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Previous eye-tracking research has characterized older adults' reading patterns as "risky," arguing that compared to young adults, older adults skip more words, have longer saccades, and are more likely to regress to previous portions of the text. In the present eye-tracking study, we reexamined the claim that older adults adopt a risky reading strategy, utilizing the boundary paradigm to manipulate parafoveal preview and contextual predictability of a target word. Results showed that older adults had longer fixation durations compared to young adults; however, there were no age differences in skipping rates, saccade length, or proportion of regressions. In addition, readers showed higher skipping rates of the target word if the preview string was a word than if it was a nonword, regardless of age. Finally, the effect of predictability in reading times on the target word was larger for older adults than for young adults. These results suggest that older adults' reading strategies are not as risky as was previously claimed. Instead, we propose that older adults can effectively combine top-down information from the sentence context with bottom-up information from the parafovea to optimize their reading strategies.

Keywords: eye movements, reading, aging, word predictability, word skipping

A large body of eye-tracking literature over the past 40–50 years has been aimed at understanding the cognitive, perceptual, and oculomotor processes that contribute to reading behavior (Clifton et al., 2016). Although this work has certainly taught us a great deal about the characteristics of eye movements during reading (for reviews, see Clifton et al., 2016; Rayner, 1978, 1998, 2009), it has been focused almost exclusively on the eye-movement patterns of skilled, young-adult readers. Only over the past decade or so have we begun to see eye-tracking studies of reading among older adults. Despite the relatively few studies, some consistent patterns have emerged. For example, several studies have demonstrated that older adults tend to have longer and more frequent fixations during reading compared to young adults (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007; Kemper, McDowd, & Kramer, 2006; Kliegl, Grabner, Rolfs, & Engbert, 2004; Laubrock, Kliegl, & Engbert, 2006; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Stine-Morrow et al., 2010; for a recent review, see Gordon, Lowder, & Hoedemaker, 2016).

Other age-related patterns have been documented as well, but with less consistency across the literature. In particular, Rayner et al. (2006) observed that compared to young adults, older adults had higher skipping rates, longer saccades, and were more likely to regress back to earlier regions (see also Laubrock et al., 2006). Based on this pattern, Rayner et al. proposed that older adults tend to adopt a *risky reading strategy*. Under this account, older readers compensate for their relatively slow visual and motor processes by relying more heavily on their intact semantic processes and their greater vocabulary and world knowledge. This is hypothesized to lead to situations during reading in which older adults guess the identity of the next word, resulting in increased skipping rates relative to young adults. These guesses sometimes turn out to be incorrect, leading to an increased likelihood that older adults will regress back to the initially skipped word. In addition, Rayner, Castelhano, and Yang (2009) observed that older adults tended to have a smaller rightward (i.e., more symmetric) perceptual span relative to young adults, which they proposed might contribute to older adults' tendency to adopt a risky reading strategy. Importantly, however, a few studies have yielded results that are inconsistent with these findings. For example, Kliegl et al. (2004) reported no differences in skipping rates between young and older adults. Moreover, Rayner, Castelhano, and Yang (2010) failed to observe significant differences in skipping rates for target words between young and older adults.[1] Inconsistent findings can even be found in Rayner et al. (2006), where a closer look at one of their critical analyses reveals significantly higher skipping rates for the older adults relative to the young adults only for the analyses that averaged across items, but not for those that averaged across subjects. Finally, Wotschack and Kliegl (2013) reported differen-

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[1] Rayner et al. (2010) did observe a significant difference in skipping rates between young and older adults when the skipping rates were computed using all words from the sentences instead of just the target words.

tial skipping rates between young and older adults as a function of task demands. When comprehension questions were very easy and were asked on only a quarter of the trials, older adults showed higher skipping rates than young adults. However, when comprehension questions were harder and were asked on every trial, this age difference was significantly reduced. This result indicates that at least part of the reason for such inconsistencies in the literature regarding age-related differences in reading behavior stems from differences in the goals of the reader.

Given these empirical inconsistencies, our primary goal in this paper is to further examine the nature of eye-movement differences between young and older adults, focusing in particular on the question of whether older adults adopt this so-called risky reading strategy. We took a novel approach toward addressing this question by systematically manipulating the contextual predictability of a target word, as well as the preview information about the target word available in the parafovea. Because increased word skipping is a key component of the risky reading strategy, the design of the current experiment allows us to examine how the effects of predictability and parafoveal preview on word skipping differ for older and younger readers. Importantly, this work makes use of the *boundary technique* (Rayner, 1975), a gaze-contingent method in which a preview letter string is displayed until the reader's eyes cross an invisible boundary on the screen, which causes the preview string to change to the target word. Previous work using the boundary technique has examined the joint effects of predictability and parafoveal preview on word skipping among young adults, but with mixed results. Balota, Pollatsek, and Rayner (1985) found that readers were more likely to skip a target word that was highly predictable from the preceding context (e.g., *The doctor told Fred that his drinking would damage his liver* . . .) compared to a target word that was less predictable (e.g., *The doctor told Fred that his drinking would damage his heart* . . .), and this pattern was identical when the string presented in parafoveal preview was a nonword that was visually similar to the target word (i.e., identical patterns of skipping when the preview was *liver* vs. *livor*, as well as when the preview was *heart* vs. *heant*). This pattern suggests that the decision of whether or not to skip is based on only a partial linguistic analysis of the previewed string, at least in a highly constraining sentence context. However, Drieghe, Rayner, and Pollatsek (2005) failed to replicate the skipping results reported in Balota et al., reporting instead that readers were more likely to skip the target word when receiving valid parafoveal preview versus preview of a nonword that was visually similar to the target (i.e., higher skipping rates when the preview was *liver* vs. *livor*, and higher skipping rates for *heart* vs. *heant*). This result indicates that readers do perform fine-grained linguistic analyses even when a target word is strongly predicted by the sentence context, consistent with findings reported in other studies (Choi & Gordon, 2013, 2014; Gordon, Plummer, & Choi, 2013). For example, Choi and Gordon (2013) found a similar effect among young adults using transposed letters as the nonword preview (e.g., *jugde* as the preview for *judge*). In this study, even though the preview looked very similar to a real word, there was no difference in skipping rates between a nonword whose base word was high frequency and a nonword whose base word was low frequency, which is consistent with the idea that readers' decision of whether or not to skip a word is based on a fine-grained linguistic analysis of the information presented in the parafovea. Importantly, however, these studies have only examined young adult readers.

