was exaggerated among older adults in both on-line and off-line comprehension. We address this phenomenon in more detail in the following section.

4.3. The Influence of Age and Working Memory on Attachment Resolution

Models of aging and language typically treat verbal WM as a key mediator of age-related differences in comprehension (DeDe et al., 2004; Stine-Morrow et al., 2008; van der Linden et al., 1999). In contrast, our findings that the effects of age on syntactic attachment were moderated by WM are consistent with a growing number of studies reporting larger influences of WM and attentional control on language processing among older adults compared to the young (Christianson et al., 2006; Federmeier, 2007; Kemtes & Kempler, 1997; Kemper & Herman, 2006; Kemper et al., 2010; Madden & Dijkstra, 2010; Stites, Federmeier, & Stine-Morrow, 2013).

One possible explanation of these findings is that the measure of WM used in the current study may not be sensitive among younger adults. We do not believe that this is likely. First, the WM measures used in the current study have been validated in younger adult samples (Waters & Caplan, 2003; Daneman & Merike, 1996; Stine-Morrow et al., 2001). Moreover WM was correlated to a similar magnitude with other individual differences (i.e., vocabulary score, fluency, speed) across all three age groups in the current study (see Appendix). A second, but related explanation is that younger adults are more homogenous as a group, resulting in limited variance in individual differences in the young relative to middle-aged and older adults. However, the *SD*'s of WM were very similar across younger, middle-aged, and older adults, suggesting that there were not substantial developmental differences in variability in reading span performance (see Appendix)[11].

We believe that the most plausible explanation for the age-by-WM interactions is that, with advancing age, attentional control resources in WM are recruited at progressively lower

[11]Note that these same arguments could also plausibly be used to explain the larger PE effects on NP1 attachment among the old (discussed below). For the same reasons, we view these explanations as unlikely, given the established link between PE and language processing in literate college-aged adults (Acheson et al., 2008; Chataeu & Jared, 2000; Cunningham & Stanovich; Unsworth & Pexman, 2003), and the similar intercorrelations between PE and other individual difference variables across age groups, and similar *SD*s for PE in each age group. Moreover, PE was actually found to be a larger moderator of comprehension of temporarily ambiguous attachments among the young, suggesting that it is a valid indicator of reading experience in younger adults, as well as the old (cf. Payne et al., 2012).

levels of difficulty in order to maintain comprehension. This hypothesis has been used to explain the finding that older adults rely more heavily on control processes in WM even in simple storage tasks, in order to maintain distinct items in short-term memory (Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Jonides, 2007; Reuter-Lorenz et al., 2001). Similarly, Wingfield and Grossman (2006) extended this hypothesis to language processing, explaining the findings that older adults show increased recruitment of WM networks during comprehension of simple active-conjoined sentences (*The man insulted the woman and hired a lawyer)* and subject-relative clauses (*The man who insulted the woman hired a lawyer),* whereas younger adults only show this increased activation in the more complex object-relative clauses (*The man who the woman insulted hired a lawyer)* (Cooke et al. 2002).

Younger adults may not need to recruit WM resources on-line in order to resolve syntactic attachment ambiguity of the sort investigated in the current study. However, because of diffuse age-related changes in brain and cognitive function and neural efficiency, which compromise internal memory representations (Gutchess et al., 2005; Li, Naveh-Benjamin, & Lindenberger, 2005; Reuter-Lorenz & Lustig, 2005), older adults must rely more heavily on WM resources in order to perform syntactic operations at lower levels of complexity compared to the young. Thus, the exaggerated effects of individual differences in verbal working memory among the old are likely the result of older adults recruiting WM resources to a larger degree than the young in a compensatory fashion, in order to bind anaphors to one of multiple possible noun phrases during sentence comprehension. Indeed, age-related associative binding deficits are substantial in episodic memory (Naveh-Benjamin, 2000), and may be dependent upon attentional control resources in WM (Kernsten & Earles, 2010; Kim & Giovanello, 2011, but see Klib & Naveh-Benjamin, 2007). Consistent with Swets et al. (2007), we suggest that one way that older adults with lower verbal working memory compensate for the increased cognitive workload of binding during syntactic ambiguity resolution is to chunk long constituents into smaller units (Payne & Stine-Morrow, 2012), which results in the observed increased high attachment bias.

4.4. Reading Experience and Aging: Implications for Models of Working Memory and Sentence Comprehension

We tested whether individual differences in print exposure, a general indicator of written language experience (Stanovich & Cunningham, 1992; Acheson, Wells, & MacDonald, 2008; Payne et al., 2012), moderated syntactic attachment resolution over and above individual differences in verbal WM. Our most notable finding was that older adults with higher levels of PE showed exaggerated on-line processing costs for NP1 attachments. Literacy experience provides increased day-to-day exposure to print and, presumably, greater exposure to a probabilistic bias towards low attachment in English (cf. Wells, et al., 2009). Because older adults with high PE have decades more experience with such attachment biases, they appeared to have an expectation for reflexive pronouns that agreed in gender with the most recent NP, reflecting a stronger late-closure preference in English (Frazier & Clifton, 1996; Rohde, Levy, & Kehler, 2011). When this late-closure is violated, high PE older adults allocated more time immediately at the reflexive pronoun, in order to resolve this violation. This effect appears to be qualitatively different from the later effects of WM in the post-disambiguating region found in the current study, and previously reported in the literature (Swets et al., 2008; Traxler, 2007).

MacDonald and Christiansen (2002) have argued that relationships between reading span performance and language processing may be artificial in nature. That is, measures of reading span and measures of on-line and off-line language comprehension are "simply different measures of language processing skill" (p. 36). They go on to argue that differences in language skill reflected in the reading span task are likely driven by differences in reading experience (see also Acheson et al., 2009; Wells et al., 2011). For example, Wells, Christiansen, Race, Acheson and MacDonald (2009) argued that "people who scored well on the reading span task were those who read more and thus had more experience than those with lower reading span scores; this extra experience was hypothesized to be both the source of the high-span group's good reading span performance and their better comprehension…" (p. 253).

In contrast to MacDonald and Christiansen's (2002) account, we found that (1) verbal working memory and print exposure were uncorrelated in the full sample, and uncorrelated within each age group; (2) WM and PE showed contrasting age-related developmental trajectories; and (3) individual differences in PE operated independently from verbal WM in predicting on-line and off-line syntactic attachment preferences. Specifically, PE moderated on-line processing only among NP1 sentences, but did not have effects on the ambiguous or NP2 attachments, sentences where WM effects were the largest.

