April 7, 2015

Running Head: Reading in Normally Aging Adults

Reading in Normally Aging Adults

Peter C. Gordon,[1] Matthew W. Lowder,[2] and Renske S. Hoedemaker[1]

[1]Department of Psychology, University of North Carolina at Chapel Hill

[2]Institute for Mind and Brain, University of South Carolina

Chapter to appear in Wright, H.H. (Ed.), *Cognitive-Linguistic Processes and Aging*. John Benjamins Publishing.

Address correspondence to:

Peter C. Gordon
Department of Psychology, CB#3270
University of North Carolina at Chapel Hill Chapel Hill, NC 27599-3270
pcg@unc.edu

The activity of reading raises fundamental theoretical and practical questions about healthy cognitive aging. Reading relies greatly on knowledge of patterns of language and of meaning at the level of words and topics of text. Further, this knowledge must be rapidly accessed so that it can be coordinated with processes of perception, attention, memory and motor control that sustain skilled reading at rates of four-to-five words a second. As such, reading depends both on crystallized semantic intelligence which grows or is maintained through healthy aging, and on components of fluid intelligence which decline with age. Reading is important to older adults because it facilitates completion of everyday tasks that are essential to independent living. In addition, it entails the kind of active mental engagement that can preserve and deepen the cognitive reserve that may mitigate the negative consequences of age-related changes in the brain. This chapter reviews research on the *front end* of reading (word recognition) and on the *back end* of reading (text memory) because both of these abilities are surprisingly robust to declines associated with cognitive aging. For word recognition, that robustness is surprising because rapid processing of the sort found in reading is usually impaired by aging; for text memory, it is surprising because other types of episodic memory performance (e.g., paired associates) substantially decline in aging. These two otherwise quite different levels of reading comprehension remain robust because they draw on the knowledge of language that older adults gain through a life-time of experience with language.

Aging and Word Recognition During Reading

Over the past 50 years, studies using eye tracking during sentence reading have yielded a rich understanding of the characteristics of eye movements of skilled, young-adult readers (Engbert, Nuthmann, Richter & Kliegl, 2005; Radach, Kennedy & Rayner, 2004; Rayner, 1978; 1998; Rayner, 2009). During reading, the eyes move across a text alternating between periods of relative stillness or fixations, and rapid movements between fixations known as saccades. Typically, each word is fixated once, for a duration of 200-350 milliseconds (Inhoff, 1984; Rayner, 1978; 1998). In addition, words that are short or low in informational value (e.g., function words) may be skipped over, and long words often receive more than one fixation. Timing and targeting of saccades is determined by a mixture of oculomotor and lexical factors. For example, short saccades tend to overshoot their targets, resulting in the skipping of short words (e.g., Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998), and words that are high in frequency or highly predictable based on sentential context are more likely to be skipped or receive shorter fixations than low frequency or less predictable words (e.g., Drieghe, Rayner & Pollatsek, 2005; White, Rayner & Liversedge, 2005). During normal reading, most saccades are progressive, moving rightward onto words that have not yet been fixated. Occasional regressive saccades occur in cases when words have inadvertently been skipped over or when the reader experiences difficulty integrating the meaning of a word into the larger context of the discourse (Rayner, 1998).

While a great deal is known about eye movements during reading by younger adults, eye-tracking studies of reading in older adults only began in earnest in the last decade (Kliegl, Grabner, Rolfs & Engbert, 2004; Rayner, Castelhano & Yang, 2010; Rayner, Reichle, Stroud, Williams & Pollatsek, 2006; Rayner, Yang, Castelhano & Liversedge, 2011) and consequently less is known about whether and how aging affects word recognition during reading. As with other language abilities, word recognition appears to be well preserved throughout healthy aging. Vocabulary knowledge is constant or continues to grow throughout the healthy lifespan, with older adults often outperforming younger adults on tests of vocabulary (Uttl, 2002; Verhaegen, 2003). In simple isolated-word recognition tasks such as lexical decision, word naming, and semantic categorization, older adults respond more slowly than younger adults, but the observed differences are smaller than the amount of age-related slowing found for non-lexical, visuo-spatial reaction time tasks (Hale & Myerson, 1996; Lima, Hale & Myerson, 1991), provided that the linguistic tasks do not require high involvement of the executive system (Verhaegen, Cerella, Semenec, Leo, Bopp & Steitz, 2002). The observation of preserved semantic priming effects further supports the notion that semantic representations are well-maintained with age (Balota, Watson, Duchek & Ferraro, 1999; Burke, White & Diaz, 1987; Laver & Burke, 1993; Myerson, Ferraro, Hale & Lima, 1992), although some degree of semantic degradation has been observed in adults over 70 years old (Verhaegen & Poncelet, 2013). However, successful comprehension during sentence reading depends on the recognition of words as the eyes move rapidly over a text, requiring effective coordination of word recognition with processes of oculomotor control and the integration of individual words into the unfolding context of the sentence. For skilled readers, eye movements are coordinated in a way that optimizes both reading speed and text comprehension, relying on the efficient combination of word knowledge or crystalized intelligence and processing skill, a component of fluid intelligence Therefore, the relative preservation of word recognition ability in older adults does not ensure that reading ability as a whole is constant with age.

Older adults generally read more slowly than younger adults, a finding that may be attributable at least partially to a general pattern of age-related cognitive slowing (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse, 1992; 1996; Verhaegen & Cerella, 2002). In addition, changes in reading rate among older adults are rooted to some degree in basic age-related changes in visual perception. Even among older adults with good high-contrast acuity, normal age-related changes to the visual system, such as reduced contrast sensitivity and reduced retinal illumination, make visual perception of written text more effortful (Fozard and Gordon-Salant, 2001; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Solan, Feldman & Tujak,1995; Owsley, 2011), leading to decreased sensitivity to fine visual detail (McGowan, White, Jordan, & Paterson, 2013) and increased effects of visual crowding (Cerella, 1985; Scialfa, Cordazzo, Bubruc & Lyon, 2012). As a result, even in adults with normal or corrected-to-normal vision, these subtle forms of visual decline can cause reading rates to slow (Akutsu, Legge, Ross & Schuebel, 1991).

Older adults may adapt to these visual challenges by relying more heavily than younger adults on low-frequency spatial information in written text. Lower spatial frequencies provide course-grained information about the words' shape and location, whereas higher spatial frequencies provide fine-grained information about individual letter features. Direct support for older adults' greater reliance on course-grained visual information comes from studies that have investigated how reading is affected by filtering text so that information is only available for a limited range of spatial frequencies (Paterson, McGowan & Jordan, 2013a). Although older adults showed greater disruption than younger adults for any kind of filtered text, they were particularly impaired when only high frequency visual information was displayed, and showed relatively less impairment for text showing only low frequencies (Jordan, McGowan & Paterson, 2014; Paterson, McGowan & Jordan, 2013b). Indirect evidence that older adults rely heavily on low-frequency spatial information comes from studies showing that older adults are more impaired than younger adults when reading (unfiltered) unspaced text (McGowan, White, Jordan & Paterson, 2013; Rayner, Yang, Schuett & Slattery, 2013). Inter-word spaces are a salient, low-spatial frequency cue to the location of word boundaries, and therefore may be especially important to older adults as a guide for targeting saccades. Removing spaces precluded this strategy and caused particular impairment to reading in older adults.

