Older Adults Make Greater Use of Word Predictability in Chinese Reading

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Abstract

An influential account of normative aging effects on reading holds that older adults make greater use of contextual predictability to facilitate word identification. However, supporting evidence is scarce. Accordingly, we used measures of eye movements to experimentally investigate age differences in word predictability effects in Chinese reading, as this non-alphabetic language has characteristics that may promote such effects. Word-skipping rates were higher and reading times lower for more highly predictable words for both age groups. Effects of word predictability on word-skipping did not differ across the two adult age groups. However, word predictability effects in reading time measures sensitive to both lexical identification (i.e., gaze duration) and contextual integration (i.e., regression-path reading times) were larger for the older than younger adults. Our findings therefore reveal that older Chinese readers make greater use of a word's predictability to facilitate both its lexical identification and integration with the prior sentence context.

Key Words: Cognitive Aging; Eye Movements during Reading; Word Predictability; Chinese

During skilled reading, the eyes make rapid movements (saccades) separated by brief fixational pauses during which linguistic information is acquired (Rayner, 1998, 2009). Research with alphabetic languages (English, German) shows that these eye movements are under cognitive control. More specifically, *when* and *where* the eyes move is governed by factors influencing how easily words can be identified, chiefly word length, word familiarity (operationalized as frequency of lexical usage), and the contextual predictability of words (Rayner, 1998, 2009). Consistent with this account, numerous studies show words that are shorter, higher in lexical frequency or more predictable from the prior sentence context have lower fixation probabilities (and so are more likely to be skipped) as well as shorter reading times (e.g., Altarriba. Kroll, Sholl, & Rayner, 1996; Brysbaert, Drieghe, & Vitu, 2005; Choi, Lowder, Ferreira, Swaab, & Henderson, 2017; Gollan et al, 2011; Hand, Miellet, O'Donnell, &Sereno, 2010; Inhoff & Rayner, 1986; Joseph, Liversedge, Blythe, White, & Rayner, 2009; Kliegl, Grabner, Rolfs, & Engbert, 2004; Paterson, McGowan, & Jordan, 2013a,b; Rayner; 1979; Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner & McConkie, 1976; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Rayner, Sereno, & Raney, 1996; Rayner, Slattery, Drieghe, & Liversedge, 2011; Staub & Benatar, 2013).

This research has led to the development of sophisticated computational models of eye movement control, such as E-Z Reader (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005), which can simulate eye movements during reading highly successfully using mechanisms based on these variables. Moreover, the same variables exert a similar influence in Chinese reading (e.g., Bai, Xin, & Yan, 2015; Li, Bicknell, Liu, Wei, & Rayner, 2014; Li, Liu, & Rayner, 2011; Li, Li, Wang, McGowan & Paterson, 2018; Liversedge et al., 2014; Ma, Li, Xu, & Li, 2018; Wang et al., 2018a,b; Yan, Tian, Bai, & Rayner, 2011; Zang, Fu, Bai, Yan, & Liversedge, 2018; Zang et al., 2016; see also Li, Zang, Liversedge, & Pollatsek, 2015; Zang, Liversedge, Bai, & Yan, 2011). Essentially the same mechanisms, therefore, appear to govern eye movement control during both alphabetic and non-alphabetic reading.

Understanding how the influence of these variables changes with reading development (see, e.g., Blythe, 2014), and as a consequence of visual and cognitive decline in older age (see, e.g., Gordon, Lowder, & Hoedemaker, 2015), is important for understanding how reading behavior changes across the lifespan and for the future development of the theoretical models. Research on normative aging effects, in particular, shows that healthy older adults (65+ years) read more slowly than young adults (18-30 years), by making more and longer fixations, and more regressions (backward eye movements; e.g., Kliegl et al., 2004; McGowan, White, Jordan & Paterson, 2014; Paterson et al., 2013a,b; Rayner et al., 2006; Stine-Morrow, Shake, Miles, Lee, Gao, & McConkie, 2010; Warrington, McGowan, Paterson & White, 2018, 2019; Whitford & Titone, 2016, 2017). Moreover, a similar slowdown is observed in Chinese reading (Li et al., 2018; Wang et al., 2018a,b; Zang et al., 2016). These normative aging effects have been simulated computationally (in E-Z Reader and SWIFT) for alphabetic languages by limiting visual processing and slowing lexical processing (Laubrock, Kliegl, & Engbert, 2006; Rayner et al., 2006). The simulations predict that, compared to young adults, older adults will have greater difficulty identifying lower frequency words due to slower lexical processing. This is corroborated by studies showing that, compared to young adults, older adults produce larger word frequency effects (by taking disproportionately longer to read words with a lower lexical frequency) in both alphabetic languages (Kliegl et al., 2004; McGowan et al., 2014; Rayner et al., 2006, 2013; Whitford & Titone, 2017) and Chinese (Wang et al., 2018a,b; Zang et al., 2016). Simulations based on the E-Z Reader model additionally suggest that older adult readers compensate for their slower lexical processing by making greater use of contextual knowledge to predict upcoming words in text. This is often described in terms of older adults adopting a more “risky” reading strategy in which, compared to young adult readers, they make greater use of context to guess the identity of the next word in a sentence and so skip this word more frequently (Rayner et al., 2006; see also McGowan & Reichle, 2018).