Our results are more consistent with findings in the literature suggesting that individuals who vary in verbal WM do not differ substantially in their reading habits, with some low-span individuals even reporting more time reading certain materials (e.g., magazines; Caplan & Waters, 2002). In larger samples assessing PE and WM in young and older adults, correlations are small or unreliable (Payne et al., 2012; Stanovich et al., 1995), and older adults often report spending more time reading than do the young (Payne et al., 2012; Stanovich et al., 1995; Stine-Morrow et al., 1996). Overall, the age-related dissociation of WM and PE effects on comprehension suggests that verbal working memory and reading experience have separable contributions to language performance, at least in relative clause attachment in older adulthood. Though these age-related dissociations of capacity and experience were predicted by Just and Varma (2002), as far as we know, this is the first direct empirical test of individual differences in both WM and PE on syntactic parsing in younger and older adults.

4.5. Limitations and Future Directions

Important caveats and assumptions of the current study need to be addressed. First, a limiting assumption of this study is that measures of reading experience, such as the Author Recognition Test, are a proxy for "language experience" more generally. It is possible that exposure to printed text is not associated with statistical learning that occurs as a function of increased exposure to speech. One result of this is that the PE and attachment effects observed in the current study during reading may not hold across modalities. At the same time, there is evidence that a wider variety of syntactic structures are encountered in the written domain, compared to speech (Biber, 1986), suggesting that print exposure is a likely correlate of syntactic exposure, and by extension, syntactic comprehension (Acheson et al., 2008). Importantly, measures such as the ART purport to index differences in rates of exposure to print and this does appear to reflect the same kind of exposure that is suggested as the active mechanism in MacDonald and Christensen's (2002) model, in which statistical exposure is increased through training network weights in a simple recursive network. Individuals with higher PE encounter greater exposure to statistical patterns in written English, resulting in a greater sensitivity to syntactic constructions with varying regularity (e.g., a Frequency × Regularity × Experience interaction; Seidenberg, 1985; MacDonald & Christensen, 2002), and thus, are more likely to be attuned to probabilistic biases inherent in the input (Acheson et al., 2008). This is supported by a recent training study showing that by simply increasing statistical exposure to written object-relative clauses, participants showed reduced on-line processing time for these constructions during reading (Wells et al., 2009).

Finally, a limitation of the current study is that it included only a single measure of WM. As is the case with any psychometric measure, having multiple indicators results in a more stable and reliable estimate (provided that the measures are valid indicators of the latent ability being assessed). At the same time, we had two major motivations for using reading span as our measure of verbal working memory. First, we wanted to be able to test the strong claim of MacDonald and Christiansen's (2002) experienced-mediated WM hypothesis that reading exposure drives the predictive effects of individual differences in reading span performance. Combining reading span with other measures of WM performance (especially if these were non-verbal tasks, e.g., spatial span, n-back) would likely obscure interpretation of this test of their theory. Indeed, Swets et al. (2007) showed that a domain-general complex WM factor (including verbal and visuospatial span measures) explained reliable variance in off-line attachment preferences in globally ambiguous sentences, but that a domain-specific verbal WM span (defined by reading span performance) predicted unique additional variance in attachment preference over and above the general span factor. Second, given the constraints of possible task fatigue from an extensive individual differences battery, we opted for a "broad" rather than a "deep" testing battery. That is, we aimed to rule out third variable explanations of potential WM and PE effects by examining the influence of other common cognitive individual differences such as fluency, speed, and vocabulary (Caplan et al., 2011; Federmeier et al., 2007; Payne et al., 2012; Stine-Morrow et al., 2008). The observed dissociation of WM and PE effects on language comprehension in the current study cannot not be explained by individual differences in psychomotor speed (Caplan et al., 2011), verbal fluency (Federmeier et al., 2007), or vocabulary (Payne et al., 2012; Stine-Morrow et al., 2008). We view this as an important finding that may have been irrecoverable with an alternate measurement battery that emphasized multiple indicators of only a single construct, rather than a small number of indicators for multiple constructs. A goal for future work is to determine if the observed effects of WM on attachment are domain-general, or if they are limited to relationships between sentence span and parsing during reading.

It is important to note that Swets and colleagues' (2007) prosodic segmentation account is entirely consistent with other models of sentence segmentation, such as Kintsch and colleagues' (Kintsch & van Dijk, 1978; Kintsch 1998; 2010) input cycle mechanism, and Frazier and Fodor's (1978) preliminary phrase packager, which have also been used to explain age differences in sentence and discourse comprehension (Christianson et al., 2006; Stine-Morrow & Miller, 2009). An interesting question for future research is how prosodic choice is related to segmentation mechanisms, and what causes these "chunking" decisions in general. One argument in the production literature is that phrase boundary placement is constrained by linguistic complexity (Breen, Watson, & Gibson, 2011; Watson & Gibson, 2004). Although some research has suggested that wrap-up effects occur more often at prosodic phrase boundaries in silent reading (Hirotani, Frazier, & Rayner, 2006), future research should be aimed at directly testing the relationship between implicit prosody and silent reading, as well age differences in segmentation strategies in silent reading and phrase-boundary placement in speech.

4.6. Concluding Remarks

The current study is unique in that, with a comparably large sample that was age- and ability-continuous, we were powered to detect individual differences that may not be able to be detected in psycholinguistics experiments with more typical sample sizes that focus on testing within-subject effects alone. There has been a growing interest in basing claims about cognitive mechanisms on broader samples than the college-aged adult (Henrich, Heine, & Norenzyan, 2010; Peterson, 2001). We view our findings as extending those of a number of studies examining how syntactic attachment resolution varies across diverse groups with different cognitive capacities and language experiences (Carreiras, & Clifton, 1999; Felser et al., 2003; Swets et al., 2007). Indeed, our findings suggest that aging brings changes in attachment ambiguity resolution during sentence understanding, and that these changes depend upon independent influences of both cognitive capacity and reading experience.

APPENDIX

References

Aaronson, D.; Ferres, S. The word-by-word reading paradigm: An experimental and theoretical approach. In: Kieras, DE.; Just, MA., editors. New methods in reading comprehension research. Erlbaum; Hillsdale, NJ: 1984. p. 31-68.

Acheson DJ, Wells JB, MacDonald MC. New and updated tests of print exposure and reading abilities in college students. Behavior Research Methods. 2008; 40:278–289. [PubMed: 18411551]

Baayen RH, Davidson DJ, Bates DM. Mixed-effects modeling with crossed random effects for subjects and items. Journal of Memory and Language. 2008; 59:390–412.

Biber D. Spoken and written textual dimensions in English: Resolving the contradictory findings. Language. 1986; 62:384–414.