During normal reading, older adults appear to be relatively successful in the use of compensatory strategies to mitigate the consequences of reduced visual abilities or processing speed. Although older adults read more slowly than younger adults, their qualitative patterns of eye movements across written text tend to be very similar to those of younger adults (Kliegl et al., 2004; Laubrock, Kliegl, & Engbert, 2006; Rayner et al., 2006). For example, older adults show similar (although not identical) effects of word frequency and contextual predictability as do younger adults (Rayner et al., 2006). However, while there is clear similarity in the overall patterns of eye movements during reading for younger and older adults (Kliegl et al., 2004), some qualitative differences do exist. Older adults typically make more fixations and more regressive saccades (Kliegl et al., 2004; Rayner et al., 2006; Rayner et al., 2013; McGowan et al., 2013; Solan, et al., 1995), and older adults make longer saccades and show higher rates of word skipping compared to younger adults (Rayner et al., 2006). Age-related changes in visual perception may underlie some of these differences. Rayner et al. (2006) manipulated visual encoding difficulty by using normal (Times New Roman) and difficult-to-read (Old English) fonts. Younger adults' eye movements on Old English font looked more similar to the eye movement behavior of older adults on Times New Roman font, suggesting that some of the qualitative changes in fixation patterns are indeed the result of greater difficulty with visual word encoding at the perceptual level. However, font-difficulty did not account for all differences in eye movement behavior, as older adults reading Times New Roman font continued to show greater saccade length and more regressive saccades then younger adults reading Old English font. Therefore, age-related differences in reading likely result from changes in cognitive ability in addition to changes in ability at the level of visual perception. One possible explanation for older adults' related tendencies toward longer saccades and higher rates of skipping is that they compensate for their slower visual and motor processes by adopting a *risky-reading* strategy (Rayner et al., 2011; Rayner et al., 2006), relying more heavily on their intact semantic and conceptual representations and less heavily on perceptual processing of text. Older adults' tendency to show larger and more consistent effects of word frequency on word skipping rates (Kliegl et al., 2004; Rayner et al., 2006; but see Rayner et al., 2011) suggests that they tend to rely on (partial) visual and word frequency information to 'guess' the identity of upcoming words, thereby skipping more words in an attempt to speed up reading rate. In addition, older adults are more likely than younger adults to make regressive saccades toward initially skipped words, suggesting that they tend to make incorrect guesses about the identity of skipped words, leading to processing problems downstream. Importantly, 'guessing' the upcoming words in this case is not meant to refer to a consciously applied strategy, but rather to an unconscious change in behavior to optimize performance despite cognitive and/or physiological limitations. Although there is no direct evidence that these age-related changes in eye movement behavior are indeed the result of a compensatory strategy, such strategic adaptation to patterns of preserved and reduced abilities is characteristic of how older adults approach many activities. For example, during a test of typing speed, Salthouse (1984) found older adults showed greater impairment relative to younger adults in cases where the number of visible characters in the upcoming text was limited, suggesting they look further ahead in the text than younger adults in an attempt to compensate for reduced cognitive and motor speed.

However, research that directly examines task strategies has shown that aging leads to conservative rather than risky response criteria (Ratcliff, Thapar, Gomez & McKoon, 2004), and the evidence that older adults adopt a risky-reading strategy is not conclusive. For example, Rayner et al. (2006) did not find evidence for older adults' greater dependence on contextual information when assessing the effects of predictability, as both older and younger readers were more likely to skip or spend less time fixating highly predictable compared to less predictable words. Similarly, Kliegl et al. (2004) found that both older and younger adults made use of word predictability to increase reading speed, although they did so through slightly different adaptations in their eye movement patterns. Younger adults showed an effect of contextual predictability as an increase in skipping rates for predictable words, whereas older adults responded to the same manipulation with a reduced probability of refixation, so that they were less likely to refixate predictable words compared to less predictable words. However, aside from these qualitative differences in eye movement behavior, both younger and older adults were shown to rely to a similar degree on contextual predictability information as a determinant of reading speed. If older adults relied more heavily on contextual information in order to speed up their reading rate, this would be expected to result in greater effects of predictability compared to those observed in younger adults.

Further evidence both for and against the notion that older adults adopt a risky-reading strategy comes from research that has examined the effects of aging on the size of readers' perceptual spans and the processing benefits obtained from parafoveal preview. During sentence reading, the perceptual span refers to the region of effective vision. For younger adult skilled readers, the perceptual span extends approximately 3-4 letters to the left of fixation, and approximately 14-15 letters to the right of fixation (McConkie & Rayner, 1975; Rayner & Bertera, 1979). Depending on word length, this means that readers can obtain useful information from one or more words to the right of the currently fixated word, in the visual region known as the parafovea. Effective parafoveal processing can speed up reading times, as words that have received greater processing in the parafovea (i.e. before the word was fixated) may be inspected for less time once they are eventually fixated (Inhoff & Rayner, 1986; Schotter, Angele & Rayner, 2012). Occasionally readers may even reach full recognition of the parafoveal word, in which case it may be skipped (Choi & Gordon, 2013; Gordon, Plummer & Choi, 2013; Pollatsek, Reichle & Rayner, 2006; Reichle, Pollatsek, Fisher & Rayner, 1998).

In non-reading tasks such as visual search or choice reaction time, older adults have been shown to process non-foveal information less effectively than younger adults (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler, Bennett, & Mamelak, 2000), but evidence on older adults' ability to effectively make use of parafoveal information during sentence reading has been less consistent. Rayner, Castelhano, and Yang (2009) manipulated the amount of parafoveal information available to the reader by using a fixed-size window that moved wherever the reader was looking, a technique known as the moving-window paradigm (McConkie & Rayner, 1975; 1976; Rayner, 2014). By varying the size of the moving window (i.e., how many words beyond the currently fixated word are visible at any given time), it is possible to estimate the average perceptual span across groups of readers. For younger adults, reading typically proceeds normally as long the visible region includes the fixated word and at least two following words, but reading tends to be disrupted when the visible region includes only one word beyond the currently fixated word (Rayner, 1986; Rayner, Well, Pollatsek, & Bertera, 1982; Rayner, Castelhano & Yang, 2009). This suggests that readers obtain useful information from up to two words to the right of fixation, but no further than that. In contrast, Rayner et al. (2009) observed that older adults showed no differences in eye movement behavior when the visible region included either one or two words to the right of fixation, but in both cases reading was significantly disrupted compared to a control condition in which the entire sentence was always visible. Since the inclusion of the second word to the right of fixation did not facilitate reading for older adults the way it does for younger adults, it appears that older adults do not obtain useful word information beyond the first word to the right of fixation. In addition, older adults showed impaired reading when information to the *left* of fixation was masked, while younger adults were not affected by this manipulation. This finding suggests that older adults' perceptual span is less asymmetric than younger adults', so that it includes relatively more information to the left of fixation. Using a technique known as the boundary paradigm (Rayner, 1975), Rayner, Yang, and Castelhano (2010) compared reading behavior across older and younger adults when target words were masked until the reader's eyes crossed an invisible boundary between the target and the immediately preceding word. Older adults were less disrupted than younger adults when parafoveal processing of targets was prevented, suggesting their reading relies less heavily on information available in the parafovea. Finally, Rayner, Yang Schuett and Slattery (2014) showed that older adults were significantly more impaired than younger adults in cases where a moving window consistently masked the word they were fixating at that time, suggesting that older adults were less able to rely on parafoveal information in cases where the foveal word was unavailable.

The notion that older adults are less effective than younger adults at using information available in the parafovea to increase their reading rate has been used to support the risky-reading interpretation of older adults' reading behavior. According to this argument, because older adults' parafoveal processing is less efficient, they may be more likely to guess the identity of upcoming words rather than attempting full identification (Rayner et al. 2011; Rayner et al. 2006). However, not all available evidence is consistent with this idea. For example, Rayner et al. (2014) did not find a significant difference in the amount of disruption in older and younger adult readers when *all* words to the right of fixation were masked by a moving window, which is inconsistent with the notion that older adults rely less heavily on information to the right of fixation. Furthermore, Risse and Kliegl (2011) provide evidence that older adults' parafoveal processing abilities may actually be relatively well preserved. Using an adaptation of the boundary paradigm, Risse and Kliegl manipulated the preview availability of the second word (N+2) following a target word, and showed that older and younger adults showed similar amounts of N+2 preview benefit. That is, word N+2 was read more quickly in cases where valid preview was available while readers were fixating two words earlier in the sentence. The finding that older adults appear to be able to make use of parafoveal information as far as two words ahead of the current fixation is inconsistent with the theory that older adults' parafoveal processing is impaired compared to younger adults.