Other research on spoken and written word recognition also suggests differential use of context by adult age groups and, in particular, that older adults benefit more from supportive context when input is degraded (Dagerman, MacDonald, & Harm, 2006; Federmeier, McLennnan, De Ochoa, & Kutas, 2002; Lash, Rogers, Zoller, & Wingfield, 2013; Madden, 1988; Pichora-Fuller, 2008; Speranza, Daneman, & Schneider, 2000; Stine & Wingfield, 1994). However, research using event-related potentials (ERPs; averaged electroencephalographic activity time-locked to a stimulus presentation) suggest more limited use of context by older readers. Such studies typically use methods in which words in sentences are presented sequentially at a fixed rate at a central location to eliminate eye movements, and a target word that has either high or low contextual predictability appears last in this sequence. The findings show that an ERP component (the N400) known to be sensitive to the contextual fit of words is delayed or smaller for older, relative to younger, adults, raising the possibility that older readers are less able to use context predictively (see e.g., Federmeier & Kutas, 2005; Hamberger, Friedman, Ritter, & Rosen, 1995; Wlotko & Federmeier, 2012; Wlotko, Federmeier, & Kutas, 2012; Payne & Federmeier, 2018).

Measures of eye movements made during natural reading are highly sensitive to the influence of linguistic variables on the processing of words (see Rayner, 1998, 2009). However, evidence of an adult age difference in contextual predictability effects on eye movement behavior has proven surprisingly elusive in research using this method. A corpus study by Kliegl et al. (2004) showed word predictability enabled faster reading by both young and older adults but that this was realized differently for the two age groups, by increasing word-skipping by young adults and decreasing the older adults' probability of making multiple fixations on words without affecting their skipping rates. Moreover, even the experiment that Rayner et al. (2006) reported alongside their simulations of aging effects provided little evidence of a larger word predictability effect for older readers. They found that the high cloze predictability of a target word increased skipping rates only marginally more for older compared to younger adults, and shortened reading times similarly for both age groups. However, as this study included a manipulation of font difficulty, participants may have experienced difficulty encoding text and so read more carefully than normal, which may help explain why larger benefits of word predictability were not observed. More propitiously, Steen-Baker et al. (2017) found a positive relationship between age and effects of the cloze predictability of a sentence-final word on reading times, such that the decrease in reading times for a measure that included time spent re-reading earlier portions of the sentence was larger for older adult readers. However, only one eye movement study to date, by Choi et al. (2017), has provided clear evidence for an adult age difference in word predictability effects during the initial processing of words, although this was observed only in reading times without affecting the probability of skipping words. This study used a parafoveal preview manipulation in which an upcoming target word that varied in predictability was displayed normally or misspelled. The crucial finding was that, while predictability shortened reading times for the target words more for the older than younger adults, predictability did not affect word-skipping for either age group. The study therefore showed that word predictability facilitated the processing of fixated words but not the parafoveal processing of upcoming words more for older compared to younger adult readers.

Given the paucity of aging research on word predictability effects in eye movements during reading, the present study examined this issue further. However, unlike in previous studies, we assessed effects in Chinese, as we considered that properties of this writing system may lead older adults to make greater use of contextual knowledge to identify words. Chinese differs from alphabetic systems like English by using a logographic script in which text is printed as a sequence of pictograms called characters (Hoosain, 1991, 1992). While some characters can function as a word on their own, most words comprise two or more characters, although text in Chinese does not include spaces or other visual cues that delineate the boundaries between words. An important task in Chinese reading, therefore, is to segment this unspaced text into words (see Li et al., 2015; Zang et al., 2011). Few studies have examined effects of contextual predictability on this process (Rayner, Li, Juhasz, & Yan, 2005; Wang, Pomplun, Chen, Ko, & Rayner, 2010), although, similarly to findings for alphabetic languages, young adults have shorter reading times and higher skipping rates for more predictable words (Rayner et al., 2005). As older adults may have particular difficulty establishing the boundaries between words due to poorer parafoveal processing of upcoming text (see Li et al., 2018), they also may rely more heavily on context to help identify words in a naturally-unspaced character-based writing system like Chinese, as compared to spaced, alphabetic writing systems like English. Investigating this issue in Chinese may therefore provide a clearer indication of adult age differences in word predictability effects.

Accordingly, the present experiment assessed effects of word predictability on the eye movements of young and older Chinese readers. Participants read sentences containing a target word that had high or low cloze probability and we examined the effects of this manipulation on reading times and skipping probabilities for these words. If contextual predictability facilitates word identification, reading times should be shorter and skipping rates may be higher for the more predictable words. Moreover, if older readers make greater use of contextual predictability to identify words, this may confer a larger processing advantage so that high predictability produces a larger increase in word-skipping and greater reduction in reading times for older compared to younger adults. However, if this age difference in effects is restricted to reading times for words (as in Choi et al., 2017), any age difference in word predictability effects may be observed only in reading time measures and not word-skipping rates for target words. Finally, it will be important to establish if any age differences in predictability effects on reading times emerge in measures of the early processing of words sensitive to the process of lexical identification or in later measures sensitive to the integration of words with the prior sentence context.

Method

The research was approved by the research ethics committee in the Academy of

Psychology and Behavior at Tianjin Normal University and conducted in accordance with the principles of the Declaration of Helsinki.