Bopp KL, Verhaeghen P. Aging and verbal memory span: A meta-analysis. Journal of Gerontology: Psychological Sciences. 2005; 60:223–233.

Breen M, Watson D, Gibson E. Intonational phrasing is constrained by meaning not balance. Language and Cognitive Processes. 2011; 26:1532–1562.

Caplan D, Waters G. Working memory and connectionist models of parsing: A response to MacDonald and Christiansen. Psychological Review. 2002; 109:66–74.

Caplan D, Waters GS. Verbal working memory and sentence comprehension. Behavioral and Brain Sciences. 1999; 22:77–94. [PubMed: 11301522]

Caplan D, DeDe G, Waters G, Michaud J, Tripodis Y. Effects of age, speed of processing, and working memory on comprehension of sentences with relative clauses. Psychology and Aging. 2011; 26:439–450. [PubMed: 21480714]

Caplan, D.; Waters, G.; DeDe, G. Specialized verbal working memory for language comprehension. In: Conway, A.; Jarrold, C.; Kane, M.; Miyake, A.; Towse, J., editors. Variation in Working Memory. Oxford University Press; New York: 2007.

Carlson K, Clifton C Jr. Frazier L. Prosodic boundaries in adjunct attachment. Journal of Memory and Language. 2001; 45:58–81.

Carreiras M, Clifton C Jr. Another word on parsing relative clauses: Eye-tracking evidence from Spanish and English. Memory & Cognition. 1999; 27:826–833. [PubMed: 10540811]

Carreiras M, Salillas E, Barber H. Event-related potentials elicited during parsing of ambiguous relative clauses in Spanish. Cognitive Brain Research. 2004; 20:98–105. [PubMed: 15130594]

Chateau C, Jared D. Exposure to print and word recognition processes. Memory & Cognition. 2000; 28:143–153. [PubMed: 10714145]

Christianson K, Hollingworth A, Halliwell JF, Ferreira F. Thematic roles assigned along the garden path linger. Cognitive Psychology. 2001; 42:368–407. [PubMed: 11368528]

Christianson K, Luke SG. Context strengthens initial misinterpretations of text. Scientific Studies of Reading. 2011; 15:136–166.

Christianson K, Williams CC, Zacks RT, Ferreira F. Younger and older adults' "good-enough" interpretations of garden-path sentences. Discourse Processes. 2006; 42:205–238. [PubMed: 17203135]

Conway AR, Kane MJ, Bunting MF, Hambrick DZ, Wilhelm O, Engle RW. Working memory span tasks: A methodological review and user's guide. Psychonomic Bulletin & Review. 2005; 12:769–786. [PubMed: 16523997]

Cooke A, Zurif EB, DeVita C, Alsop D, Koenig P, Detre J, Gee J, Pinango M, Balogh J, Grossman M. The neural basis for sentence comprehension: grammatical and short-term memory components. Human Brain Mapping. 2002; 15:80–94. [PubMed: 11835600]

Cuetos F, Mitchell DC. Cross-linguistic differences in parsing: Restrictions on the use of the late closure strategy in Spanish. Cognition. 1988; 30:73–105. [PubMed: 3180704]

Cunningham AE, Stanovich KE. Assessing print exposure and orthographic processing skill in children: A quick measure of reading experience. Journal of Educational Psychology. 1990; 82:733–74.

Daneman M, Merikle PM. Working memory and language comprehension: A meta-analysis. Psychonomic Bulletin and Review. 1996; 3:422–433. [PubMed: 24213976]

DeDe G, Caplan D, Kemtes K, Waters G. The relationship between age, verbal working memory and language comprehension. Psychology and Aging. 2004; 19:601–616. [PubMed: 15584786]

DeDe G, Caplan D, Kemtes K, Waters G. The relationship between age, verbal working memory and language comprehension. Psychology and Aging. 2004; 19:601–616. [PubMed: 15584786]

Fallon M, Peelle JE, Wingfield A. Spoken sentence processing in young and older adults modualted by task demands: Evidence from self-paced listening. Journal of Gerontology: Psychological Sciences. 2006; 61B:10–17.

Federmeier KD. Thinking ahead: The role and roots of prediction in language comprehension. Psychophysiology. 2007; 44:591–505.

Fedorenko E, Gibson E, Rohde D. The nature of working memory capacity in sentence comprehension: Evidence against domain-specific working memory resources. Journal of Memory and Language. 2006; 54:541–553.

Felser C, Marinis T, Clahsen H. Children’s processing of ambiguous sentences: A study of relative clause attachment. Language Acquisition: A Journal of Developmental Linguistics. 2003; 11:127–163.

Ferreira F, Bailey KGD, Ferraro V. Good-enough representations in language comprehension. Current Directions in Psychological Science. 2002; 11:11–15.

Fodor JD. Psycholinguistics cannot escape prosody. In Proceedings of the Speech Prosody 2002 Conference. 2002; 1:83–90.

Forstmann BU, Tittgemeyer M, Wagenmakers E-J, Derrfuss J, Imperati D, Brown S. The speed-accuracy tradeoff in the elderly brain: A structural model-based approach. The Journal of Neuroscience. 2011; 31:177242–177249.

Frazier, L.; Clifton, C. Construal. MIT Press; Cambridge, MA: 1996.

Frazier L, Fodor JD. The sausage machine: A new two-stage parsing model. Cognition. 1978; 6:291–325.

Frazier L, Carlson K, Clifton C. Prosodic phrasing is central to language comprehension. Trends in Cognitive Sciences. 2006; 6:244–249. [PubMed: 16651019]

Gernsbacher, MA. Language comprehension as structure building. Erlbaum; Hillsdale, NJ: 1990.

Gibson E. Linguistic complexity: Locality of syntactic dependencies. Cognition. 1998; 68:1–76. [PubMed: 9775516]

Gilboy E, Sopena JM, Clifton C, Frazier L. Argument structure and association preference in Spanish and English complex NPs. Cognition. 1995; 54:131–167. [PubMed: 7874875]

Green MJ, Mitchell DC. Absence of real evidence against competition during syntactic ambiguity resolution. Journal of Memory and Language. 2006; 55:1–17.

Grodner D, Gibson E. Consequences of the serial nature of linguistic input for sentential complexity. Cognitive Science. 2005; 29:261–290. [PubMed: 21702774]

Gutchess AH, Welsh RC, Hedden T, Bangert A, Minear M, Liu LL, Park DC. Aging and the neural correlates of successful picture encoding: Frontal activations compensate for decreased medial-temporal activity. Journal of Cognitive Neuroscience. 2005; 17:84–96. [PubMed: 15701241]

Hayes, A. Introduction to Mediation, Moderation, and Conditional Process Analysis. The Guilford Press; New York, NY: 2013.