As described above, the primary goal of the present study was to reexamine the claim that older adults adopt a risky reading strategy. To do so, we compared eye-movement patterns between young and older readers, focusing in particular on whether there are any age differences in skipping rates, saccadic amplitude, and proportion of regressions, given that age-related changes in these measures are considered the hallmark signs of the risky reading strategy (Rayner et al., 2006). In addition to testing for these hallmark signs of risky reading, we also examined whether more general age-related differences in reading behavior would emerge. For example, several studies have demonstrated that compared to young adults, older adults tend to have longer fixation durations and more fixations during reading (Kliegl et al., 2004; Rayner et al., 2006; Stine-Morrow et al., 2010). Thus, a demonstration of robust age-related differences in fixation durations and number of fixations, combined with a failure to detect any evidence of risky reading among older adults, would provide a compelling case against the notion that older adults adopt such a reading strategy.

A second goal of this study was to test for age-related modulation of the effect of word predictability and parafoveal preview on word skipping. The effect of word predictability on word skipping has been reported in several studies (Balota et al., 1985; Drieghe et al., 2005; Ehrlich & Rayner, 1981; Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner, Slattery, Drieghe, & Liversedge, 2011; Rayner et al., 2006; Rayner & Well, 1996; for a review, see Staub, 2015). However, work examining whether the size of this predictability effect differs for older and younger subjects has produced inconclusive results. Kliegl et al. (2004) reported that word predictability had qualitatively different effects on fixation probabilities for young and older adults. Specifically, increased word predictability led to increased skipping rates among young adults, whereas increased word predictability led to decreased probability of multiple fixations among older adults and no effects on skipping rates. In addition, Rayner et al. (2006) tested for age-related differences in the magnitude of the predictability effect on skipping, finding a main effect of predictability such that predictable words were skipped more often than unpredictable words, but only very weak evidence that words were skipped more often for older adults relative to for young adults (i.e., a significant age difference in the item analysis, but not in the subject analysis). Interestingly, there was no interaction between age and predictability. One aspect of the Rayner et al. study that is often overlooked, however, is that it included a font manipulation (Times New Roman vs. Old English). Although word length was tightly controlled across predictability conditions in terms of number of letters, it is possible that the physical width occupied by the word could have differed across font conditions, as Times New Roman and Old English are both proportional fonts.[2] Given that physical width is a critical factor influencing word skipping (Brysbaert, Drieghe, & Vitu, 2005), an additional motivation of the current experiment was to

[2] The physical width of words is perfectly correlated with character length when a monospace font (e.g., Courier New) is used; however, when a proportional font is used, physical width is strongly influenced by which characters the word contains.

reinvestigate the effects of predictability and age on word skipping using a monospace font.

Previous research is inconsistent regarding the extent to which age modulates effects of word predictability during reading. Some evidence suggests that older adults more actively utilize the sentence- or discourse-level context to facilitate word recognition compared to young adults (see, e.g., Cohen & Faulkner, 1983; Madden, 1988; Speranza, Daneman, & Schneider, 2000; Stine-Morrow, Soederberg Miller, Gagne, & Hertzog 2008; Stine-Morrow, Soederberg Miller, & Nevin, 1999). For example, Speranza et al. found an interaction between word predictability and age using a perceptual identification task. They asked young and older adults to identify the final word in a sentence and found that older adults showed a greater difference in accuracy between high and low predictability conditions compared to young adults when target words were visually masked. However, other evidence suggests no differences between young and older adults in the magnitude of predictability effects. As described above, Rayner et al. (2006) showed similar effects of word predictability on skipping between young and older adults (see also Kliegl et al., 2004). The current study was designed in part to distinguish between these two theoretical perspectives. If older adults rely on sentence context to facilitate word recognition more than young adults, then when a word in parafoveal preview is highly predictable from the preceding context (e.g., *The doctor told Fred that his drinking would damage his liver* . . .), older adults should be more likely to skip this word (e.g., *liver*) than young adults, and older adults might also be more likely than young adults to skip the target word when the parafoveal preview is a nonword that closely resembles a real word (e.g., *livor*). If age does not modulate the effects of word predictability on eye movements during reading, the effect of word predictability on skipping rates should be comparable between young and older adults.