Participants. Thirty young adults aged 18-22 years (*M*=19 years; 29 female) and 30 older adults aged 61-81 years (*M*=69 years; 19 female) from Tianjin Normal University and the local Tianjin community participated in the experiment. All were native Chinese readers. No previous study has examined adult age differences in word predictability effects on eye movements during Chinese reading. However, the sample size in the present experiment exceeded that in a previous investigation of word predictability effects for young adult Chinese readers (Rayner et al., 2005; $N = 16$) and also the only previous study to show a clear age difference in effects of word predictability on early eye movement measures in an alphabetic language (Choi et al., 2017; $N = 24$ in each age group). Moreover, a power analysis using the SIMR package (Green & McLeod, 2016) in R (R Development Core Team, 2016) based on the effect size in gaze durations for target words in the Choi et al. study indicated that an experiment with the same sample size and stimulus numbers as the present experiment would have appropriate statistical power to detect an age difference in word predictability effects (i.e., power = 80% in the present experiment).

The two age groups of participants in the present experiment were closely matched on years of formal education (young adults, $M = 13$ years, range = 13-14 years; older adults, $M = 13$ years, range = 9-16 years, $t < 1$), screened for normal visual acuity (better than 20/40 in Snellen values) using a Tumbling E chart (Taylor, 1978), and the older adults were screened for non-impaired cognitive abilities using the Beijing version of the Montreal Cognitive Assessment (applying an exclusion criterion of < 26/30; Nasreddine et al., 2005). The young adults had higher acuity (*M*=20/20) than the older adults (*M*=20/27), as is typical for these age groups (Elliott, Yang, & Whitaker, 1995). Additional assessments using the Vocabulary subtest from the WAIS-III Chinese version (Wechsler, Chen, & Chen, 2002) and WAIS-III Digit Span subtest (Wechsler, 1997) showed no age difference in vocabulary knowledge (young adults, M=16.1, SD=1.3; older adults, M=16.2, SD=.7; t<1.1), but higher digit spans for the young adults (young adults M = 14, SD = 2.6; older adults, M = 12, SD = 2.5; $t(58)$ = 3.33, p < .01; note values refer to test scores), consistent with a short-term memory advantage for younger adults (Ryan, Sattler, & Lopez, 2000).

Materials and Design. Stimuli were 60 sets of sentences containing one of a pair of interchangeable two-character target words. The words had high or low predictability from the prior sentence context. This was assessed using a cloze procedure with sentence fragments truncated immediately before the target word. Ten young and 10 older adults who did not participate in the experiment provided a continuation for these fragments. A word was selected as highly predictable if more than 80% of each age group guessed it to be the next word in the sentence, and as less predictable if fewer than 15% guessed it to be the next word. Only predicted words that were two characters long were selected as stimuli, and the final set of high and low predictable words were matched for lexical frequency (high predictability, M = 99 counts / million, low predictability, M = 62 counts / million, t = 1.57, p = .12) using the SUBTLEX-CH database (Cai & Brysbaert, 2010). These words were also matched for number of first and second character strokes (first character, high predictability, M = 7.6 strokes, low predictability, M = 8.0 strokes, t = .98, p = .33; second character, high predictability, M = 7.7 strokes, low predictability, M = 7.4 strokes, t = .61, p = .54) and number of strokes overall (high predictability, *M* = 15.3 strokes, low predictability, *M* = 15.4 strokes, $t = .25$, p = .80). The cloze predictability of the final set of words is show in Table 1.

[Table 1]

An Analysis of Variance showed that cloze predictability did not differ significantly as a function of age group (main effect of age group, $F(1,118) = 2.59$, $p = .11$; interaction effect, $F < 1$) but was significantly higher for high compared to low predictable words ($F(1,118) = 8496$, $p < .001$). Consequently, while the sample sizes used to assess cloze predictability were smaller than recommended (see Smith & Levy, 2013), the procedure we used was effective in generating sets of high and low predictable target words. An additional 10 participants in each age group evaluated the naturalness of the sentences (using a 7-point scale ranging from highly unnatural to highly natural). Naturalness did not differ significantly across sentences with high and low predictable words ($M = 6.46$ vs. $M = 6.37$, $t(59) = 1.59$, $p = .12$). Sentences containing these words therefore were considered to be equally natural. However, to be sure that words with low predictability were not implausible in the sentence contexts, we conducted a further test in which 20 young adults (who did not take part in the other screening tests) evaluated the plausibility of each target word as a sentence continuation (using a 7-point scale ranging from highly implausible to highly plausible). The results confirmed that both high and low predictable words were highly plausible in the sentence contexts although, in common with other research (Frisson, Harvey, & Staub, 2017), the more predictable words also had higher plausibility (high predictability, $M = 6.81$, $SD = .13$; low predictability, $M = 6.61$, $SD = .32$; $t(59) = 3.97$, $p < .001$).

An issue not addressed when designing the stimuli relates to the possibility that encountering an unpredicted but plausible word may violate the expectation for a highly predicted word. For instance, the "The prisoners were busy planning their…" strongly evokes the word "escape", and while "party" is also a plausible continuation, it violates this expectation. Evidence from various studies suggest that an unpredictable word that violates an expectation for a more highly predictable word may disrupt processing rather than function as an effective baseline condition (e.g., Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Steen-Baker et al., 2017; Stine & Wingfield, 1994). The stimuli in the present experiment had these characteristics; the high predictable words were always the preferred continuations for sentences containing the low predictable words. Consequently, effects of this manipulation might reflect both a processing advantage when encountering an expected word in the high predictability condition and disruption to processing due to violation of this expectation in the low predictability condition. Nevertheless, the design we used was similar to that in previous eye movement studies (e.g., Rayner et al., 2005, 2006), ensuring the comparability of our results with their findings. Moreover, recent research suggests that age differences in effects of contextual constraint on eye movements are not moderated by the degree to which an expectation is violated (Steen-Baker et al., 2017), and so it was unlikely that this would differentially affect the performance of the young and older participants in the present experiment. We return to this issue in the Discussion.