Based on the observation of preserved parafoveal processing in older adults, Risse and Kliegl have proposed an interpretation of older adults' eye movements that can be construed as an alternative to the risky-reading theory. They suggest that older adults' patterns of eye movements during reading may result from a reduced ability to flexibly adjust their fixation patterns in response to foveal and parafoveal processing demands. This alternative interpretation is supported by two main observations from the same study. First, older adults showed a comparatively lower post-skipping cost, referring to the tendency for fixation durations to be longer right after a word has been skipped (Pollatsek, et al., 2006; Radach & Heller, 2000; Reichle, et al., 1998; Vitu, McConkie, Kerr, &O'Regan, 2001). Post-skipping cost is typically attributed to the fact in cases where the previous word was skipped, the currently fixated word has received less parafoveal processing compared to cases in which the previous word was not skipped, as it is separated from the saccade's launch site by the skipped-over word. Therefore, if older adults indeed have reduced parafoveal preview capacity, one would expect to find larger post-skipping cost compared to younger adults rather than the observed reduction in post-skipping cost. Second, Risse and Kliegl observed a parafoveal-on-foveal effect that was smaller for older compared to younger adults. Parafoveal-on-foveal effects occur when the difficulty of the word to the right of the fixation influences fixation durations on the currently fixated word (Kennedy , Pynte & Ducrot, 2002; Kliegl, Nuthman, & Engbert 2006;Wotschack & Kliegl, 2013). In Risse and Kliegl's study, younger adults showed larger reductions in target word gaze duration when the word following the target was an easy-to-process function word compared to a more-difficult-to-process noun. Although it should be kept in mind that parafoveal-on-foveal effects themselves are somewhat controversial (e.g., Kliegl, 2007; Rayner, Pollatsek, Drieghe, Slattery & Reichle, 2007), these findings suggest that although parafoveal processing of words may be intact in older adults, they may be less likely to use the acquired parafoveal information to flexibly adapt their fixation durations based on local and short-term changes in processing difficulty.

Consistent with the idea that older adults respond less flexibly to local changes in processing difficulty, older adults appear to be more impaired than younger adults when reading disappearing text (Rayner et al., 2011). In a disappearing text paradigm (Ishida & Ikeda, 1989; Rayner, Inhoff, Werner, Morrison, Slowaczek & Bertera, 1981), each word in a sentence is masked within a short duration of time after the onset of the first fixation on that word. Surprisingly, reading for younger adult skilled readers is only minimally disrupted when words are visible for as little as 60 ms each, suggesting that this is enough time for readers to obtain the visual information necessary for subsequent lexico-semantic encoding. Rayner and colleagues found that older readers were much more disrupted than younger adults when reading disappearing text with 60 ms mask onsets, although the amount of additional disruption caused by even earlier mask onsets (40 and 50 ms) was similar for older and younger adults. When only one target word in a sentence was replaced by mask, this was more disruptive than when all words were masked, but importantly this additional disruption was much greater for older compared to younger adults. Together, these results suggest that older adults were less sensitive and less responsive to sudden, localized changes in the stimuli.

The lack of flexible adaptation to local variation in processing difficulty observed by Risse and Kliegl (2011) and Rayner et al. (2011) may be attributed to reductions in inhibitory control of eye movements during reading, as proposed by Laubrock et al. (2006). In general, these ideas are consistent with the notion of a general age-related decline in inhibitory control in cognitive tasks (Hasher, Stoltzfus, Zacks, & Ryma, 1991). Evidence from non-reading tasks suggests that older adults exhibit weaker saccadic control (Scialfa, Hamaluk, Pratt & Skaloud, 1999; Butler, Zacks, & Henderson, 1999) and slower saccadic latency (Cassavaugh, Kramer & Peterson, 2004) compared to younger adults. Rayner et al. (2006) found few age-based differences in average landing position, meaning older and younger adults' first fixations into a word tend to land at similar sites relative to the word's center, suggesting that the oculomotor control needed for effective saccade targeting is not affected by age. However, older adults' ability to effectively coordinate eye movements during reading with processes of lexico-semantic encoding has not been directly assessed and more research is needed to determine how possible changes in oculomotor control affect older adults' reading behavior. For now, the idea that a reduced ability to flexibly respond to processing demands provides an alternative to the risky reading interpretation of the qualitative differences observed in older adults' reading behavior.

Longer saccades, greater skipping and more frequent regressive saccades may be an indicator of reduced sensitivity to local processing challenges. As a result, older adults' first-pass sentence reading may be a relatively coarse-grained scan, followed by regressive saccades in cases where the initial analysis proved insufficient and specific words must be encoded in a more fine-grained manner.

To summarize, studies of older adults' eye movements during sentence reading suggest that their word recognition is relatively unimpaired. Although older adults read more slowly than young adults, their qualitative patterns of eye movements in response to lexical characteristics (e.g., frequency) and sentence characteristics (e.g., word predictability) largely resemble those of younger adults, demonstrating the influence of preserved crystalized intelligence in the form of word knowledge. Remaining age-related differences in reading behavior may be attributed in part to older adults' reduced visual abilities and in part to potential compensatory strategies as suggested by the risky-reading account. Alternatively, older adults may be less adept at effectively coordinating word recognition with processes of oculomotor control, impairing their ability to flexibly adapt their patterns of fixation in response to immediate processing demands. By this account, age-related changes in reading ability are the result of a reduction in skills related to rapid processing and coordination of multiple cognitive processes, a component of fluid intelligence that declines with age.

Aging, Reading and Memory

Remembering what has been read enhances the value of reading. Although age-related deficits in text memory are well-documented (see Johnson, 2003, for a meta-analysis and review), the magnitude of these deficits is not nearly as pronounced as those that have been reported in list-memory paradigms (Alexander et al., 2012; Zelinski & Kennison, 2007), which is consistent with the broader observation noted above that many domains of language comprehension are maintained or even enhanced with increasing age (see, e.g., Burke & Shafto, 2008; Thornton & Light, 2006; Salthouse, 2009; Verhaeghen, 2003). Here we consider the effects of aging on sentence processing and text memory at different levels of linguistic representation, focusing in particular on factors that contribute to older adults' relatively preserved language comprehension abilities.

Successful language comprehension must occur to give rise to an enduring memory of what was read. This process is often described in terms of building, maintaining, and integrating linguistic representations at several different levels, including the surface level, textbase, and situation-model (Kintsch, 1988, 1998). The surface level represents the exact words of the text, as well as the syntactic relations that link them together grammatically. The textbase contains the integrated ideas and meaningful propositions expressed by the text. Finally, the situation model involves a more elaborate understanding of what the text is about including higher-level representations of events, actions, goals, and causal relationships.

Work that has focused on sentence processing at the surface level, specifically with regard to the syntactic operations that are needed to construct higher-level propositions, has found that processing is minimally affected by age, except for sentences with very complex syntactic constructions (e.g., Caplan, DeDe, Waters, Michaud, & Tripodis, 2011; Kemper, 1987; Kemper, Crow, and Kemtes, 2004; Kemper & Liu, 2007; Kemtes & Kemper, 1997). In cases where processing at the surface level breaks down, readers of all ages are likely to adopt a representation of the sentence that is incomplete, inaccurate, or otherwise deemed "good enough" for the task at hand (Christianson, Hollingsworth, Halliwell, & Ferreira, 2001; Christianson, Williams, Zacks, & Ferreira, 2006; Ferreira, Bailey, & Ferraro, 2002; Ferreira &

Patson, 2007). For example, after reading temporarily ambiguous garden-path sentences such as *While Anna dressed the baby played in the crib*, Christianson et al. (2006) found that younger adults adopted an incorrect interpretation of the sentence about 30% of the time (e.g., incorrectly answering “yes” to the question, “Did Anna dress the baby?”), whereas older adults were incorrect about 50% of the time.