Method

Participants

Twenty-four young adults (19–25 years old; mean age = 21.14) and 24 older adults (67–80 years old; mean age = 72.2) participated in the experiment. The young adults were undergraduate students from the University of California, Davis, who participated in exchange for course credit. The older adults were residents of the Davis, California community who volunteered to participate and were compensated with a $20 payment. All participants provided informed consent, and all procedures were approved by the Institutional Review Board at UC Davis. In addition, all participants had normal or corrected-to-normal vision and were native speakers of English. The older adult participants were well-educated, reporting a mean of 17.05 years of education (Davis is a college town, and thus many of the older participants were affiliated with the university in some way). In addition, all participants completed a modified version of the Author Recognition Test (ART; Acheson, Wells, & MacDonald, 2008; Stanovich & West, 1989) as an indirect measure of print exposure and verbal ability. In the ART, participants are presented with a checklist of authors and foils and are instructed to indicate the names they recognize as authors. Scores are adjusted for false alarms. The older adults (M = 42.1) had significantly higher scores than the young adults (M = 12.8), t = 10.14, $p < .0001$, consistent with previous demonstrations that verbal ability tends to increase throughout adulthood (e.g., Salthouse, 2009; Verhaeghen, 2003). In addition, this difference further demonstrates that the older adults in our sample were cognitively intact.

Materials and Design

Each participant read four warm-up sentences followed by the 84 experimental sentences. The experimental sentences consisted of a sentence frame that had one high probability completion (e.g., *The doctor told Fred that his drinking would damage his* . . .). Before the target word was presented, we systematically manipulated the letter string that was available in parafoveal preview according to the factors of preview validity and lexical predictability. Specifically, the parafoveal preview string was either the most likely word or a nonword that closely resembled the predictable word (e.g., *liver* vs. *livor*); alternatively, the preview string was either an unpredictable but plausible word or a nonword that closely resembled the unpredictable word (e.g., *heart* vs. *heant*). After the eyes crossed the invisible boundary (e.g., at the right edge of the word *his*), the preview string was replaced with either the predictable or unpredictable target word (e.g., *liver* or *heart*).

The four conditions are illustrated in Table 1. As this example demonstrates, the factors of preview validity and predictability were not crossed in a straightforward 2 × 2 design. That is, in the invalid preview condition, the preview was created by changing the penultimate letter of the word that was used in the different predictability condition. This design allows us to systematically investigate the effects of preview validity and predictability on skipping rates (i.e., before the display change), as well as effects of predictability on fixation durations (i.e., by only analyzing the valid preview conditions). It is not suited to investigating questions related to fixation durations on the target word as a function of preview condition, but it is the other measures that target our primary hypothesis concerning the characteristics of the risky reading strategy.

All experimental sentences were taken from Drieghe et al. (2005), which in turn had been selected from Balota et al. (1985). As reported in Drieghe et al. (2005), the predictable words showed much higher cloze probability and were rated as more plausible than the unpredictable words. The target words used for the predictable and unpredictable conditions were matched in length and did not differ significantly in frequency (predictable: 3.24, unpre-

Table 1
Example Sentences Used in the Experiment

Preview condition	Sentence
Predictable valid preview	The doctor told Fred that his drinking would damage his [*liver*:**liver**] very quickly.
Unpredictable valid preview	The doctor told Fred that his drinking would damage his [*heart*:**heart**] very quickly.
Invalid preview, similar to predictable word	The doctor told Fred that his drinking would damage his [*livor*:**heart**] very quickly.
Invalid preview, similar to unpredictable word	The doctor told Fred that his drinking would damage his [*heant*:**liver**] very quickly.

Note. The words in italics are the preview strings and those in bold are the target words.

dictable: 3.21; SUBTLEXus database; Brysbaert & New, 2009), $t < 1$, $p > .25$. In addition, the target words did not differ significantly in orthographic neighborhood size (predictable: 5.18, unpredictable: 5.57), $t < 1$, $p > .56$. Creation of the nonword preview condition always involved changing the penultimate letter of the corresponding word (e.g., *liver—livor*; *heart—heant*) to a visually similar letter that was of the same shape (e.g., an ascending letter was replaced with a different ascending letter). Additional material always followed the target word, ensuring that the target word was never the final word of the sentence.

The experimental sentences were counterbalanced across the four preview conditions, resulting in four counterbalanced lists that were rotated across participants. Each participant read 21 sentences per condition, and no participant read the same target word twice.

Apparatus

An Eyelink 1000 plus eye-tracking system (SR Research, Osgoode, Ontario, Canada) was used to record participants' eye movements as they read the sentences. Viewing was binocular, but only the right eye was monitored at a sampling rate of 1000Hz. Sentences were presented on a ViewSonic G225f monitor with a screen resolution of 1024 × 768 pixels and with a 150Hz monitor refresh rate. Participants were seated 85 cm away from the monitor. A headrest and a chinrest were used to minimize head movement. Sentences were presented in black on a white background using 16 point Courier New font (a monospaced font). Each letter extended 13 pixels in horizontal width, so that 2.92 characters subtended about 1° of visual angle. The experiment was controlled with the Experiment Builder software provided by SR Research.

Procedure

Participants were instructed to read the sentences at a natural pace for comprehension. The eye tracker was calibrated using a nine-point calibration grid at the beginning of the session and as needed throughout the duration of the session. At the beginning of each trial, a fixation point was presented near the left edge of the monitor, marking the location where the first word of the sentence would appear. Once the participant fixated on this point, the experimenter presented the sentence. After reading the sentence, the participant pressed a button on a handheld button box, which caused the sentence to disappear and a short true-or-false question about the sentence to appear in its place. Participants pressed one key to answer "True" and another key to answer "False." The questions probed basic events from the sentence and were not designed to be very difficult. For example, for the sentence "*The doctor told Fred that his drinking would damage his liver very quickly,*" the question was "*True or false? Fred went to the doctor.*" After reading the four practice sentences, the remaining 84 sentences were presented in a different random order for each participant. The experiment lasted approximately 20 min. Mean comprehension accuracy was high (93.7%), with no significant difference in accuracy between the two age groups (94.5% for the young vs. 92.8% for the older adults group, $F(1, 46) = 1.75$, $p > .19$). The fact that the older and younger groups performed equivalently provides additional evidence that the older participants were cognitively intact.