The sentences were 19-31 characters long (*M* = 23), including the two-character target word, and the target word was always located near the middle of a sentence. An example stimulus is shown in Figure 1.

[Figure 1]

Sentence frame and target word combinations were divided into 2 lists, each containing one version of each sentence frame (i.e., with either a high or low predictable target word) and an equal number of sentences containing high and low predictable target words. Fifteen participants from each age group were randomly allocated to each list. Accordingly, a mixed experimental design was used with the between-participants factor age group (young adult, older adult) and within-participants factor word predictability (high, low). Dependent variables included sentence reading time and measures of eye movements during reading at the level of both the sentence and the target word.

Apparatus and Procedure. An EyeLink 1000 Plus eye-tracker (SR Research inc., Toronto, Canada) recorded right-eye gaze location every millisecond during binocular viewing. This system has high spatial (<.01° RMS) and temporal (1000 Hz) resolution. Sentences were displayed in Song font as black-on-white text. At the 75cm viewing distance used in the experiment, each character subtended approximately 1° horizontally and so was of normal size for reading.

Participants took part individually and were instructed to read normally and for comprehension. At the start of the experiment, a 3-point horizontal calibration procedure was performed across the same line as each sentence was presented (ensuring .30° or better accuracy for all participants, and so accurate to within half a character width). Calibration accuracy was checked before each trial, and the eye-tracker recalibrated as required to maintain high spatial accuracy throughout the experiment. At the start of each trial, a fixation square equal in size to one character was presented on the left side of the screen. Once the participant fixated this location, a sentence was presented with the first character replacing the square. Participants pressed a response key once they finished reading each sentence. The sentence was replaced on 25% of trials by a comprehension question requiring a yes / no response (see Figure 1 for an example question), and participants responded by pressing one of two response keys. The experiment lasted approximately 40 minutes for each participant.

Results

Accuracy answering the comprehension questions that followed sentences (analysed using linear mixed-effects models, see subsequently) was high for all participants (> 80%) and similar across age groups (young adults, $M = 93\%$; older adults, $M = 92\%$; $\beta = .27$, $SE = .29$, $z = .91$), indicating that both groups understood the sentences well.

Following standard procedures, fixations less than 80 ms and longer than 1200 ms fixations were removed (affecting 3.9% of fixations). The proportion of deleted fixations was similar for the young and older adults. Trials with track loss or error were also excluded (affecting less than 2% of trials). The remaining data were analysed by Linear Mixed-Effects Models (LMEMs, Baayen, Davidson, & Bates, 2008) using R (R Development Core Team, 2016) and the lme4 package (Bates, Maechler, & Bolker, 2011). For binomial variables, generalized LMEMs were conducted with the Laplace approximation. A maximal random effects structure was used (Barr, Levy, Scheepers, & Tily, 2013), with participants and stimuli as crossed random effects. For sentence-level measures, age group was a fixed factor, and for target word measures, age-group, predictability, and their interaction were fixed factors. Older adults typically read more slowly than young adults and so differential effects of word predictability may reflect a multiplicative slower processing for the low compared to high predictability words by the older, relative to the younger, adult readers (e.g., Faust, Balota, Spieler, & Ferraro, 1999). We therefore adjusted word-level reading time data to take account of this using log-transformation (Wagenmakers, Krypotos, Criss, & Iverson, 2012). Effects based on both untransformed and log-transformed data are reported for transparency and because previous eye movement studies of aging affects have reported effects based only on untransformed data (including in the word predictability study by Choi et al., 2017). Contrasts of main effects and contrasts to examine interactions were defined using sliding contrasts (the contr. sdif function) in the MASS package (Venables & Ripley, 2002). As each variable had two levels, these produced effect coding for main effects equivalent to other methods such as contr.sum. Following convention, *t/z* values greater than 1.96 were considered significant, as when the degrees of freedom are high (as in the present experiment), *p*-values are less than .05 when *t/z*-values exceed 1.96.

Standard sentence-level and word-level measures are reported (see Rayner, 2009). Sentence-level measures were sentence reading time (the time taken from the onset of the sentence display until the participant pressed a key to indicate they had finished reading), number of fixations, average fixation duration, forward saccade length (mean length, in characters, of progressive eye movements) and number of regressions (backwards eye movements). Word-level analyses included measures informative about first-pass reading, i.e., the initial processing of a word prior to a fixation to its right or a regression from that word. These comprised word-skipping (probability of not fixating a word during first-pass reading), first-fixation duration (FFD, duration of the first fixation on a word during first-pass reading), single-fixation duration (SFD, duration of the first fixation on a word receiving only one first-pass fixation), gaze duration (GD, sum of all first-pass fixations on a word) and regressions-out (RO, probability of a first-pass regression from a word). We also examined regression-path reading time (RPRT, sum of all fixations from the first fixation on a word during first-pass reading until the eyes move to the right of the word, including any time spent re-reading earlier portions of text) as a measure of difficulty integrating a target word with the context prior to moving on in the sentence (for discussion, see Liversedge, Paterson, & Pickering, 1998; Steen-Baker et al., 2017). Finally, we report total reading time (TRT, sum of all fixations on a word) and regressions-in (RI, probability of a regression back to a word) as measures of the later processing of target words.