Hasher, L.; Lustig, C.; Zacks, R. Inhibitory mechanisms and the control of attention. In: Conway, A.; Jarrold, C.; Kane, M.; Miyake, A.; Towse, J., editors. Variation in Working Memory. Oxford University Press; New York: 2006.

Henrich J, Heine SJ, Norenzyan A. The weirdest people in the world? Behavioral and Brain Sciences. 2010; 33:61–135. [PubMed: 20550733]

Hirotani M, Frazier L, Rayner K. Punctuation and intonation effects on clause and sentence wrap-up: Evidence from eye movements. Journal of Memory and Language. 2006; 54:425–443. doi: 10.1016/j.jml.2005.12.001.

Jaeger TF. Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. Journal of Memory and Language. 2008; 59:434–446. [PubMed: 19884961]

Jost K, Bryck RB, Vogel EK, Mayr U. Are old adults just like low working memory young adults? Filtering efficiency and age differences in visual working memory. Cerebral Cortex. 2011; 21:1147–1154. [PubMed: 20884722]

Jun S. Prosodic phrasing and attachment preferences. Journal of Psycholinguistic Research. 2003; 32:219–249. [PubMed: 12690832]

Just MA, Carpenter P. A capacity theory of comprehension: Individual differences in working memory. Psychological Review. 1992; 99:122–149. [PubMed: 1546114]

Just MA, Varma S. A hybrid architecture for working memory: Reply to MacDonald and Christiansen (2002). Psychological Review. 2002; 109:55–65.

Kemper S, Liu C. Eye movements of young and older adults during reading. Psychology and Aging. 2007; 22:84–93. [PubMed: 17385986]

Kemper S, Herman RE. Age differences in memory-load interference effects in syntactic processing. Journals of Gerontology: Psychological and Social Sciences. 2006; 61B:327–332.

Kemper S, Schmalzried R, Hoffman L, Herman R. Aging and the vulnerability of speech to dual task demands. Psychology and Aging. 2011; 25:949–962. [PubMed: 21186917]

Kemtes KA, Kemper S. Younger and older adults' on-line processing of syntactically ambiguous sentences. Psychology and Aging. 1997; 12:362–371. [PubMed: 9189996]

Kernsten AW, Earles JL. Effects of aging, distraction, and response pressure on the binding of actors and actions. Psychology and Aging. 2010; 25:620–630. [PubMed: 20853968]

Kilb A, Naveh-Benjamin M. Paying attention to binding: Further studies assessing the role of reduced attentional resources in the associative deficit of older adults. Memory & Cognition. 2007; 35:1162–1174. [PubMed: 17910197]

Kim S-Y, Giovanello KS. The effects of attention on age-related memory relational memory deficits: Evidence form a novel attentional manipulation. Psychology and Aging. 2011; 26:678–688. [PubMed: 21707178]

King JW, Just MA. Individual differences in syntactic parsing: The role of working memory. Journal of Memory and Language. 1991; 30:580–602. doi:10.1016/0749-596X(91)90027-H.

Kintsch, W. Comprehension: A paradigm for cognition. Cambridge University Press; Cambridge, England: 1998.

Kintsch W, Mangalath P. The construction of meaning. Topics in Cognitive Science. 2010; 3:346–370.

Kintsch W, van Dijk TA. Toward a model of text comprehension and production. Psychological Review. 1978; 85:363–394.

Kuperman V, Dambacher M, Nuthmann A, Kliegl R. The effect of word position on eye-movements in sentence and paragraph reading. The Quarterly Journal of Experimental Psychology. 2010; 63:1838–1857. [PubMed: 20373225]

Levy R. Expectation-based syntactic comprehension. Cognition. 2008; 106:1126–1177. [PubMed: 17662975]

Long, DL.; Johns, CL.; Morris, PE. Comprehension ability in mature readers. In: Traxler, M.; Gernsbacher, M., editors. Handbook of Psycholinguistics. Academic Press; Burlington, MA: 2007. p. 801-834.

MacDonald MC, Christiansen MC. Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). Psychological Review. 2002; 109:35–54. doi: 10.1037/0033-295X.109.1.35. [PubMed: 11863041]

MacDonald M, Just M, Carpenter P. Working memory constraints on the processing of syntactic ambiguity. Cognitive Psychology. 1992; 24:56–98. [PubMed: 1537232]

Madden C, Dijkstra K. Contextual constraints in situation model construction: An investigation of age and reading span. Aging, Neuropsychology, & Cognition. 2010; 17:19–34.

Metusalem R, Kutas M, Urbach TP, Hare M, McRae K, Elman JL. Generalized event knowledge activation during online sentence comprehension. Journal of Memory and Language. 2012; 66:545–567. [PubMed: 22711976]

Miller LMS, Stine-Morrow EAL. Aging and the effects of knowledge on on-line reading strategies. Journal of Gerontology: Psychological Sciences. 1998; 53B:P223–P233.

Mitchell, DC. Sentence parsing. In: Gernsbacher, MA., editor. Handbook of Psycholinguistics. Academic Press; New York: 1994. p. 375-409.

Naveh-Benjamin M. Adult-age differences in memory performance: Tests of an associative deficit hypothesis. Journal of Experimental Psychology: Learning, Memory and Cognition. 2000; 26:1170–1187.

Park D, Reuter-Lorenz P. The adaptive brain: Aging and neurocognitive scaffolding. Annual Review of Psychology. 2009; 60:173–96.

Payne BR, Stine-Morrow EAL. Aging, parafoveal preview, and semantic integration in sentence processing: Testing the cognitive workload of wrap-up. Psychology and Aging. 2012; 27:638–649. doi: 10.1037/a0026540. [PubMed: 22229390]

Payne BR, Gao X, Noh SR, Anderson CJ, Stine-Morrow EAL. The effects of print exposure on sentence processing and memory among older adults: Evidence for efficiency and reserve. Aging, Neuropsychology, and Cognition. 2012; 19:122–149.

Pearlmutter NJ, MacDonald ME. Individual differences and probabilistic constraints in syntactic ambiguity resolution. Journal of Memory and Language. 1995; 34:521–542.

Peterson RA. On the use of college students in social science research: Insights from a second-order meta-analysis. Journal of Consumer Research. 2001; 28:450–61.

Preacher KJ, Curran PJ, Bauer DJ. Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis. Journal of Educational and Behavioral Statistics. 2006; 31:437–448.