Results

Eye-Movement Analyses

There was no significant age difference in mean display change time (the time from when the eyes crossed the invisible boundary to when the display changed; 7.70 ms for older adults, 7.69 ms for young adults). We adopted the data-exclusion criteria outlined in Rayner et al. (2010). Specifically, fixations shorter than 120 ms or longer than 800 ms were excluded from further analyses. In addition, fixations were excluded if they occurred before or after a blink during first-pass reading, or if they occurred during instances of track-loss. Finally, all trials in which the display change occurred prior to the first saccade that crossed the invisible boundary (typically caused by a fixation on the boundary) were excluded. In total, 20.2% of the data points were removed from the analyses. The number of exclusions per condition was not systematically different across preview conditions.

The eye-movement analyses are presented in three parts. First, we examined global eye movement differences between young and older adults across all words of the sentence to test whether there is any evidence that older adults adopt a risky reading strategy. Thus, we analyzed a range of dependent variables, which included mean fixation durations and skipping rates across all words of the sentences, as well as whole-sentence reading times, total number of fixations per sentence, forward saccade length per sentence, and regression proportion per sentence. Note that we excluded fixations associated with display changes in the global eye-movement analysis. Second, we analyzed probability of skipping the target words as a function of age and preview condition. *Probability of skipping* was calculated as the proportion of trials in which the target word was not fixated during first-pass reading. Finally, we examined reading times on the target word as a function of age and word predictability. Note that we conducted duration analyses only with the valid preview trials. The Appendix contains supplemental analyses that examine reading times on the target word as a function of preview validity, word predictability, and age. As noted in the Method section, the design of this experiment does not manipulate preview validity and word predictability in a fully crossed manner. Accordingly, the results reported in the Appendix should be interpreted with caution. For both the global and the target word analyses, five standard reading-time measures were computed. S*ingle-fixation duration* (SFD) was the duration of the initial, first-pass fixation on the target word given that the word received only one first-pass fixation. *First-fixation duration* (FFD) was the duration of the initial, first-pass fixation on the target word regardless of whether there were subsequent first-pass fixations on the word. G*aze duration* (GZD) was the sum of all first-pass fixation durations on the target word. SFD, FFD, and GZD are thought to reflect the earliest stages of word recognition, including perceptual encoding and lexical access. *Regression path duration* (RPD) was the sum of all fixation durations beginning with the initial fixation on the target word and ending when the eyes exited the word to the right, including time spent rereading earlier words and time spent rereading the word itself. *Total time* (TTime) was the sum of all fixations on the target word. RPD and TTime are thought to reflect later stages of processing, including integrating the word with the rest of the sentence.

The data were analyzed using the lme4 package in R (Bates, Maechler, & Bolker, 2012; R Development Core Team, 2011), with subjects and items as crossed random effects. Fixation duration measures were analyzed using linear mixed effects (LME) models with the lmer function, and the probability of skipping was analyzed using generalized linear mixed models with the glmer function. Random-effects structures included random intercepts for subject and item.[3] The categorical variables of preview type, word predictability, and age and the interactions among these variables were included in the models as fixed effects. Statistical significance was computed using the lmerTest package in R, which provides t values and degrees of freedom based on the Satterthwaite approximation.

Global Eye-Movement Results

Means and standard deviations are reported in Table 2. We found that older adults had longer whole-sentence reading times, $b = 1326.10$, $SE = 421.73$, $t = 3.14$, $p < .005$, and made more fixations per sentence, $b = 3.95$, $SE = 1.41$, $t = 2.8$, $p < .01$, compared to young adults. Analyses of FFD and SFD revealed marginally significant effects of age, such that reading times tended to be longer for older adults than for young adults [FFD: $b = 12.81$, $SE = 7.65$, $t = 1.68$, $p = .10$; SFD: $b = 14.51$, $SE = 7.77$, $t = 1.87$, $p = .068$]. The age effect was significant in GZD, RPD, and TTime such that older adults showed longer durations compared to young adults [GZD: $b = 21.89$, $SE = 10.51$, $t = 2.08$, $p < .05$; RPD: $b = 104.63$, $SE = 29.2$, $t = 3.58$, $p < .001$; TTime: $b = 79.67$, $SE = 25.21$, $t = 3.16$, $p < .005$]. These results are generally consistent with previous literature (Kliegl et al., 2004; Rayner et al., 2006, 2010; Stine-Morrow et al., 2010).

In contrast, there were no significant age differences in the proportion of regressions, $b = -0.026$, $SE = 0.17$, $t = -1.56$, $p = .13$, forward saccade length, $b = -0.37$, $SE = 0.46$, $t = -0.8$, $p = .43$, or skipping rates, $b = -0.028$, $SE = 0.1$, $z = -0.27$, $p = .79$. Thus, we obtained no evidence suggesting that older adults make longer saccades, make more regressions, or show higher skipping rates than young adults, which is inconsistent with the risky reading proposal put forth by Rayner et al. (2006).

Probability of Skipping Target

Figure 1 and Table 3 show the probability of skipping the target word as a function of preview string and age. In the analyses, we constructed three planned contrasts: (1) valid previews (e.g., *liver* or *heart*) versus invalid previews (e.g., *livor* or *heant*), (2) predictable word (e.g., *liver*) versus unpredictable word (e.g., *heart*), and (3) predictable nonword (e.g., *livor*) versus unpredictable nonword (e.g., *heant*). In the generalized linear mixed effect model, the preview condition as specified with the three contrasts was included as a fixed effect, along with age and the interaction between preview condition and age. Intercepts for subjects and items were included as random effects. The contrast analyses revealed that readers skipped the valid previews more frequently than the invalid previews, $b = 0.28$, $SE = 0.07$, $z = 4.04$, $p < .001$. This result supports the idea that the lexical status of the preview string (i.e., word vs. nonword) is an important factor affecting skipping rate (Angele & Rayner, 2013; Choi & Gordon, 2013, 2014). No other effects were significant, $|z| < 1.09$, ns.