Additional work has investigated possible age differences in sentence processing at the textbase level, focusing in particular on *wrap-up effects* during reading. Wrap-up refers to the increase in reading time that is typically observed at the ends of clauses and sentences (Just & Carpenter, 1980; Rayner, Kambe, & Duffy, 2000; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989), which has been proposed to reflect semantic integration of the concepts in the sentence into a coherent textbase representation (e.g., Daneman & Carpenter, 1983; Haberlandt & Graesser, 1989; Payne & Stine-Morrow, 2012, 2014). Younger adults tend to show larger wrap-up effects than older adults (e.g., Stine, 1990; Stine, Cheung, & Henderson, 1995), suggesting that younger adults might encode stronger representations of the textbase during reading. However, several studies have shown that there are large individual differences in wrap-up effects among both younger and older adults, and that individuals across all age groups who show larger wrap-up effects tend to also show better comprehension and subsequent memory for what was read (e.g., Haberlandt, Graesser, Schneider, & Kiely, 1986; Miller & Stine-Morrow, 1998; Payne & Stine-Morrow, 2012, 2014; Smiler, Gagne, & Stine-Morrow, 2003; Stine, 1990; Stine-Morrow, Milinder, Pullara, & Herman, 2001). In fact, some work suggests that providing explicit instructions on reading strategies that support conceptual integration can improve memory for what was read among both younger and older adults (Stine-Morrow, Noh, & Shake, 2010). Additional work suggests that older adults may show increased wrap-up effects to compensate for decreased levels of crystallized intelligence (e.g., Chin et al., 2015; discussed in greater detail below).

Any age differences in sentence processing and memory that may arise at the surface-form and textbase levels seem to disappear when higher levels of linguistic representation are assessed, which may reflect different strategies of resource allocation during reading among older and younger adults (e.g., Radvansky & Dijkstra, 2007; Stine-Morrow, Miller, & Hertzog, 2006; Stine-Morrow, Miller, Gagne, & Hertzog, 2008). Early support for this notion came from Stine-Morrow, Loveless, and Soederberg (1996), who collected self-paced-reading times and subsequent recall measures from older and younger adults. The results showed that the young adults who showed the highest levels of recall for the text tended to devote more online processing to surface level factors (e.g., showed large word-frequency effects) and textbase factors (e.g., slowed down on portions of the text that were propositionally dense), whereas the older adults who showed the highest levels of recall tended to devote more online processing to aspects of the text that may have helped them build a strong situation model (e.g., spending more time on earlier portions of the text when characters were being introduced compared to later portions of the text). Similar work by Radvansky, Zwaan, Curiel, and Copeland (2001) assessed readers' recognition memory for aspects of the texts that corresponded to the surface level (e.g., verbatim words from the text), the textbase level (e.g., a paraphrase from the text), and the situation model (e.g., an inference drawn from the text). Results showed that younger adults had better memory than older adults when the recognition task assessed the surface or textbase level; however, older adults outperformed younger adults when the memory task assessed aspects of the situation model.

A number of other studies have provided additional evidence that when memory for text is assessed at higher levels of text meaning, older adults do as well or better than young adults (e.g., Ferstl, 2006; Radvansky, Copeland, Berish, & Dijkstra, 2003; Radvansky, Copeland, & Zwaan, 2003; Radvansky, Gerard, Zacks, & Hasher, 1990; Stine-Morrow, Gagne, Morrow, & DeWall, 2004; see Radvansky, 1999, Radvansky & Dijkstra, 2007, for reviews). For example, Radvansky, Copeland, and Zwaan (2003) examined older and younger adults' representations of the spatial relations they formed while reading texts. Participants had shorter reading times for sentences where two entities could easily be integrated into a functional spatial relationship (e.g., a hammer poised above a nail), compared to sentences where the two entities did not have a functional spatial relationship (e.g., a hammer to the right of a nail). Further, a subsequent memory test showed that participants had better memory for the functional relations compared to the nonfunctional relations. Critically, there was no evidence of an age difference in the magnitude of these effects for either the reading-time data or the memory data, consistent with the notion that older adults retain the ability to construct situation models during language comprehension and rely on these representations later when they remember what they read. Notably, Radvansky et al. (2001) have proposed that older adults do build adequate linguistic representations at the lower-level surface and textbase levels, which they may then use as a temporary "scaffold" on their way to building a strong situation model, at which point the surface and textbase representations fade rapidly.

A variety of perspectives on aging, sentence processing, and text memory have noted that working-memory capacity tends to decline with increasing age (e.g., Craik & Byrd, 1982), and this has commonly been used as an explanatory framework when age deficits are observed in language tasks (e.g., Borella, Ghisletta, & de Ribaupierre, 2011; Christianson et al., 2006;

Hertzog, Dixon, Hultsch, & MacDonald, 2003; Kemper et al., 2004; Kemper & Liu, 2007; Norman, Kemper, & Kynette, 1992; Stine-Morrow, Ryan, & Leonard, 2000; Stine-Morrow et al., 2006; van der Linden et al., 1999). Although some of this work has found relationships between working-memory capacity and language performance among older adults, several other studies have found no evidence of a relationship between working-memory capacity and age-related differences in online processing patterns or memory performance (e.g., Radvansky & Copeland, 2001, 2004, 2006; Smiler et al., 2003; Stine-Morrow et al., 1996; Stine-Morrow, Miller, & Leno, 2001), and still others have shown that age-related differences may be more appropriately conceptualized as stemming from differences in other constructs such as crystallized intelligence (i.e., knowledge) rather than working-memory capacity (e.g., Chin et al., 2015; Miller, 2009; Miller, Cohen, & Wingfield, 2006; Miller & Gagne, 2008; Miller & Stine-Morrow, 1998; Miller, Stine-Morrow, Kirkorian, & Conroy, 2004). Further, as noted above, age differences in memory for text tend to be much smaller than differences that have been reported using other paradigms, such as list learning (Alexander et al., 2012, Zelinski & Kennison, 2007), and the sentence-processing mechanisms that are necessary to build enduring memory representations of what was read tend to be relatively insensitive to the effects of aging except for sentences with very complex syntactic structures (e.g., Caplan et al., 2011; Kemper, 1987; Kemper et al., 2004; Kemper & Liu, 2007; Kemtes & Kemper, 1997). All of this suggests that conceptualizing age-related changes in sentence processing and text memory within a framework that focuses on declines in working-memory capacity is inadequate.

The notion that there is a relationship between the relative preservation with aging of both sentence comprehension and text recall is consistent with an emphasis in the broader psycholinguistics literature to move away from capacity-limited working-memory models of sentence processing (e.g., Baddeley, 1986, 2000; King & Just, 1991; Just & Carpenter, 1992) and toward models that characterize comprehension as dependent on how syntactic, semantic, and pragmatic information is encoded, stored, and retrieved during sentence processing (e.g., Gordon & Lowder, 2012; Gordon, Hendrick & Johnson, 2001; Johnson, Lowder, & Gordon, 2011; Ledoux & Gordon, 2006; Lewis & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006; Van Dyke & Lewis, 2003), with these same processes of encoding and retrieval underlying text memory. Such *cue-based* approaches to sentence processing fit well with the idea of long-term working memory (LTWM; Ericsson & Kintsch, 1995), which proposes that the ongoing memory resources required for skilled performance cannot be met by temporary, limited-capacity systems, but instead require a highly organized system that allows information to be retrieved from long-term memory rapidly and efficiently.

Conceptualizing sentence processing and text memory within a cue-based LTWM framework leads to the expectation that language comprehension and text memory work well when the processes of encoding and retrieval involve meaningful representations that are supported by multiple cues; otherwise, both work poorly. This account is consistent with work demonstrating that older adults show limited or no impairments when the language task provides them with opportunities to draw on their broad knowledge of language and more general world knowledge (e.g., Arbuckle, Vanderleck, Harsany, & Lapidus, 1990; Hess & Flannagan, 1992; Hess, Flannagan, & Tate, 1993; Light & Anderson, 1983; Miller et al., 2006; Miller & Stine-Morrow, 1998; Morrow, Leirer, Andrassy, Heir, & Menard, 1998). For example, Miller and Stine-Morrow presented older and younger participants with vague, difficult-to-understand passages to read. Half of the participants received a title to go along with each passage that provided a schematic context that helped clarify the meaning of the text (Bransford & Johnson, 1972), while half of the participants received no titles. Readers who received titles had shorter reading times compared to readers who did not receive titles, particularly at the ends of clauses and sentences where conceptual integration of the material is proposed to take place. In addition, memory for the passages was better when a title had been provided. Importantly, this manipulation of contextual knowledge was more beneficial to older than younger adults, suggesting that older adults' ability to use meaningful cues to guide the encoding and retrieval of text is very well-preserved.