Sentence-Level Analyses. Table 2 shows sentence-level means and Table 3 summarizes the corresponding statistical effects. The results show that, compared to the young adults, the older adults had longer sentence reading times, and made more and longer fixations, and more regressions. This pattern of effects is consistent with the older adults experiencing greater reading difficulty. Forward saccade length did not differ significantly across the age groups, however, as previous studies of aging effects on Chinese reading have also shown. The overall pattern of findings was therefore consistent with previous research (Li et al., 2018; Wang et al., 2018a,b; Zang et al., 2016), and the older adults in the present study showed typical patterns of age-related difficulty.

[Tables 2 & 3]

Target Word Analyses. Target word means are shown in Table 4 and the corresponding statistical effects summarized in Table 5. Compared to the young adults, the older adults skipped the target words less often. The older adults also had longer reading times for these words (with age group effects in FFD, SFD, GD, RPRT and TRT), with the same pattern of effects in untransformed and log-transformed analyses. Compared to the young adults, the older adults also made more regressions back to the target words. This pattern of effects was consistent with previous studies of aging effects in Chinese reading and so provided a further indication that the older adults experienced typical age-related reading difficulty (Li et al., 2018; Wang et al., 2018a,b; Zang et al., 2016).

[Tables 4 & 5]

There were also clear main effects of word predictability. The low predictable words were skipped less often and had longer reading times (with effects in FFD, SFD, GD, RPRT and TRT) compared to the high predictable words. Note that these word predictability effects were observed reliably in analyses of both untransformed and log-transformed reading time data. In addition, readers made more regressions for the low compared to the high predictable words. This effect was observed both in the likelihood of a regression from the target word to re-read text, and in regressions back to target words, suggesting readers had greater difficulty integrating less predictable words with the sentence context. The overall pattern of effects resonates with word predictability effects reported previously in Chinese for young adult readers (Rayner et al., 2005), although note that this previous study did not report regression effects. Word predictability effects have not been widely studied in Chinese reading. This aspect of our findings therefore provides important further important evidence that Chinese readers, like readers of English, exploit word predictability.

Crucially, analyses of both untransformed and log-transformed data produced significant interactions between age group and word predictability in reading times for words. The interaction effect in the untransformed data was significant in all reading time measures

(FFD, SFD, GD, TRT), due to larger word predictability effects (i.e., longer reading times for low compared to high predictability words) for the older than younger adults. The same effect in the log-transformed reading times was significant in GD and RPRT only. As gaze durations provide a measure of the early processing of words associated with the process of lexical identification during reading (e.g., Rayner, 2009), and RPRT provides a measure of sentence integration difficulty (e.g., Liversedge et al., 1998), it appears that higher word predictability facilitated both the lexical identification of target words and their integration with prior context to a greater extent for the older compared to the younger adult readers. The interaction effects in GD and RPRT are shown in Figure 2.

[Figure 2]

No significant interaction between age group and word predictability was observed in word-skipping (or regressions), showing that adult age differences in predictability effects were restricted to reading times for target words. Moreover, the predictability effect in word-skipping by both the young and older adults was very modest (only 3% for each age group), suggesting that contextual predictably did not strongly facilitate the parafoveal identification of words for either group of readers.

Discussion

The present findings showed effects of word predictability in reading times and skipping rate for words that are highly resonant with previous findings in Chinese obtained from skilled young adult readers (Rayner et al., 2005). Moreover, the patterns of age-related reading difficulty we observed were very similar to those reported in previous studies of aging effects on eye movements during Chinese reading (Li et al., 2018; Wang et al., 2018a,b; Zang et al., 2016). The present study therefore replicates previous evidence for both word predictability effects and age-related difficulty in Chinese reading. Crucially, our findings also showed an age difference in the effects of word predictability. Compared to the young adults, the older adult participants in the present experiment made greater use of context to process words, although this effect was restricted to gaze durations and regression-path reading times for words and not observed in word-skipping.

Such findings are important in the context of the theoretical claim that older adults are more “risky” readers who make greater use of contextual predictability to compensate for their slower lexical processing of words (Rayner et al., 2006; see also McGowan & Reichle, 2018). This greater use of context would be expected to benefit the identification of fixated words, as we have observed. However, a key additional component of this “risky” reading hypothesis is that, compared to young adults, older adults use contextual predictability to guess the identity of the next word in a sentence so that they can increase reading speed by skipping words more frequently. This account of aging effects on eye movement control in reading has been highly influential although the supporting evidence is scant. For instance, while Kleigl et al. (2004) showed a differential effect of word predictability on the eye movements of young and older adult readers, the study provided no evidence that older readers make greater use of context to predict upcoming words. Moreover, even the eye movement study that Rayner et al. (2006) presented alongside their account of the “risky” reading hypothesis provided limited support for this claim. The results showed that higher contextual predictability increased word-skipping rates only marginally more for older compared to younger adults, and shortened reading times for words similarly for both age groups. More recently, Choi et al. (2017) also showed an age difference in predictability effects in reading time measures sensitive to the lexical identification of words but no age difference in predictability effects on word-skipping. Steen-Baker et al. (2017) showed, in addition, that effects of word predictability in a reading time measure sensitive to the integration of words with prior context were greater for older readers.