To further evaluate whether the tendency to skip differs for the subjects in the two age groups, we conducted an additional analysis on a subset of the data using only trials on which a saccade was launched from five or fewer character positions before the target word (Drieghe et al., 2005). Thus, this analysis included only trials where the reader was fixating an area very close to the target word, maximizing the chances that he or she would be extracting parafoveal preview information. Again, the effect of the valid versus invalid preview contrast on skipping rate was significant, $b = 0.24$, $SE = 0.08$, $z = 2.90$, $p < .005$. No other effects were significant, $|z| < 1.68$, ns. Particularly noteworthy, and in contrast to Rayner et al. (2006), there was no main effect of age on skipping rates. There was also no interaction between age and preview condition. Importantly, our failure to find an age difference in skipping rates is inconsistent with the notion that older adults adopt a risky reading strategy. Notice too that this similarity in performance for skipping stands in contrast with the age-related differences we observed in the global eye-movement analyses of fixation durations, number of fixations, and whole-sentence reading times (see Table 2).

Reading Times on Target Word

Table 4 shows reading times on the target word as a function of predictability and age. For SFD, GZD, and TTime, the main effect of predictability was significant such that reading times in the predictable target condition were shorter than in the unpredictable target condition, [SFD: $b = 11.63$, $SE = 5.53$, $t = 2.10$, $p < .05$: GZD: $b = 13.29$, $SE = 6.23$, $t = 2.14$, $p < .05$: TTime: $b = 39.04$, $SE = 12.11$, $t = 3.22$, $p < .005$]. In addition, the interaction between age and predictability was significant on GZD and RPD such that the predictability effect was greater for older adults than for young adults, [GZD: $b = 17.31$, $SE = 8.73$, $t = 1.98$, $p < .05$: RPD: $b = 41.44$, $SE = 20.33$, $t = 2.04$, $p < .05$].

Discussion

The present study was designed to examine the nature of age effects on eye movements during reading. In particular, the study focused on two questions. First, do older adults adopt a risky reading strategy during reading, and second, to what extent do effects of predictability and preview type on word skipping differ by age. To sum up our results, in our global analysis of eye movements across all words, we found that older adults had longer fixation durations, made more fixations per sentence, and showed longer whole-sentence reading times compared to young adults. However, there were no age differences in skipping rates, forward saccade length, or the proportion of regressions, contrary to the predictions of the risky reading hypothesis. Readers were more likely to skip the target word if the preview string was a word than if it was a nonword, but there was no evidence that this effect was modulated by age. Finally, reading times for predictable words were shorter than for unpredictable target words, and this effect was enhanced for older adults relative to young adults.

[3] In the LME analyses, the random effects structures included the maximally appropriate random intercepts as well as by-subject and by-item random slopes for preview type. In cases where the model failed to converge, the random effects structure was sequentially simplified until convergence was achieved (Barr, Levy, Scheepers, & Tily, 2013).

Table 2
Mean Eye-Movement Measures on All Words

	SRT		TNFix		FFD		SFD		GZD		RPD		TTime		FSL		PS		RegProp	
Age	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young	4071	1795	16.4	6.7	209	82	209	81	238	126	368	439	331	239	8.6	2.3	.36	.48	.25	.11
Old	5396	2404	20.4	8.2	222	94	224	94	259	140	472	659	411	311	8.2	2.1	.35	.48	.28	.11

Note. Fixation durations are given in milliseconds. Saccade length is given in number of characters. SRT = sentence reading times; TNFix = total number of fixations; FFD = first fixation duration; SFD = single fixation duration; GZD = gaze duration; RPD = regression path duration; TTime = total time; FSL = forward saccade length; PS = probability of skipping; RegProp = regression proportion.

As described in our introduction Rayner, et al. (2006) proposed that older adults adopt a risky reading strategy, according to which they skip words based on partial linguistic information extracted from the parafovea, leading to increased skipping rates, longer saccade length, and higher regression rates. However, the current study provides no support for the notion that older adults adopt this strategy. Importantly, these null findings cannot be attributed to an overall failure to detect age-related differences in reading patterns. That is, although we did not obtain any evidence consistent with the claim that older adults adopt a risky reading strategy, we did observe robust age-related differences in fixation durations, number of fixations, and whole-sentence reading times, as well as larger predictability effects for older adults versus young adults. Thus, although it is true that our null findings should be interpreted with some degree of caution, we think they are strengthened by the presence of robust age-related differences in other measures of reading behavior.