Rayner K, Kambe G, Duffy SA. The effect of clause wrap-up on eye movements during reading. The Quarterly Journal of Experimental Psychology. 2000; 53:1061–1080. [PubMed: 11131813]

Reuter-Lorenz, PA.; Jonides, J. The executive is central to working memory: insights from age, performance, and task variations. In: Conway, A.; Jarrold, C.; Kane, M.; Miyake, A.; Towse, J., editors. Variations in Working Memory. Oxford University Press; New York: 2007.

Rohde H, Levy R, Kehler A. Anticipating explanations in relative clause processing. Cognition. 2011; 118:339–358. [PubMed: 21216396]

Rozek E, Kemper S, McDowd J. Learning to ignore distracters. Psychology and Aging. 2012; 27:61–66. [PubMed: 22004518]

Seidenberg MS. The time course of phonological code activation in two writing systems. Cognition. 1985; 19:1–30. [PubMed: 4039640]

Smiler AP, Gagne DD, Stine-Morrow EAL. Aging, memory load, and resource allocation during reading. Psychology and Aging. 2003; 18:203–209. [PubMed: 12825770]

Smith GA, Brewer N. Slowness and age: speed-accuracy mechanisms. Psychology and Aging. 1995; 10:238–247. [PubMed: 7662183]

Snijders, TAB.; Bosker, RJ. Multilevel analysis. Sage Publications; London, UK: 2011.

Stanovich KE, Cunningham AE. Studying the consequences of literacy within a literate society: The cognitive correlates of print exposure. Memory & Cognition. 1992; 20:51–68. [PubMed: 1549065]

Stanovich KE, West RF. Exposure to print and orthographic processing. Reading Research Quarterly. 1989; 24:402–433.

Stanovich KE, West RF, Harrison MR. Knowledge growth and maintenance across the life span: The role of print exposure. Developmental Psychology. 1995; 31:811–826.

Starns JJ, Ratcliff R. The effects of aging on the speed-accuracy compromise: Boundary optimality in the diffusion model. Psychology and Aging. 2010; 25:377–390. [PubMed: 20545422]

Staub A, Clifton C. Syntactic prediction in language comprehension: Evidence from either … or. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2006; 32:425–36.

Stine EAL, Hindman J. Age differences in reading time allocation for propositionally dense sentences. Aging and Cognition. 1994; 1:2–16.

Stine-Morrow EAL, Milinder L, Pullara P, Herman B. Patterns of resource allocation are reliable among younger and older readers. Psychology and Aging. 2001; 16:69–84. [PubMed: 11302369]

Stine-Morrow EAL, Miller LMS, Hertzog C. Aging and self regulated language processing. Psychological Bulletin. 2006; 132:582–606. [PubMed: 16822168]

Stine-Morrow EAL, Miller LMS, Gagne DD, Hertzog C. Self-regulated reading in adulthood. Psychology and Aging. 2008; 23:131–153. [PubMed: 18361662]

Stine-Morrow EAL, Noh SR, Shake MC. Age differences in the effects of conceptual integration training on resource allocation in sentence processing. Quarterly Journal of Experimental Psychology. 2010; 63:1430–1455.

Stine-Morrow EAL, Ryan S, Leonard JS. Age differences in on-line syntactic processing. Experimental Aging Research. 2000; 26:315–322. [PubMed: 11091938]

Stine-Morrow EAL, Shake MC, Miles JR, Lee K, Gao X, McConkie G. Pay now or pay later: Aging and the role of boundary salience in self-regulation of conceptual integration in sentence processing. Psychology and Aging. 2010; 25:168–176. doi:10.1037/a0018127. [PubMed: 20230137]

Stine-Morrow EAL, Miller LMS. Aging, self-regulation, and learning from text. Psychology of Learning and Motivation. 2009; 51:255–285.

Stine-Morrow EAL, Loveless MK, Soederberg LM. Resource allocation in on-line reading by younger and older adults. Psychology and Aging. 1996; 11:475–486. [PubMed: 8893316]

Stine EAL. On-line processing of written text by younger and older adults. Psychology and Aging. 1990; 5:68–78. [PubMed: 2317303]

Stites MC, Federmeier KD, Stine-Morrow EAL. Cross-age comparisons reveal multiple strategies for lexical ambiguity resolution during natural reading. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2013 Online First.

Swets B, Desmet T, Hambrick DZ, Ferreira F. The role of working memory in syntactic ambiguity resolution: A psychometric approach. Journal of Experimental Psychology: General. 2007; 136:64–81. [PubMed: 17324085]

Swets B, Desmet T, Clifton C, Ferreira F. Underspecification of syntactic ambiguities: Evidence from self-paced reading. Memory & Cognition. 2008; 36:201–216. [PubMed: 18323075]

Traxler MJ. Working memory contributions to relative clause attachment processing: A hierarchical linear modeling analysis. Memory & Cognition. 2007; 35:1107–1121. [PubMed: 17910193]

Traxler MJ, Pickering MJ, Clifton C Jr. Adjunct attachment in not a form of lexical ambiguity resolution. Journal of Memory and Language. 1998; 39:558–592.

Traxler MJ. A hierarchical linear modeling analysis of working memory and implicit prosody in the resolution of adjunct attachment ambiguity. Journal of Psycholinguistic Research. 2009; 38:491–509. [PubMed: 19377881]

Unsworth SJ, Pexman PM. The impact of reader skill on phonological processing in visual word recognition. Quarterly Journal of Experimental Psychology. 2003; 56A:63–81. [PubMed: 12587895]

Van der Linden M, Hupet M, Feyereisen P, Schelstraete M-A, Bestgen Y, Bruyer R. Cognitive mediators of age-related differences in language comprehension and verbal memory performance. Aging, Neuropsychology, and Cognition. 1999; 6:32–55.

van Gompel RPG, Pickering MJ, Pearson J, Liversedge SP. Evidence against competition during syntactic ambiguity resolution. Journal of Memory and Language. 2005; 52:284–307.

Verhaghen P. Aging and vocabulary score: A meta-analysis. Psychology and Aging. 2003; 18:332–339. [PubMed: 12825780]

Waters G, Caplan D. The relationship between age, processing speed, working memory capacity, and language comprehension. Memory. 2005; 13:403–413. [PubMed: 15952262]

Waters GS, Caplan D. The reliability and stability of verbal working memory measures. Behavioral Research Methods. 2003; 35:550–564.

Watson D, Gibson E. The relationship between intonational phrasing and syntactic structure in language production. Language and Cognitive Processes. 2004; 19(6):713–755.