Whereas Miller and Stine-Morrow (1998) showed that conceptual integration of vague texts is easier when the reader is armed with the relevant schematic knowledge (i.e., knowledge that the reader has possessed for his or her entire life), other evidence suggests that recently-learned knowledge has a very different pattern of effects on conceptual integration. Miller et al. (2004) examined the effects of health knowledge on processing and memory of health-related texts by assigning older and younger adults to either a training program where they were taught knowledge that would be relevant to comprehending the texts, or to a control program. Although older and younger adults who had received the relevant training showed better comprehension for the material they read compared to control participants, the online reading times between the two age groups showed different patterns of effects. Specifically, older adults who had recently acquired the information relevant to understanding the texts showed larger wrap-up effects than control older adults, whereas there was no difference in the magnitude of wrap-up effects between knowledgeable and less-knowledgeable younger adults. This suggests that older adults who have recently acquired relevant domain knowledge about a text may allocate more processing resources to portions of the text that require conceptual integration; however, this extra processing effort pays off in terms of achieving high levels of comprehension and memory for what was read (see also Miller, 2009). Taken together, these findings point toward very different roles for schematic knowledge and domain knowledge during reading among older adults. When the information in a text reflects a topic older adults know extremely well that draws on their wealth of schematic knowledge, it seems that this knowledge is easily accessed during reading and can automatically be applied to the information contained in the text to facilitate processing. In contrast, when the information in a text is about a more complex domain of knowledge, especially on a topic that older adults have only recently learned about, there may not be a straightforward conceptual mapping between the information contained in the text and the reader's knowledgebase, resulting in slower, more effortful integration.

Aside from being able to draw on relevant knowledge during language comprehension, older adults also rely on their intact crystallized semantic intelligence (e.g., Beier & Ackerman, 2005; Verhaghen, 2003). Of particular note, Chin et al. (2015) examined the effects of both domain knowledge and crystallized intelligence on older adults' reading times and subsequent recall of texts. Results showed that higher levels of crystallized intelligence (as measured by vocabulary scores) were associated with larger wrap-up effects at clause and sentence boundaries, presumably reflecting higher levels of conceptual integration. In addition, higher levels of crystallized intelligence were associated with better recall. Interestingly, older adults who had lower levels of crystallized intelligence seemed to achieve higher levels of recall when they paused more at clause and sentence boundaries, which suggests that wrap-up might be used as a reading strategy to compensate for lower crystallized abilities and promote better understanding of what was read. Although the benefits associated with high levels of crystallized abilities were demonstrated across all texts, high levels of domain knowledge only showed effects for texts specific to the relevant knowledge domain. For these texts, readers with higher levels of knowledge showed larger wrap-up effects compared to readers with lower levels of knowledge.

Older adults' well-preserved crystallized intelligence may be the result of the many more years of reading experience they have accumulated compared to young adults (Mol & Bus, 2011; Stanovich, West, & Harrison, 1995). Indeed, recent work (Payne, Gao, Noh, Anderson, & Stine-Morrow, 2012; Payne, Grison, Gao, Christianson, Morrow, & Stine-Morrow, 2014) has begun to investigate whether age differences in sentence processing and text memory can be explained at least in part by considering scores on the Author Recognition Test (ART; Acheson, Wells, & MacDonald, 2008; Stanovich & West, 1989)—a checklist of names from which individuals must select the ones they recognize as authors. The ART is a very quick-to-administer paper-and-pencil task, yet it has been shown to be a reliable and valid measure of an individuals' exposure to printed language (Stanovich & West, 1989; West, Stanovich, & Mitchell, 1993), and it shows strong positive correlations with vocabulary knowledge (Beech, 2002; Lewellen, Goldinger, Pisoni, & Greene, 1993; Stanovich et al., 1995), reading comprehension ability (Martin-Chang & Gould, 2008; Stanovich & Cunningham, 1992, 1993), spelling ability (Lewellen et al., 1993; Stanovich & West, 1989), and SAT scores (Hall, Chiarello, & Edmonson, 1996; Lewellen et al., 1993; Stanovich et al., 1995). Despite these strong relationships with other verbal-ability measures, researchers have only recently begun to relate variability in individuals' print exposure to online reading patterns.

For example, Payne et al. (2012) found that higher ART scores among older adults were associated with reduced effects of word length and word frequency, slower reading times at clause and sentence boundaries, and better memory for what was read. The authors interpret these findings as supporting the idea that high levels of print exposure result in more efficient lexical processing at the surface level while more resources are allocated to the portions of the sentence where conceptual integration at the textbase level must take place, and that these reading patterns then give rise to successful comprehension and enduring memory representations.

In sum, age-related deficits in sentence processing and text memory tend to emerge at lower levels of representation, such as the surface-level and textbase levels, particularly when sentences are very complex; however, older adults perform as well or better than younger adults when the higher-level situation-model representation of the text is assessed. Further, older adults tend to compensate for their decreased levels of fluid intelligence by drawing on the crystallized intelligence (e.g., knowledge, vocabulary, print exposure) that they have accumulated, which leads to efficient reading strategies that support comprehension and memory. This latter point is largely consistent with the cue-based LTWM framework. That is, the lifetime of reading experience that older adults accrue provides them with a well-organized structure in long-term memory of the patterns that tend to occur in natural language, which older adults can access rapidly and efficiently when they encounter meaningful cues in text that match their stored representations. This perspective is consistent with the notion that sustained engagement in reading throughout the lifespan can continue to enhance the cognitive architecture that supports the highly skilled processes of language comprehension and text memory.

Conclusion

Reading is an important life skill in modern, industrialized societies. It plays an important role in economic and other practical activities and in entertainment and understanding of events in the world. This skill is very robust over the adult lifespan because it relies so heavily on the kinds of semantic knowledge that are maintained throughout healthy aging. Research examining word recognition during reading shows that aging does not result in large qualitative differences from the patterns of eye movements seen in younger adults but that aging does lead to systematic changes in a number of ways that are consistent with reduced visual and oculomotor capabilities in combination with greater reliance on knowledge of the patterns of language. Research examining text memory has shown that it is very well preserved with aging as compared to other types of episodic memory. The preservation of text memory in combination with relatively well preserved sentence processing ability supports a shift away from models of working memory in which memory representations that are relevant to processing are temporarily maintained in a resource-intensive way and toward models based on long-term working memory. These newer models focus on how the organization of language allows the creation of highly-structured memory representations that can be accessed effectively, both during and after language processing, using the rich memory retrieval cues that language provides.

References

Acheson, D. J., Wells, J. B., & MacDonald, M. C. (2008). New and updated tests of print exposure and reading abilities in college students. *Behavior Research Methods, 40,* 278-289.

Akutsu, H., Legge, G. E., Ross, J. A., & Schuebel, K. J. (1991). Psychophysics of reading--X. effects of age-related changes in vision. *Journal of Gerontology, 46*(6), 325-331.

Alexander, G. E., Ryan, L., Bowers, D., Foster, T. C., Bizon, J. L., Geldmacher, D. S., & Glisky, E. L. (2012). Characterizing cognitive aging in humans with links to animal models. *Frontiers in Aging Neuroscience, 4,* 1-18.

Arbuckle, T. Y., Vanderleck, V. F., Harsany, M., & Lapidus, S. (1990). Adult age differences in memory in relation to availability and accessibility of knowledge-based schema. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 305–315.

Baddeley, A. D. (1986). *Working memory*. New York: Oxford University Press.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America A, 5*(12), 2210-2219.