The only significant effect we found on skipping rates was a main effect of preview condition such that both young and older adults were more likely to skip the target word if the string in parafoveal preview was a word versus a nonword.[4] Choi and Gordon (2013) found a similar effect among young adults using transposed letters as the nonword preview (e.g., *jugde* as the preview for *judge*), so that the preview looked very similar to a real word. The preview strings in the nonword preview condition in the current study also looked very similar to real words, as we substituted the penultimate letter of a real word to a visually similar letter (e.g., *heant*). The current study, along with previous work, suggests that readers perform a fairly fine-grained analysis of the letter string in the parafovea, and the decision of whether or not to skip the string is based in part on its lexical status (Angele & Rayner, 2013; Choi & Gordon, 2013, 2014; Gordon et al., 2013). Moreover, these tendencies seem to be similar for young and older readers. As noted in the introduction, previous work has suggested that older adults have a smaller rightward perceptual span than young adults do (Rayner et al., 2009, 2010), although others have not replicated this finding (Risse & Kliegl, 2011). In addition, previous work has shown that older adults show a greater reduction than young adults in parafoveal preview benefit as a function of cognitive load on the foveated word (Payne & Stine-Morrow, 2012). The paradigm and experimental design used here do not allow us to assess age differences in factors such as the size of the perceptual span or the effects of cognitive load on the perceptual span. However, the inconsistencies in this literature, combined with our failure to find age-related differences in skipping rates, further highlight the need for additional work to better understand the specific circumstances under which age-related differences in eye-movement behavior emerge. Future work should also employ experimental designs that allow for a more careful examination of the joint effects of preview validity, word predictability, and age on fixation durations (although see the Appendix).

A key question, of course, is why we did not observe any evidence supporting the risky reading strategy. As described above, Rayner et al. (2006) reported higher skipping rate and larger saccade length for older adults compared to young adults. However, in the current study we found that skipping rate and saccade length did not differ for the two age groups, not only in the target word analysis, but also in the analysis of all words. We speculate that one reason may have to do with differences in level of engagement with the text across the two experiments. In the

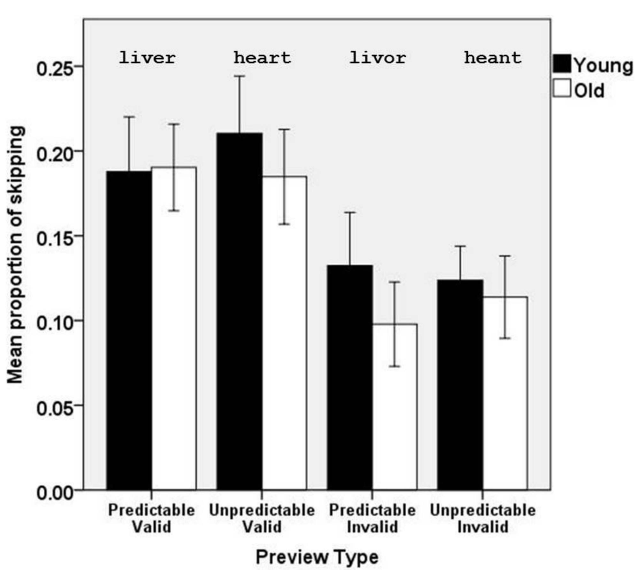

Figure 1. Skipping rates as a function of age and preview type. Error bars represent 1 standard error.

[4] The basic pattern of this skipping effect deviates from effects reported in previous work. Specifically, Drieghe et al. (2005) found effects of both predictability and preview validity on skipping rates, whereas Balota et al. (1985) found higher skipping rates for predictable versus unpredictable preview strings (with no effect of preview validity). Given that we used the same materials as these previous studies, it is difficult to pin down the source of the inconsistencies, and doing so is beyond the scope of this paper. Our more important point here is to note that the skipping effect we obtained was identical for young and older adults.

Table 3
Probability of Skipping Target Words

	Skip target word			
	All cases (%)		Cases where Launched from within 5 letters (%)	
Preview	Young	Old	Young	Old
Predictable, Valid (*liver*)	18.4	18.9	26.7	29.4
Unpredictable, Valid (*heart*)	20.9	18.7	29.3	28.7
Predictable, Invalid (*livor*)	12.8	12.1	20.3	19.4
Unpredictable, Invalid (*heant*)	13.1	10.5	20.3	13.8

current study, every sentence was followed by a comprehension question, whereas Rayner et al. included comprehension questions on only a fourth of the sentences. Previous work has revealed that readers process linguistic information more deeply when they are questioned after every sentence rather than just occasionally (Swets, Desmet, Clifton, & Ferreira, 2008). It is possible that both groups of participants in the current study, including the older adults, adopted a more careful reading strategy throughout the experiment, as they knew they would have to answer a question after each sentence and they would presumably be motivated to answer the questions correctly. In contrast, older adults in the Rayner et al. study may have adopted a riskier strategy because the majority of trials did not probe their comprehension. In fact, this observation is consistent with previous work. As described in the introduction, Wotschack, and Kliegl (2013) showed that age-related differences in skipping rates were modulated by the frequency and difficulty of comprehension questions. When questions were easy and asked infrequently, older adults showed higher skipping rates than young adults, but when questions were difficult and asked on every trial, this difference was reduced. This work highlights the importance of more carefully considering readers' goals in experimental paradigms, especially when testing older adults (see also Stine-Morrow, Milinder, Pullara, & Herman, 2001). It is also possible that subtle differences between our experimental procedures and those used by Rayner et al. could explain the different patterns of results. For example, previous work has demonstrated that older adults are negatively impacted by tasks that are orthogonal to the main task of comprehending the language input (e.g., acceptability judgment, Davis, Zhuang, Wright, & Tyler, 2014).