Wells JB, Christiansen MH, Race DS, Acheson DJ, MacDonald MC. Experience and sentence comprehension: Statistical learning and relative clause comprehension. Cognitive Psychology. 2009; 58:250–271. [PubMed: 18922516]

Wingfield A, Grossman M. Language and the aging brain: Patterns of neural compensation revealed by functional brain imaging. Journal of Neurophysiology. 2006; 96:2830–2839. [PubMed: 17110737]

Key Messages

- We investigated age and individual differences in relative clause attachment resolution.
- Working memory predicted off-line and on-line attachment preferences, especially among older adults.
- Effects of print exposure operated independently from working memory.
- Aging brings differences in syntactic parsing, depending on capacity and experience.

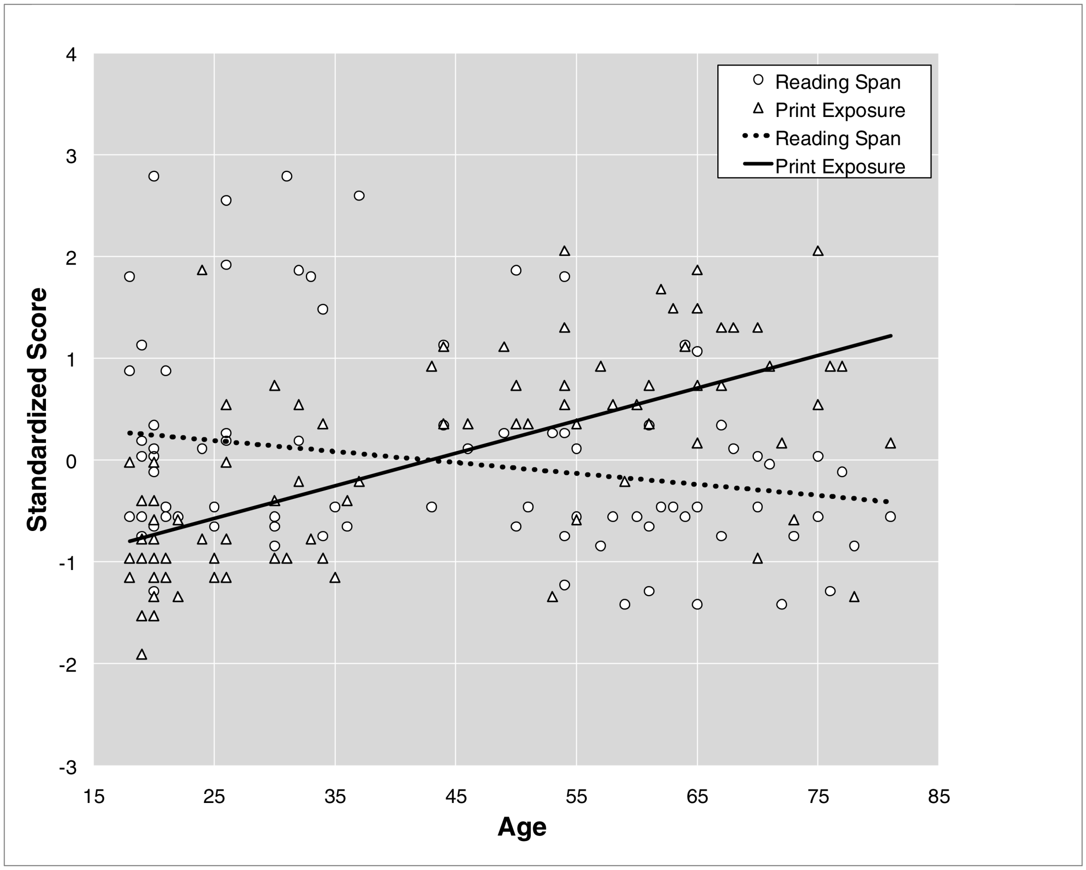

Figure 1.
Divergent Age-Related Trajectories of Reading Span and Print Exposure

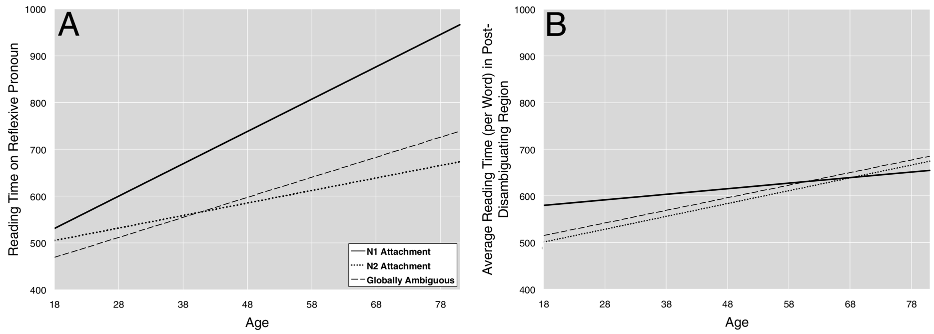

Figure 2.

Effects of Age on Reading Time as a Function of Sentence Condition for the (A) Reflexive Pronoun Region and (B) Post-Disambiguating Region

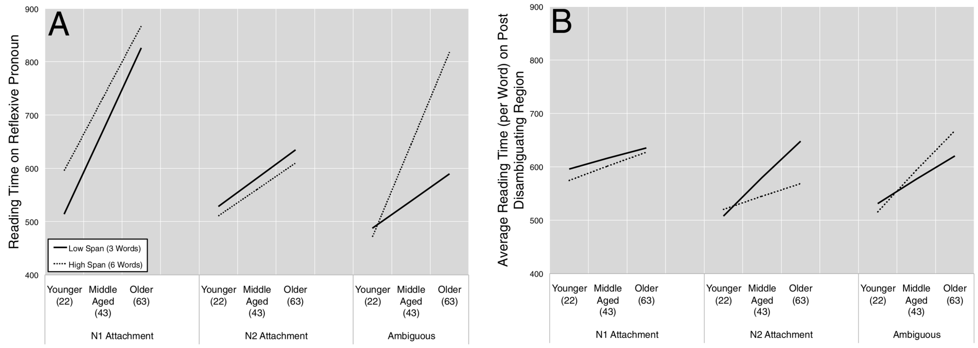

Figure 3.
Effects of Working Memory, Age, and Sentence Type on Reading Time for the (A) Reflexive pronoun region and (B) Post-disambiguating region