Balota, D. A., Watson, J. M., Duchek, J. M., & Ferraro, F. R. (1999). Cross-modal semantic and homograph priming in healthy young, healthy old, and in Alzheimer's disease individuals. *Journal of the International Neuropsychological Society, 5*(07), 626-640.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12*(1), 12-21.

Beech, J. R. (2002). Individual differences in mature readers in reading, spelling, and grapheme-phoneme conversion. *Current Psychology, 21,* 121-132.

Beier, M. E., & Ackerman, P. L. (2005). Age, ability and the role of prior knowledge on the acquisition of new domain knowledge. *Psychology and Aging, 20,* 341–355.

Borella, E., Ghisletta, P., & de Ribaupierre, A. (2011). Age differences in text processing: The role of working memory, inhibition, and processing speed. *Journal of Gerontology: Psychological Sciences, 66*, 311-320.

Bransford, J., & Johnson, M. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior, 11,* 717-726.

Brysbaert, M., & Vitu, F. (1998). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 125–148). Oxford, England: Elsevier.

Brysbaert, M., Drieghe, D., & Vitu, F. (2005). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Cognitive processes in eye guidance* (pp. 53–77). Oxford, England: Oxford University Press

Burke, D. M., & Shafto, M. A. (2008). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed., pp. 373-443). New York: Psychology Press.

Burke, D. M., White, H., & Diaz, D. L. (1987). Semantic priming in young and older adults: Evidence for age constancy in automatic and attentional processes. *Journal of Experimental Psychology: Human Perception and Performance, 13*(1), 79-88.

Butler, K. M., Zacks, R. T., & Henderson, J. M. (1999). Suppression of reflexive saccades in younger and older adults: Age comparisons on an antisaccade task. *Memory & Cognition, 27*(4), 584-591.

Caplan, D., DeDe, G., Waters, G., Michaud, J., & Tripodis, Y. (2011). Effects of age, speed of processing, and working memory on comprehension of sentences with relative clauses. *Psychology and Aging, 26*, 439-450.

Cassavaugh, N., Kramer, A. F., & Peterson, M. S. (2004). Aging and the strategic control of the fixation offset effect. *Psychology and Aging, 19*(2), 357-361.

Cerella, J. (1985). Age-related decline in extrafoveal letter perception. *Journal of Gerontology, 40*(6), 727-736.

Chin, J., Payne, B., Gao, X., Conner-Garcia, T., Graumlich, J. F., Murray, M. D., et al. (2015). Memory and comprehension for health information among older adults: Distinguishing the effects of domain-general and domain-specific knowledge. *Memory 23*, 577-589.

Choi, W., & Gordon, P. C. (2013). Coordination of word recognition and oculomotor control during reading: The role of implicit lexical decisions. *Journal of Experimental Psychology: Human Perception and Performance, 39*(4), 1032-1946.

Christianson, K., Hollingworth, A., Halliwell, J. F., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology, 42*, 368-407.

Christianson, K., Williams, C. C., Zacks, R. T., & Ferreira, F. (2006). Misinterpretations of garden-path sentences by older and younger adults. *Discourse Processes, 42*, 205-238.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191-211). New York: Plenum Press.

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 561-584.

Drieghe, D., Rayner, K., & Pollatsek, A. (2005). Eye movements and word skipping during reading revisited. *Journal of Experimental Psychology: Human Perception and Performance, 31*(5), 954-969.

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*(4), 777-813.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102,* 211-245.

Ferreira, F., & Patson, N. (2007). The good enough approach to language comprehension. *Language and Linguistics Compass, 1*, 71-83.

Ferreira, F., Bailey, K. G. D., & Ferraro, V. (2002). Good-enough representations in language comprehension. *Current Directions in Psychological Science, 11*, 11-15.

Ferstl, E. C. (2006). Text comprehension in middle aged adults: Is there anything wrong? *Aging, Neuropsychology, and Cognition, 13*, 62-85.

Fozard, J. L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J. E. Birren and K. Warner Schaie (Eds.), *Handbook of Psychology of Aging* (pp. 214–266). New York: Academic Press.

Gordon, P. C., & Lowder, M. W. (2012). Complex sentence processing: A review of theoretical perspectives on the comprehension of relative clauses. *Language and Linguistics Compass, 6*, 403-415.

Gordon, P. C., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1411-1423.

Gordon, P. C., Plummer, P., & Choi, W. (2013). See before you jump: Full recognition of parafoveal words precedes skips during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(2), 633-614.

Haberlandt, K., & Graesser, A. C. (1989). Processing new arguments at clause boundaries. *Memory & Cognition, 17*, 186-193.

Haberlandt, K., Graesser, A. C., Schneider, N. J., & Kiely, J. (1986). Effects of task and new arguments on word reading times. *Journal of Memory and Language, 25*, 314-322.

Haegerstrom-Portnoy, G., Schneck, M. E., & Brabyn, J. A. (1999). Seeing into old age: Vision function beyond acuity. *Optometry & Vision Science, 76*(3), 141-158.

Hale, S., & Myerson, J. (1996). Experimental evidence for differential slowing in the lexical and nonlexical domains. *Aging, Neuropsychology, and Cognition, 3*(2), 154-165.

Hall, V. C., Chiarello, K. S., & Edmonson, B. (1996). Deciding where knowledge comes from depends on where you look. *Journal of Educational Psychology, 88,* 305-313.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(1), 163-169.

Hertzog, C., Dixon, R. A., Hultsch, D. F., & MacDonald, S. W. S. (2003). Latent change models of adult cognition: Are changes in processing speed and working memory associated with changes in episodic memory? *Psychology and Aging, 18*, 755-769.

Hess, T. M., & Flannagan, D. A. (1992). Schema-based retrieval processes in young and older adults. *Journal of Gerontology: Psychological Sciences, 47*, 52–58.

Hess, T. M., Flannagan, D. A., & Tate, C. S. (1993). Aging and memory for schematically vs. taxonomically organized verbal materials. *Journals of Gerontology, 48B,* P37-P44.

Inhoff, A. W. (1984). Two stages of word processing during eye fixations in the reading of prose. *Journal of Verbal Learning and Verbal Behavior, 23*(5), 612-624.

Inhoff, A. W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics, 40*(6), 431-439.

Ishida, T., & Ikeda, M. (1989). Temporal properties of information extraction in reading studied by a text-mask replacement technique. *Journal of the Optical Society of America A, 6*(10), 1624-1632.

Johnson, M. L., Lowder, M. W., & Gordon, P. C. (2011). The sentence-composition effect: Processing of complex sentences depends on the configuration of common noun phrases versus unusual noun phrases. *Journal of Experimental Psychology: General, 140*, 707-724.

Johnson, R. E. (2003). Aging and the remembering of text. *Developmental Review, 23*, 261-346.

Jordan, T. R., McGowan, V. A., & Paterson, K. B. (2014). Reading with filtered fixations: Adult age differences in the effectiveness of low-level properties of text within central vision. *Psychology and Aging, 29*(2), 229-235.

Just, M. A., & Carpenter, P. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review, 87*, 329-354.

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

Kemper, S. (1987). Syntactic complexity and elderly adults' prose recall. *Experimental Aging Research, 13*, 47-52.

Kemper, S., & Liu, C. (2007). Eye movements of young and older adults during reading. *Psychology and Aging, 22*, 84-93.

Kemper, S., Crow, A., & Kemtes, K. (2004). Eye-fixation patterns of high- and low-span young and older adults: Down the garden path and back again. *Psychology and Aging, 19*, 157-170.

Kemtes, K. A., & Kemper, S. (1997). Younger and older adults' on-line processing of syntactically ambiguous sentences. *Psychology and Aging, 12*, 362-371.

Kennedy, A., Pynte, J., & Ducrot, S. (2002). Parafoveal-on-foveal interactions in word recognition. *The Quarterly Journal of Experimental Psychology: Section A, 55*(4), 1307-1337.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*, 580-602.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review, 95*, 163-182.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York: Cambridge University Press.