Although we did not find evidence that older adults adopt a risky reading strategy, we did observe that older adults showed stronger predictability effects than young adults did (in measures of gaze duration and regression-path duration). The finding that older adults rely more heavily than young adults on sentence context to facilitate word recognition might be interpreted to be broadly consistent with one of the core ideas of the risky reading strategy—that is, that older adults draw on their relatively intact semantic knowledge to compensate for their relatively impaired visual acuity. The crucial point of the risky reading hypothesis, however, is that older adults rely on their semantic knowledge to make risky guesses about upcoming words (thus high skipping rates) that are often incorrect (thus high regression rates). Our lack of any evidence supporting these key elements of the risky reading strategy suggests instead that older adults' reliance on sentence context to aid word recognition is in fact an efficient processing strategy. Nevertheless, because the current study did not employ a neutral context condition, we cannot know for sure what is driving this effect. Although it may be the case that greater predictability results in differential facilitation for older versus young adults, it is also possible that greater *unpredictability* results in differential processing costs for older adults. Disentangling these possibilities is an important goal for future work. Nonetheless, both of these possibilities are consistent with the idea that older adults rely more heavily than young adults on contextual information to aid in word recognition (Cohen & Faulkner, 1983; Madden, 1988; Speranza et al., 2000; Stine-Morrow et al., 1999), but are inconsistent with some work on aging and language comprehension in the cognitive neuroscience literature(Rayner & Clifton, 2009). Specifically, experiments using event-related potentials (ERPs) have suggested that older adults show weaker (and later) effects of predictability compared to young adults (Federmeier & Kutas, 2005; Federmeier, Van Petten, Schwartz, & Kutas, 2003).

This discrepancy may be explained at least in part by considering the relatively artificial text presentation format commonly used in ERP experiments. That is, whereas eye tracking during reading allows readers to proceed through the sentence at their own pace, most ERP experiments present the sentence in rapid serial visual presentation (RSVP) format (i.e., the sentence is presented word-by-word in the center of the screen at a fixed duration). Moreover, often the presentation rate is slower than average reading speeds even for older adults (e.g., 400–500 ms per word). While RSVP has the important methodological advantage of minimizing the eye movements that lead to large ERP artifacts, it also differs from natural reading in important ways. As mentioned, words in RSVP experiments are typically presented rather slowly compared to the speeds at which even older readers naturally read, and readers are denied parafoveal preview information and the ability to regress to earlier words, which may lead to qualitatively different reading strategies from what is observed during natural reading. Reading in RSVP format might be particularly challenging for older adults, who tend to demonstrate declines in many aspects of cognitive ability such as working memory capacity (e.g., Carpenter, Miyake, & Just, 1994; Hasher & Zacks, 1988). Importantly, older adults' declines may be less evident during natural reading when readers can preview information and can freely return to earlier portions of the sentence to refixate words and strengthen the unfolding linguistic representation.

Table 4
Fixation Durations on Target Words

	FFD		SFD		GZD		RPD		TTime	
Target condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young adults										
Predictable	217	66	214	65	229	81	276	225	272	140
Unpredictable	225	68	228	71	242	85	278	134	309	195
Older adults										
Predictable	227	67	219	64	243	90	289	185	314	186
Unpredictable	244	69	237	73	273	104	331	229	372	217

Note. Fixation durations are given in milliseconds. FFD = first fixation duration; SFD = single fixation duration; GZD = gaze duration; RPD = regression path duration; TTime = total time.

Conclusion

Although older adults do read more slowly than young adults do, we found no indication that they attempt to compensate for this slowdown by adopting a risky reading strategy (Rayner et al., 2006). Instead, older adults appear to perform a fairly detailed linguistic analysis of parafoveal preview information, which informs their decision about whether or not to skip a word in much the same way as for young adults. However, older adults do show larger predictability effects than young adults do. Taken together, these results suggest that older adults' reading strategies are not as risky as has sometimes been claimed. Instead, we propose that older adults integrate upcoming words into existing contexts in a careful way, combining top-down information from the sentence context with bottom-up input from the parafovea to optimize processing.

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Appendix

Additional analysis of reading times on target word

Table A1 presents reading times on the target word as a function of preview validity, word predictability, and age. Table A2 presents the results of the linear mixed effects analyses. It is important to note that the effect of preview benefit is not entirely straightforward, given the manipulation we used in the current experiment. Typically, the size of the preview benefit is computed by subtracting fixation durations for the valid preview from those for the invalid preview, which is interpreted as reflecting the difficulty associated with integrating a previewed string into the target word. As described in the main text, the nonword previews in the present experiment (e.g., *livor*, *heant*) were created by changing the penultimate letter of the word that was used in the different predictability condition. Thus, the preview benefit does not only reflect integration processes of the previewed string into the target word, but also reflects predictability effects. Accordingly, these results should be interpreted with some degree of caution.

Single Fixation Duration (SFD) and First Fixation Duration (FFD)

Analyses of SFD and FFD showed no significant main effects of age. However, the effect of preview was significant in both mea-

(*Appendix continues*)

Table A1
Reading Times on Target Word by Preview Validity, Word Predictability, and Age

	FFD		SFD		GZD		RPD		TTime	
Target condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young adults										
HP-VP	217	66	214	65	229	81	276	225	272	140
HP-NP	249	86	258	82	268	105	319	173	328	189
UP-VP	225	68	228	71	242	85	278	134	309	195
UP-NP	241	87	243	79	269	130	338	244	389	280
Older adults										
HP-VP	227	67	219	64	243	90	289	185	314	186
HP-NP	261	78	267	75	290	100	370	247	378	213
UP-VP	244	69	237	73	273	104	331	229	372	217
UP-NP	247	76	247	77	279	115	361	278	422	241

Note. Fixation durations are given in milliseconds. FFD = first fixation duration; SFD = single fixation duration; GZD = gaze duration; RPD = regression path duration; TTime = total time; HP-VP = high predictable–valid preview; HP-NP = high predictable–nonword preview; UP-VP = unpredictable–valid preview; UP-NP = unpredictable–nonword preview.

sures, such that reading times were shorter for valid previews versus nonword previews. In addition, the effect of predictability was significant on SFD and marginally significant on FFD, such that reading times were faster for predictable than unpredictable target words. These main effects were qualified by a significant interaction between preview and predictability in both SFD and FFD, such that the magnitude of the preview benefit was greater when the target word was predictable compared to when it was unpredictable. This result indicates that readers are able to use valid preview information for a highly predictable word to facilitate word recognition more effectively than when the target word is unpredictable. Interestingly, this process appears to be equivalent in young and older adults.