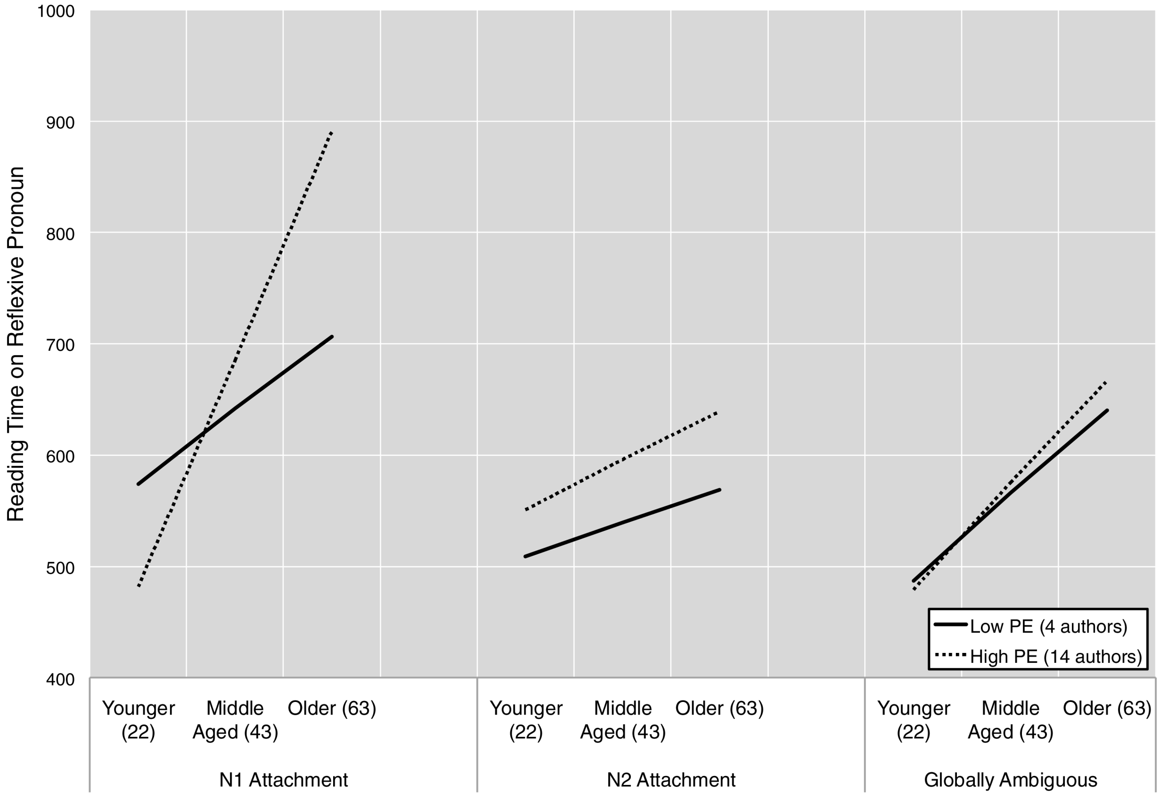

Figure 4.
Effects of Print Exposure, Age, and Sentence Type on Reading Time in the Reflective Pronoun Region

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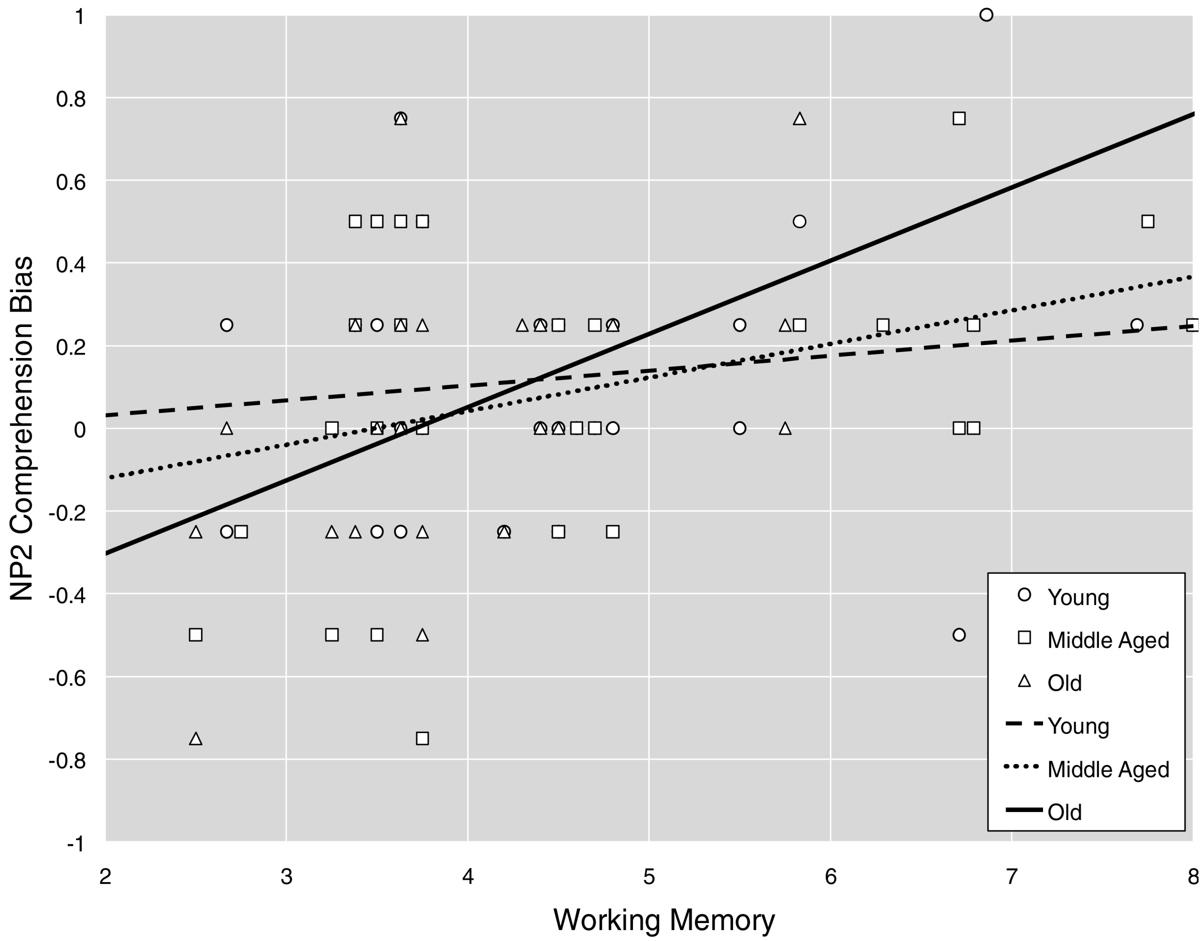

Figure 5.
NP2 Comprehension Bias as a Function of WM and Age

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Table 1

Sample Characteristics

			Correlations					
	M	**SD**	**1**	**2**	**3**	**4**	**5**	**6**
1. Education	16.21	2.64						
2. Working Memory	4.35	1.31	.01					
3. Print Exposure	9.10	5.30	**.56**	−.05				
4. Vocabulary	9.86	4.19	**.56**	.12	**.69**			
5. Processing Speed	.00	.83	.00	**.35**	−.14	.01		
6. Phonemic Fluency	43.75	9.76	.14	**.29**	.05	.18	**.64**	
7. Age	42.84	20.32	**.36**	**−.22**	**.65**	**.43**	**−.35**	**−.25**

Note. Correlations in bold are significant at $p < .05$. Processing Speed is an unweighted average of standardized scores on letter and pattern comparison tasks.