Kliegl, R. (2007). Toward a perceptual-span theory of distributed processing in reading: A reply to Rayner, Pollatsek, Drieghe, Slattery, and Reichle (2007). *Journal of Experimental Psychology: General, 136*(3), 530-537.

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology, 16*(1-2), 262-284.

Kliegl, R., Nuthmann, A., & Engbert, R. (2006). Tracking the mind during reading: The influence of past, present, and future words on fixation durations. *Journal of Experimental Psychology: General*, *135*(1), 12-35.

Laubrock, J., Kliegl, R., & Engbert, R. (2006). SWIFT explorations of age differences in eye movements during reading. *Neuroscience & Biobehavioral Reviews*, *30*(6), 872-884.

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging, 8*(1), 34-43.

Ledoux, K., & Gordon, P. C. (2006). Interruption-similarity effects during discourse processing. *Memory, 14*, 789-803.

Lewellen, M. J., Goldinger, S. D., Pisoni, D. B., & Greene, B. G. (1993). Lexical familiarity and processing efficiency: Individual differences in naming, lexical decision, and semantic categorization. *Journal of Experimental Psychology: General, 122*, 316-330.

Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive Science, 29*, 375-419.

Lewis, R. L., Vasishth, S., & Van Dyke, J. A. (2006). Computational principles of working memory in sentence comprehension. *Trends in Cognitive Sciences, 10*, 447-454.

Light, L. L., & Anderson, P. A. (1983). Memory for scripts in young and older adults. *Memory & Cognition, 11*, 435–444.

Lima, S. D., Hale, S., & Myerson, J. (1991). How general is general slowing? Evidence from the lexical domain. *Psychology and Aging, 6*(3), 416-425.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9*(3), 339-355.

Martin-Chang, S. L., & Gould, O. N. (2008). Revisiting print exposure: Exploring differential links to vocabulary, comprehension, and reading rate. *Journal of Research in Reading, 31*, 273-284.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics, 17*(6), 578-586.

McConkie, G. W., & Rayner, K. (1976). Asymmetry of the perceptual span in reading. *Bulletin of the Psychonomic Society, 8*(5), 365-368.

McGowan, V. A., White, S. J., Jordan, T. R., & Paterson, K. B. (2014). Aging and the use of interword spaces during reading: Evidence from eye movements. *Psychonomic Bulletin & Review, 21*(3), 740-747.

Miller, L. M. S. (2009). Age differences in the effects of domain knowledge on reading efficiency. *Psychology and Aging, 24*, 63-74.

Miller, L. M. S., & Gagne, D. D. (2008). Adult age differences in reading and rereading processes associated with problem solving. *International Journal of Behavioral Development, 32*, 34-45.

Miller, L. M. S., & Stine-Morrow, E. A. L. (1998). Aging and the effects of knowledge on on-line reading strategies. *Journal of Gerontology: Psychological Sciences, 53B*, P223-P233.

Miller, L. M. S., Cohen, J. A., & Wingfield, A. (2006). Knowledge reduces demands on working memory during reading. *Memory & Cognition, 34*, 1355-1367.

Miller, L. M. S., Stine-Morrow, E. A. L., Kirkorian, H., & Conroy, M. (2004). Adult age differences in knowledge-driven reading. *Journal of Educational Psychology, 96*, 811-821.

Mol, S. E., & Bus, A. G. (2011). To read or not to read: A meta-analysis of print exposure from infancy to early adulthood. *Psychological Bulletin, 137*, 267-296.

Morrow, D. G., Leirer, V. O., Andrassy, J. M., Heir, C. M., & Menard, W. E. (1998). The influence of list form and category headings on age differences in understanding medication instructions. *Experimental Aging Research, 24*, 231-256.

Myerson, J., Ferraro, F. R., Hale, S., & Lima, S. D. (1992). General slowing in semantic priming and word recognition. *Psychology and Aging, 7*(2), 257-270.

Norman, S., Kemper, S., & Kynette, D. (1992). Adults' reading comprehension: Effects of syntactic complexity and working memory. *Journal of Gerontology: Psychological Sciences, 47*, P258-P265.

Owsley, C. (2011). Aging and vision. *Vision Research, 51*(13), 1610-1622.

Paterson, K. B., McGowan, V. A., & Jordan, T. R. (2013a). Filtered text reveals adult age differences in reading: Evidence from eye movements. *Psychology and Aging, 28*(2), 352-364.

Paterson, K. B., McGowan, V. A., & Jordan, T. R. (2013b). Effects of adult aging on reading filtered text: Evidence from eye movements. *Peerj, 1*, e63.

Payne, B. R., & Stine-Morrow, E. A. L. (2012). Aging, parafoveal preview, and semantic integration in sentence processing: Testing the cognitive workload of wrap-up. *Psychology and Aging, 27*, 638-649.

Payne, B. R., & Stine-Morrow, E. A. L. (2014). Adult age differences in wrap-up during sentence comprehension: Evidence from ex-Gaussian distributional analyses of reading time. *Psychology and Aging, 29*, 213-228.

Payne, B. R., Gao, X., Noh, S. R., Anderson, C. J., & Stine-Morrow, E. A. L. (2012). The effects of print exposure on sentence processing and memory among older adults: Evidence for efficiency and reserve. *Aging, Neuropsychology, and Cognition, 19*, 122-149.

Payne, B. R., Grison, S., Gao, X., Christianson, K., Morrow, D. G., & Stine-Morrow, E. A. L. (2014). Aging and individual differences in binding during sentence understanding: Evidence from temporary and global syntactic attachment ambiguities. *Cognition, 130*, 157-173.

Pollatsek, A., Reichle, E. D., & Rayner, K. (2006). Tests of the EZ reader model: Exploring the interface between cognition and eye-movement control. *Cognitive Psychology, 52*(1), 1-56.

Radach, R. & Heller, D. (2000) Relations between spatial and temporal aspects of eye movement control. In: *Reading as a perceptual process*, ed. A. Kennedy, R. Radach, D. Heller & J. Pynte. Elsevier

Radach, R., Kennedy, A., Rayner, K. (Eds.), 2004. *Eye movements and information processing during reading*. Psychology Press, New York.

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

Radvansky, G. A., & Copeland, D. E. (2004). Working memory and situation model processing: Language comprehension and memory. *American Journal of Psychology, 117*, 191-213.

Radvansky, G. A., & Copeland, D. E. (2006). Memory retrieval and interference: Working memory issues. *Journal of Memory and Language, 55*, 33-46.

Radvansky, G. A., & Copeland, D. E., (2001). Working memory and situation model updating. *Memory & Cognition, 29*, 1073-1080.

Radvansky, G. A., & Dijkstra, K. (2007). Aging and situation model processing. *Psychonomic Bulletin & Review, 14*, 1027-1042.

Radvansky, G. A., Copeland, D. E., & Zwaan, R. A. (2003). Aging and functional spatial relations in comprehension and memory. *Psychology and Aging, 18*, 161-165.

Radvansky, G. A., Copeland, D. E., Berish, D. E., & Dijkstra, K. (2003). Aging and situation model updating. *Aging, Neuropsychology, and Cognition, 10*, 158-166.

Radvansky, G. A., Gerard, L. D., Zacks, R. T., & Hasher, L. (1990). Younger and older adults' use of mental models as representations for text materials. *Psychology and Aging, 5*, 209-214.

Radvansky, G. A., Zwaan, R. A., Curiel, J. M., & Copeland, D. E. (2001). Situation models and aging. *Psychology and Aging, 16*, 145-160.

Ratcliff, R., Thapar, A., Gomez, P., & McKoon, G. (2004). A diffusion model analysis of the effects of aging in the lexical-decision task. *Psychology and Aging*, *19*(2), 278-289.

Rayner, K. (1978). Eye movements in reading and information processing. *Psychological Bulletin, 85*(3), 618-660.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. Journal of Experimental Child Psychology, 41, 211–236.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372-422.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology*, *62*(8), 1457-1506.