For both SFD and FFD, subsequent post-hoc analyses for the interaction effect revealed that for the valid preview condition, the predictability effect was significant such that fixation durations were shorter for the predictable target than for the unpredictable target, (SFD: $b = 15.00$, $SE = 4.24$, $t = 3.539$, $p < .0001$; FFD: $b = 13.42$, $SE = 3.80$, $t = 3.535$, $p < .0001$). However, for the nonword preview condition, a reverse effect of predictability was observed such that fixation durations were longer for the predictable target than for the unpredictable target, (SFD: $b = -15.19$, $SE = 5.18$, $t = -2.933$, $p < .01$; FFD: $b = -10.48$, $SE = 4.19$, $t = -2.498$, $p < .05$].

Gaze Duration (GZD)

Analysis of GZD showed no significant main effect of age. However, as with SFD and FFD, the effect of preview was significant such that reading times were shorter for valid previews versus nonword previews. More interestingly, there was a significant three-way interaction between preview, predictability, and age. In order to understand the nature of the three-way interaction, we conducted a series of post-hoc analyses in which linear mixed effects analyses were performed separately on one level of each factor (preview, predictability, and age). These analyses revealed two important findings: First, older adults showed a larger predictability effect than young adults only in the valid preview condition, $b = 17.31$, $SE = 8.73$, $t = 1.981$, $p < .05$; and second, young adults showed a larger preview effect than older adults, but only when the target word was unpredictable, $b = -23.77$, $SE = 10.87$, t = --2.19, $p < .05$. These results suggest that older adults utilize sentence context more effectively than young adults to

Table A2
Linear Mixed Effect Models

	First fixation duration			Single fixation duration			Gaze duration			Regression path duration			Total time		
	b	*SE*	*t*	*b*	*SE*	*t*	*b*	*SE*	*t*	*b*	*SE*	*t*	*b*	*SE*	*t*
(intercept)	215.4	7.04	**30.61**	213.1	7.46	**28.57**	227.1	9.21	**24.65**	273.9	16.0	**17.1**	266.2	18.8	**14.1**
Preview	33.11	5.12	**6.47**	44.52	5.58	**7.98**	39.25	7.07	**5.55**	42.63	15.4	**2.76**	58.83	14.0	**4.21**
Predictability	8.48	5.06	1.68	11.52	5.26	**2.19**	13.23	6.98	1.90	−1.09	15.2	−.07	39.23	13.5	**2.91**
Age	10.51	9.74	1.08	7.47	10.4	.72	14.78	12.8	1.15	12.73	21.4	.6	44.9	25.5	1.76
Preview × Predictability	−16.6	7.3	**−2.27**	−25.17	8.05	**−3.13**	−10.52	10.1	−1.04	21.58	22.1	.98	24.93	19.9	1.25
Preview × Age	1.22	7.3	.17	3.84	8.19	.47	8.44	10.1	.84	40.43	22.0	1.84	7.51	19.8	.38
Predictability × Age	9.86	7.13	1.38	5.97	7.48	.8	17.46	9.8	1.78	43.53	21.4	**2.04**	17.74	18.8	.94
Preview × Predictability × Age	−16.0	10.4	−1.55	−11.53	11.6	−1.00	−31.31	14.3	**−2.19**	−72.60	31.3	**−2.32**	−35.84	28.1	−1.27

Random effects	Var	*SD*	Var	*SD*	Var	*SD*	Var	*SD*	Var	*SD*
Item	176.5	13.28	182.1	13.49	203.1	14.25	2312	48.08	2213	47.04
Subject	834.8	28.89	957.4	30.94	1404	37.47	2779	52.72	5719	75.62
Residual	4570	67.60	4201	64.81	8746	93.52	42231	205.5	35532	188.5

Note. Numbers in bold represent $p < .05$.

(*Appendix continues*)

facilitate target word processing when there is valid preview information in the parafovea, but that older adults' parafoveal processing is disrupted when the target word is unpredictable.

Regression Path Duration (RPD) and Total Time (TTime)

Analysis of RPD revealed significant main effects of preview, such that reading times were shorter for valid previews versus nonword previews. In addition, there was a significant two-way interaction between predictability and age. Post-hoc analyses showed a larger predictability effect for older adults versus young adults, $b = 39.5$, $SE = 19.11$, $t = 2.07$, $p < .05$. This result suggests that older adults are more likely than young adults to have difficulty integrating unpredictable words with the preceding context, causing them to regress back to earlier regions of the sentence. Importantly, however, this two-way interaction was qualified by a significant three-way interaction between preview, predictability, and age. Follow-up analyses revealed that the two-way interaction between predictability and age was only significant in the valid preview condition, $b = 41.64$, $SE = 19.78$, $t = 2.11$, $p < .05$. Moreover, only a main effect of the preview condition was observed in the young adults, whereas there was a significant two-way interaction between predictability and preview for older adults, such that the preview benefit was greater in the predictable than in the unpredictable condition, $b = -51.07$, $SE = 23.92$, $t = -2.14$, $p < .05$. Consistent with the results reported above, this finding indicates that older adults show more processing disruption relative to young adults for unpredictable words.

Analysis of TTime revealed main effects of preview and predictability such that target words were read faster in the valid preview condition versus the nonword preview condition, and target words were read faster in the predictable condition versus the unpredictable condition.

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