The present findings add to this more recent evidence that, compared to young adults, older readers make greater use of context to identify words and integrate them with the prior sentence context. Similarly to Choi et al. (2017), we observed a larger word predictability effect for older compared to younger adults in a reading time measure (gaze duration) sensitive to the early lexical processing of words and no corresponding effect in word-skipping (although note that the Choi et al. study reported only untransformed analyses of reading time data and so the extent to which the age difference they observed are due to generally slower processing by older readers is unclear; see Faust et al., 1999). In addition, similarly to Steen-Baker et al. (2017), we found a larger predictability effect for older adults in a measure (regression-path reading time) sensitive to integration difficulty. Together, these findings demonstrate that older adults make greater use of context to facilitate word identification and integrate words with context during sentence reading.

Such effects are consistent with a compensatory use of contextual information to offset slower lexical processing by older readers (McGowan & Reichle, 2018; Rayner et al., 2006). However, they may also reflect a processing benefit of older adults' greater vocabulary knowledge and experience of reading due to their increased exposure to text (Verbruggen, 2003; Payne, Gao, Noh, Anderson & Stine-Morrow, 2012). This greater use of contextual knowledge appears to help readers process the identities of fixated words more quickly. However, it is unclear if it can advantage their parafoveal processing of words. No studies to date have shown such an effect. Moreover, we observed only modest effects of word predictability on word-skipping for either the young or older adult participants in our study, suggesting that contextual predictability had a relatively weak influence on parafoveal word identification for both age groups. The evidence to date therefore provides little support for the view that older adults compensate for slower lexical processing by making greater use of context to guess upcoming words and so skip these words more frequently (a key component of the “risky” reading hypothesis; Rayner et al., 2006; McGowan & Reichle, 2018).

It is nevertheless important to consider whether the absence of such an effect is attributable to other factors, including task demands associated with the experiments. In relation to the present experiment, it seems likely that the older adult participants experienced particular difficulties due to visual demands associated with recognizing complex Chinese characters (Zhang, Zhang, Xue, & Yu, 2007; Wang, He, & Legge, 2014) and delineating word boundaries in a naturally unspaced text (see Li et al., 2018). Such difficulties may have lead the older adults to read more slowly than the young adults, including skipping words less frequently. Indeed, studies of eye movement control in Chinese reading show that older adults typically read much more slowly than young adults (generally a 40-50% reduction in reading speed) and skip words much less often (Li et al., 2018; Wang et al., 2018a,b; Zang et al., 2016). Consequently, task demands associated with Chinese reading that depress word-skipping by older readers may have mitigated against observing age differences in word predictability effects on skipping rates in our experiment.

Whether the absence of an age difference in predictability effects on word-skipping in the Choi et al. (2017) study can be similarly attributed to task demands is less clear. One potentially important issue in their study (which Choi et al. acknowledge) concerns the frequency and difficulty of comprehension questions that followed sentence displays. An earlier study by Wotschack and Kliegl (2013) showed that eye movement behavior is modifiable by the use of comprehension questions and, in particular, that including questions that are difficult after every trial in an experiment can eliminate age differences in word-skipping. Consequently, Choi e al.'s use of a comprehension question on each trial, compared with the use of questions on only 25% of trials in both the present experiment and the experiment by Rayner et al. (2006), also may have mitigated against observing age differences in skipping rates in their study. Moreover, the paradigm that Choi et al. used, which involved making surreptitious changes to upcoming words, as well as the use of stimuli which included deliberate misspellings, also may have encouraged their older participants to read more carefully. Consequently, while this study clearly shows an age difference in effects of predictability on the processing of fixated words in alphabetic reading, further work is needed to clarify if such effects can be observed in word-skipping.

This might be achieved by manipulating the frequency and difficulty of comprehension questions, following Wotschack, and Kliegl (2013), to determine if age differences in predictability effects on word-skipping are larger when comprehension questions that follow sentences are easier and used on fewer trials. We may also observe larger age differences in predictability effects on word-skipping during Chinese reading under conditions in which the parafoveal processing of words is maximized by, for example, using one- rather than two-character words as targets in sentences, or assessing skipping rates for very high frequency characters that convey only grammatical information (see, e.g., Zang et al., 2017). A further concern will be to determine whether the interaction effect in the present experiment is due to older adults benefiting more, relative to young adults, from highly predictable words, as might be assumed based on simulations of aging effects in models of eye movement control (Rayner et al., 2006; McGowan & Reichle, 2018), or incurring a large processing cost for unpredicted words even when these are contextually plausible. Further investigations of age differences in predictability effects might tackle this and related questions by comparing effects for words with varying cloze predictability relative to unexpected words (e.g., Wlotko et al., 2012), examining whether there is a cost for less predictable words by comparing effects in lexically constraining relative to neutral contexts (e.g., Frisson et al., 2017), or manipulating the strength of the expectation for a high predictability competitor (see, e.g., Federmeier et al., 2007; Steen-Baker et al., 2017; Stine & Wingfield, 1994).

In sum, the present findings provide novel and important evidence that older adults make greater use of contextual predictability to identify words during Chinese reading, although the mechanisms underlying these effects require further investigation. Crucially, our findings also cast doubt on older readers' use of word predictability to increase word-skipping rates to compensate for their slower lexical processing. However, as word-skipping may be susceptible to task demands and the present research examined this effect in a writing system in which older readers typically skip words infrequently, it clearly also will be important to investigate this issue further.