Rayner, K. (2014). The gaze-contingent moving window in reading: Development and review. *Visual Cognition*, *22*(3), 242-258.

Rayner, K., & Bertera, J. H. (1979). Reading without a fovea. *Science (New York, N.Y.)*, *206*(4417), 468-469.

Rayner, K., Castelhano, M. S., & Yang, J. (2009). Eye movements and the perceptual span in older and younger readers. *Psychology and Aging, 24*(3), 755-760.

Rayner, K., Castelhano, M. S., & Yang, J. (2010). Preview benefit during eye fixations in reading for older and younger readers. *Psychology and Aging, 25*(3), 714-718.

Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 7*(1), 167-179.

Rayner, K., Kambe, G., & Duffy, S. A. (2000). The effect of clause wrap-up on eye movements during reading. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 53*, 1061-1080.

Rayner, K., Pollatsek, A., Drieghe, D., Slattery, T. J., & Reichle, E. D. (2007). Tracking the mind during reading via eye movements: Comments on Kliegl, Nuthmann, and Engbert (2006). *Journal of Experimental Psychology: General, 136*(3), 520-529.

Rayner, K., Reichle, E. D., Stroud, M. J., Williams, C. C., & Pollatsek, A. (2006). The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. *Psychology and Aging, 21*(3), 448-465.

Rayner, K., Sereno, S. C., Morris, R. K., Schmauder, A. R., & Clifton, C. Jr. (1989). Eye movements and on-line language comprehension processes. *Language and Cognitive Processes, 4*, 21-49.

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics, 31*, 537–550.

Rayner, K., Yang, J., Castelhano, M. S., & Liversedge, S. P. (2011). Eye movements of older and younger readers when reading disappearing text. *Psychology and Aging, 26*(1), 214-223.

Rayner, K., Yang, J., Schuett, S., & Slattery, T. J. (2013). Eye movements of older and younger readers when reading unspaced text. *Experimental Psychology, 60*(5), 354-361.

Rayner, K., Yang, J., Schuett, S., & Slattery, T. J. (2014). The effect of foveal and parafoveal masks on the eye movements of older and younger readers. *Psychology and Aging, 29*(2), 205-212.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*(1), 125-157.

Risse, S., & Kliegl, R. (2011). Adult age differences in the perceptual span during reading. *Psychology and Aging, 26*(2), 451-460.

Salthouse, T. A. (1984). Effects of age and skill in typing. *Journal of Experimental Psychology: General, 113*(3), 345-371.

Salthouse, T. A. (1992). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79*(2), 155-170.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428.

Salthouse, T. A. (2009). Decomposing age correlations on neuropsychological and cognitive variables. *Journal of the International Neuropsychological Society, 15*, 650-661.

Schotter, E. R., Angele, B., & Rayner, K. (2012). Parafoveal processing in reading. *Attention, Perception, & Psychophysics, 74*(1), 5-35.

Scialfa, C. T., Cordazzo, S., Bubric, K., & Lyon, J. (2013). Aging and visual crowding. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 68*(4), 522-528.

Scialfa, C. T., Hamaluk, E., Skaloud, P., & Pratt, J. (1999). Age differences in saccadic averaging. *Psychology and Aging, 14*(4), 695-699.

Sekuler, B., Bennett, P. J., Mamelak, M. (2000). Effects of aging on the useful field of view. *Experimental Aging Research, 26*(2), 103-120.

Slattery, T. J., Angele, B., & Rayner, K. (2011). Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance, 37*(6), 1924-1938.

Smiler, A. P., Gagne, D. D., & Stine-Morrow, E. A. L. (2003). Aging, memory load, and resource allocation during reading. *Psychology and Aging, 18*, 203-209.

Solan, H. A., Feldman, J., & Tujak, L. (1995). Developing visual and reading efficiency in older adults. *Optometry & Vision Science, 72*(2), 139-145.

Stanovich, K. E., & Cunningham, A. E. (1992). Studying the consequences of literacy within a literate society: The cognitive correlates of print exposure. *Memory & Cognition, 20*, 51-68.

Stanovich, K. E., & Cunningham, A. E. (1993). Where does knowledge come from? Specific associations between print exposure and information acquisition. *Journal of Educational Psychology, 85*, 211-229.

Stanovich, K. E., & West, R. F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly, 24*, 402-433.

Stanovich, K. E., West, R. F., & Harrison, M. R. (1995). Knowledge growth and maintenance across the life span: The role of print exposure. *Developmental Psychology, 31*, 811-826.

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

Stine, E. A. L., Cheung, H., & Henderson, D. T. (1995). Adult age differences in the on-line processing of new concepts in discourse. *Aging and Cognition, 2*, 1-18.

Stine-Morrow, E. A. L., Gagne, D. D., Morrow, D. G., & DeWall, B. H. (2004). Age difference in rereading. *Memory & Cognition, 32*, 696-710.

Stine-Morrow, E. A. L., Loveless, M. K., & Soederberg, L. M. (1996). Resource allocation in on-line reading by younger and older adults. *Psychology and Aging, 11, 475-486.*

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

Stine-Morrow, E. A. L., Miller, L. M. S., & Hertzog, C. (2006). Aging and self-regulated language processing. *Psychological Bulletin, 132*, 582-606.

Stine-Morrow, E. A. L., Miller, L. M. S., & Leno, R. (2001). Patterns of on-line resource allocation to narrative text by younger and older readers. *Aging, Neuropsychology, and Cognition, 8*, 36-53.

Stine-Morrow, E. A. L., Miller, L. M. S., Gagne, D. D., & Hertzog, C. (2008). Self-regulated reading in adulthood. *Psychology and Aging, 23*, 131-153.

Stine-Morrow, E. A. L., Noh, S. R., & Shake, M. C. (2010). Age differences in the effect of conceptual integration training on resource allocation in sentence processing. *The Quarterly Journal of Experimental Psychology, 63*, 1430-1455.

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

Thornton, R., & Light, L. L. (2006). Language comprehension and production in normal aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (6th ed., pp. 262-288). New York: Academic Press.

Uttl, B. (2002). North American Adult Reading Test: Age norms, reliability, and validity. *Journal of Clinical and Experimental Neuropsychology, 24*(8), 1123-1137.

van der Linden, M., Hupet, M., Feyereisen, P., Schelstraete, M., Bestgen, Y., Bruyer, R., et al. (1999). Cognitive mediators of age-related differences in language comprehension and verbal memory performance. *Aging, Neuropsychology, and Cognition, 6*, 32-55.

Van Dyke, J. A., & Lewis, R. L. (2003). Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language, 49*, 285-316.

Verhaegen, C., & Poncelet, M. (2013). Changes in naming and semantic abilities with aging from 50 to 90 years. *Journal of the International Neuropsychological Society, 19*(02), 119-126.

Verhaeghen, P. (2003). Aging and vocabulary score: A meta-analysis. *Psychology and Aging, 18*(2), 332-339.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience & Biobehavioral Reviews, 26*(7), 849-857.

Verhaeghen, P., Cerella, J., Semenec, S. C., Leo, M. A., Bopp, K. L., & Steitz, D. W. (2002). Cognitive efficiency modes in old age: Performance on sequential and coordinative verbal and visuospatial tasks. *Psychology and Aging, 17*(4), 558.

Vitu, F., McConkie, G. W., Kerr, P., & O'Regan, J. K. (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect. *Vision Research, 41*(25), 3513-3533.

West, R. F., Stanovich, K. E., & Mitchell, H. R. (1993). Reading in the real world and its correlates. *Reading Research Quarterly, 28*, 35-50.

White, S. J., Rayner, K., & Liversedge, S. P. (2005). The influence of parafoveal word length and contextual constraint on fixation durations and word skipping in reading. *Psychonomic Bulletin & Review*, *12*(3), 466-471.

Wotschack, C., & Kliegl, R. (2013). Reading strategy modulates parafoveal-on-foveal effects in

Zelinski, E. M., & Kennison, R. F. (2007). Not your parents' test scores: Cohort reduces psychometric aging effects. *Psychology and Aging, 22*, 546-5