Table 2

Fixed Parameter Estimates and Standard Errors from Linear Mixed Effects Models of Reading Time

	Model 1: Age		Model 2: Age and WM		Model 3: Age and PE	
Estimates	**RPR**	**PDR**	**RPR**	**PDR**	**RPR**	**PDR**
Intercept	456.81 (74.28) ***	464.34 (73.26) ***	486.59 (96.74) ***	472.12 (81.29) ***	472.97 (103.93) ***	454.37 (83.67) ***
Conditional Effects[1]						
Age	2.67 (1.59)	2.75 (.86) **	1.95 (2.21)	2.39 (1.23)	2.18 (2.16)	2.95 (1.19) *
C1	−50.49 (48.71)	106.57 (20.39) ***	−69.61 (50.59)	96.87 (21.19) ***	−104.22 (66.05)	142.22 (27.64) ***
C2	−65.28 (48.71)	14.91 (20.43)	−107.65 (50.57) *	−4.53 (21.24)	−98.41 (66.04)	24.41 (27.83)
WM	-	-	−4.85 (80.33)	30.68 (44.13)	20.27 (30.66)	−5.12 (17.44)
PE	-	-	16.76 (39.55)	−2.76 (22.44)	4.22 (97.42)	−18.82 (53.72)
WP Covariate	-	−12.88 (6.35)		−12.70 (6.36)	-	−13.06 (6.36)
2-Way Interactions[1]						
Age × C1	4.24 (1.05) ***	−1.56 (.44) ***	4.67 (1.15) **	−1.17 (.48) *	4.65 (1.38)***	−2.08 (.58) ***
Age × C2	1.61 (1.05)	−.05 (.44)	3.00 (1.15) **	.64 (.48)	2.35 (1.38)	−.18 (.58)
WM × Age	-	-	−.19 (2.03)	−1.10 (1.11)	-	-
WM × C1	-	-	58.57 (52.51)	−45.08 (22.00)*	-	-
WM × C2	-	-	−69.15 (52.50)	−55.24 (22.07)*	-	-
PE × Age	-	-	-	-	.47 (1.92)	.24 (1.05)
PE × C1	-	-	-	-	−130.95 (63.51) *	59.50 (26.52) *[2]
PE × C2	-	-	-	-	−27.16 (63.50)	16.85 (26.79)
3-Way Interactions						
WM × Age × C1	-	-	−.40 (1.32)	1.28 (.55) *	-	-
WM × Age × C2	-	-	3.10 (1.32) *	1.88 (.55) ***	-	-
PE × Age × C1	-	-	-	-	2.90 (1.25) *	−1.04 (.53)
PE × Age × C2	-	-	-	-	.08 (1.26)	−.32 (.53)

Note. RPR = Reflexive Pronoun Region; PDR = Post-Disambiguating Region; WM = Working Memory; C1 = Contrast 1 (NP1 vs. NP2); C2 = Contrast 2 (Ambiguous vs. NP2); PE = Print Exposure; WP Covariate = Word Position covariate in post-disambiguating region models.

[1] These parameters should not be interpreted as unconditional marginal effects (see Footnote 7).

[2] The significant PE × C1 interaction in the post-disambiguating region is not reliable after removing the unreliable PE × Age × C1 interaction (t<1).

Table 3

Parameter Estimates (Log Odds) and Standard Errors from Logit Mixed-Effects Models of Comprehension

Estimates	Model 1: Age	Model 2: Age and WM	Model 3: Age and PE
Intercept	2.56 (.46)***	1.67 (.63)**	3.34 (.65)***
Conditional Effects[1]			
Age	−.01 (.01)	.03 (.01)*	−.02 (.01)
C1	−1.37 (.13)***	−.55 (.14)***	−2.32 (.18)***
WM	-	−1.28 (.51)*	.03 (.20)
PE	-	−.07 (.27)	1.11 (.61)
2-Way Interactions[1]			
Age × C1	.02 (.003)***	−.01 (.003)**	.04 (.003)***
WM × Age	-	.05 (.01) ***	-
WM × C1	-	.66 (.14)***	-
PE × Age	-	-	−.02 (.01)
PE × C1	-	-	−1.06 (.18) ***
3-Way Interactions			
WM × Age × C1	-	−.04 (.004)***	-
PE × Age × C1	-	-	.01 (.003)***

Note. WM = Working Memory, C1 = Contrast 1 (NP1 vs. NP2). PE = Print Exposure. [1]These parameters should not be interpreted as unconditional marginal effects (see Footnote 7).

Table 1

Sample Characteristics by Age Group

Young Adults								
			Correlations					
	M	**SD**	**1**	**2**	**3**	**4**	**5**	
1. Education	14.91	1.75						
2. Working Memory	4.92	1.32	.03					
3. Print Exposure	4.94	3.67	.22	.26				
4. Vocabulary	7.80	3.48	.25	.23	.52			
5. Processing Speed	.19	.70	.07	.15	.29	.15		
6. Phonemic Fluency	45.12	8.67	−.08	.18	.35	.30	.60	-
Middle-Aged Adults								
			Correlations					
	M	SD	1	2	3	4	5	
1. Education	16.52	2.35						
2. Working Memory	4.58	1.51	.04					
3. Print Exposure	9.94	4.34	.55	−.10				
4. Vocabulary	9.97	3.70	.48	.16	.58			
5. Processing Speed	.19	.70	.10	.40	−.05	.15		
6. Phonemic Fluency	45.13	11.04	.15	.22	.19	.21	.63	-
Older Adults								
			Correlations					
	M	SD	1	2	3	4	5	6
1. Education	*17*.46	3.20						
2. Working Memory	3.92	.92	.20					
3. Print Exposure	13.22	4.29	.48	.10				
4. Vocabulary	12.24	4.30	.61	.33	.70			
5. Processing Speed	−.45	.69	.20	.29	−.04	.23		
6. Phonemic Fluency	40.48	9.00	.55	.46	.15	.42	.63	
7. MMSE	29.06	.94	.04	.08	.46	.18	.19	.26

r's > .33 reach conventional levels of statistical significance *(p* < .05).