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Figure Legend

Figure 1. Example sentence and comprehension question. The sentence translates as “As a junior high school student, O Yang decided to study / perform well to win the praise of the teacher.” The question translates as “Is O Yang a junior high school student?” High and Low predictable target words are underlined although these were not underlined in the experiment.

Figure 2. Word predictability effect for older and younger adults in (a) gaze durations, and (b) regression path reading times. Error bars show the Standard Error of the Mean.

Figure 1

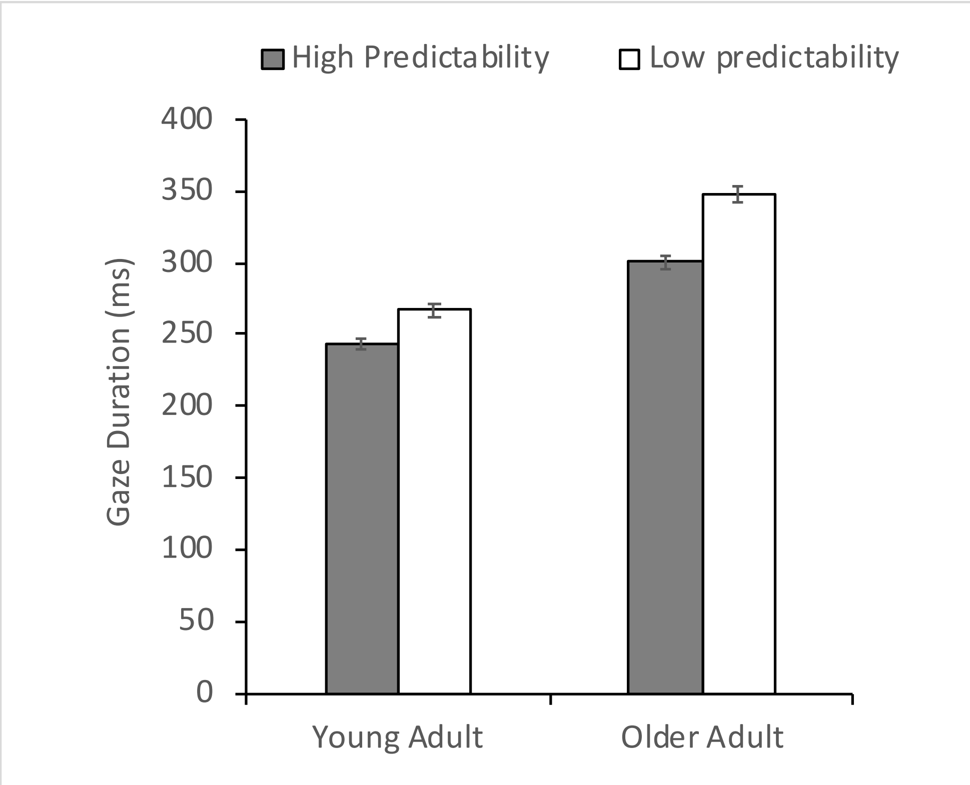
High predictability sentence: 作为一名初中生，欧阳决定好好学习以赢得老师的表扬。

Low predictability sentence: 作为一名初中生，欧阳决定好好表现以赢得老师的表扬。

Question: 欧阳现在是一名初中生吗？

Figure 2

a.


High Predictability
Low predictability
Gaze Duration (ms)
400
350
300
250
200
150
100
50
0
Young Adult
Older Adult

b.

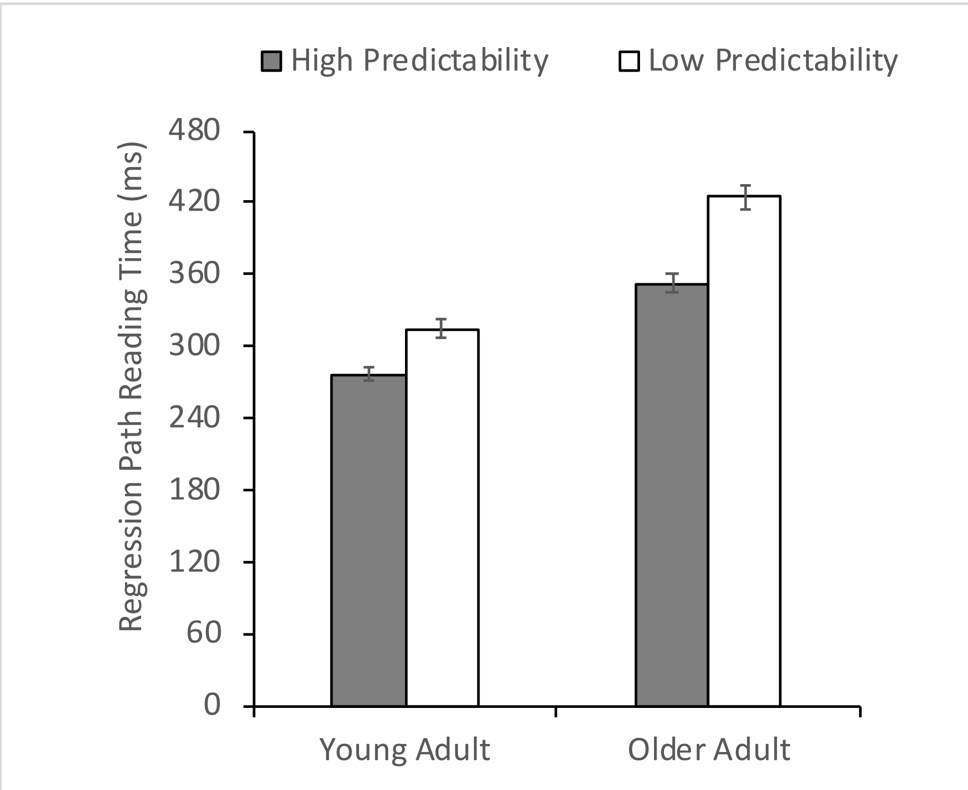

High Predictability
Low Predictability
Regression Path Reading Time (ms)
480
420
360
300
240
180
120
60
0
Young Adult
Older Adult

Table 1. Cloze Predictability of Selected Target Word Stimuli

Age Group	High predictability	Low predictability
Older Adult	.91 (.09)	.02 (.05)
Young Adult	.90 (.09)	.01 (.03)

Note. Scores show the probability of young and older adult participants guessing the target word as the next word in the sentence. The Standard Deviation is shown in parentheses.

Table 2. Means for Sentence-Level Measures

	Young Adult	Older Adult
Sentence reading time (ms)	3293 (36)	6096 (71)
Average fixation duration (ms)	246 (1)	274 (1)
Number of fixations	12.7 (.1)	20.0 (.2)
Number of regressions	3.0 (.05)	5.0 (.07)
Forward saccade length (characters)	2.5 (.02)	2.3 (.02)

Note. The Standard Error of the Mean is shown in parentheses.

Table 3. Means for Target Word Measures

	Young Adult		Older Adult	
	High Predictability	Low Predictability	High Predictability	Low Predictability
Word-skipping (%)	32 (2)	29 (2)	17 (1)	14 (1)
First-fixation duration (ms)	227 (3)	243 (3)	266 (3)	295 (4)
Single-fixation duration (ms)	226 (3)	241 (3)	264 (4)	293 (4)
Gaze duration (ms)	243 (4)	267 (4)	301 (5)	348 (6)
Regressions out (%)	8 (1)	11 (1)	9 (1)	13 (1)
Regression-path reading time (ms)	277 (6)	315 (7)	353 (9)	425 (10)
Total reading time (ms)	305 (6)	355 (7)	415 (9)	497 (10)
Regressions in (%)	13 (1)	19 (2)	17 (1)	25 (2)

Note. The Standard Error of the Mean is shown in parentheses

Table 4. Statistical Effects for Sentence-Level Measures

		Sentence reading time	Average fixation duration	Number of fixations	Number of regressions	Forward saccade length
Intercept	β	4799.10	262.34	16.62	3.97	2.43
	SE	272.40	4.11	.76	.23	.07
	t	17.62	63.89	21.80	17.52	33.41
Age group	β	2941.70	32.83	7.70	2.18	.24
	SE	517.90	8.12	1.43	.43	.14
	t	5.68*	4.04*	5.38*	5.06*	1.70

Note. Asterisks indicate statistically significant effects

Table 5. Statistical Effects for Target Word Measures

		Word-skipping	First-fixation duration	Single-fixation duration	Gaze duration	Regressions out	Regression-path reading time	Total reading time	Regressions in
Intercept	β	1.58	256.16	255.68	286.18	2.36	339.37	390.69	1.64
	SE	.16	5.25	5.32	7.44	.12	10.84	15.75	.10
	t/z	10.14	48.76	48.06	38.44	20.10	31.31	24.81	16.52
Intercept (log-transformed)	β		5.49	5.49	5.57		5.68	5.81	
	SE		.02	.02	.02		.03	.03	
	t/z		284.14	280.09	234.94		201.27	175.58	
Age group	β	1.20	48.93	47.53	72.63	.16	102.34	135.37	.39
	SE	.30	10.32	10.48	14.44	.20	20.71	30.17	.18
	t/z	4.03*	4.74*	4.54*	5.03*	.82	4.94*	4.49*	2.12*
Age group (log-transformed)	β		.18	.17	.23		.27	.31	
	SE		.04	.04	.05		.05	.06	
	t/z		4.67*	4.49*	4.93*		4.97*	4.97*	

Predictability	β	.34	21.75	21.32	34.57	.38	53.19	68.70	.47
	SE	.12	3.78	3.90	5.53	.13	9.12	10.82	.14
	t/z	2.78*	5.76*	5.46*	6.26*	2.89*	5.83*	6.35*	3.25*
Predictability	β		.08	.08	.11		.14	.17	
(log-transformed)	SE		.01	.02	.02		.02	.02	
	t/z		7.01*	5.28*	6.75*		6.85*	7.08*	
Age group ×	β	.19	15.06	14.60	25.46	.10	36.99	36.5	.01
Predictability	SE	.20	6.90	6.67	9.24	.26	15.95	15.31	.21
	t/z	.94	2.18*	2.19*	2.76*	.40	2.32*	2.39*	.05
Age group ×	β		.04	.04	.06		.07	.04	
Predictability	SE		.02	.03	.03		.03	.03	
(log transformed)	*t/z*		1.72	1.58	2.03*		2.16*	1.12	

Note. Asterisks indicate statistically significant effects