Underlying Mechanisms of Prediction Error Costs in Chinese Reading in Older Adults

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Abstract

Whether the cognitive processing mechanisms of reading undergo only quantitative changes or also qualitative changes with aging constitutes an important issue in the field of lifespan development research. To achieve effective language processing, readers must integrate existing experiential knowledge and current context to engage in predictive processing of upcoming information. Therefore, addressing the aforementioned issue requires answering how the predictive processing mechanisms change in older adults' reading, namely, how prediction error cost is generated. This study intends to employ synchronous eye-tracking and EEG recording technology to acquire real-time behavioral and neural indices of language processing during natural reading, focusing on the generation mechanism of prediction error cost in older adults, and primarily explaining the causes of prediction error cost from three aspects: parafoveal vision, working memory load, and language ability. The research findings will be of significant importance for constructing a lifespan development model of Chinese reading.

Full Text

The Mechanism of Prediction Error Cost in Chinese Reading for Older Adults

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Abstract: An important question in lifespan developmental research concerns whether the cognitive mechanisms underlying reading undergo only quantitative changes or also qualitative changes with aging. Effective language processing requires readers to combine prior experience with current contextual information

to generate predictions about upcoming information. Therefore, addressing this question necessitates examining how predictive processing mechanisms change in older adults' reading, specifically how prediction error costs emerge. This research proposes to use co-registration of eye movements and EEG to obtain real-time behavioral and neural indices of language processing during natural reading, focusing on the mechanism of prediction error cost in older adults. The study will primarily explain the origins of prediction error cost from three perspectives: parafoveal vision, working memory load, and language ability. The findings will have significant implications for constructing a lifespan developmental model of Chinese reading.

Keywords: contextual effects, prediction error cost, Chinese reading, cognitive aging, co-registration of eye movements and EEG

By the end of 2019, China' s population aged 60 and above had exceeded 250 million, indicating that the country is entering a stage of rapid population aging (National Bureau of Statistics, 2020). Traditional perspectives on human development emphasize education and learning during the early stages of life to build knowledge bases and enhance abilities. However, as life expectancy increases and population structures age, the ability to maintain information updating and learning capabilities becomes increasingly important for sustaining vitality across the entire lifespan. Reading serves as a primary channel for human learning and information acquisition, yet research on reading ability development has primarily focused on early developmental stages, with insufficient attention paid to changes in reading behavior during older adulthood and their underlying cognitive mechanisms. In other words, the critical question of whether cognitive processing in reading undergoes only quantitative changes or also qualitative changes with aging remains unresolved.

Current research on reading and aging indicates that older adults (aged 60+) read more slowly than young adults (aged 18-30), exhibiting more frequent and longer fixations as well as more regressions during reading (Kliegl et al., 2004; Rayner et al., 2006; Stine-Morrow et al., 2010; Warrington et al., 2019; Whitford & Titone, 2017). Studies on Chinese reading further reveal that to accommodate the dense character text and lack of clear word boundaries, older adults develop more cautious oculomotor strategies, characterized by fewer word-skipping saccades and shorter forward saccades (Wang et al., 2020; Li et al., 2019; Li et al., 2018; Wang, Li, Li, Xie, Chang et al., 2018; Wang, Li, Li, Xie, Liversedge, & Paterson, 2018; Zang et al., 2016; Zhao et al., 2021; Zhao et al., 2019). The dominant computational models of eye movement control in reading—the E-Z Reader model and the SWIFT model—have both simulated reading aging by modifying parameters. However, the empirical data underlying these simulations offer divergent perspectives on whether cognitive processing in reading undergoes quantitative versus qualitative changes with age.

Kliegl et al. (2004) found that although older adults generally exhibited longer fixation durations than young adults, there was no interaction between age and word frequency, suggesting that both groups showed similar lexical processing

patterns with older adults simply processing more slowly overall—a quantitative change. Laubrock et al. (2006) subsequently simulated these findings using the SWIFT model. In contrast, Rayner et al. (2006) observed interactions between age and word frequency across multiple measures including skipping rates and fixation durations, indicating different lexical processing patterns between age groups. Older adults showed larger word frequency effects and particular difficulty processing low-frequency words, suggesting they rely more heavily on predictive processing using prior context to compensate for slower lexical processing—a qualitative change. This study successfully simulated these aging effects by modifying E-Z Reader model parameters. Subsequent research has consistently found similar age-by-frequency interactions (Liu et al., 2019; McGowan & Reichle, 2018; Rayner et al., 2013; Wang, Li, Li, Xie, Chang et al., 2018; Wang, Li, Li, Xie, Liversedge, & Paterson, 2018; Whitford & Titone, 2017; Zang et al., 2016).

Resolving this controversy requires moving beyond basic lexical processing to address fundamental theoretical orientations in reading research. The interactive processing approach posits that readers combine their experiential knowledge with current context to predict and pre-activate upcoming information, representing a crucial component of effective language processing (Bai & Yan, 2017). The recently proposed Chinese Reading Model (CRM), though not yet applied to aging simulations, incorporates predictability as a key parameter (Li & Pollatsek, 2020). Therefore, examining whether cognitive processing in reading undergoes only quantitative or also qualitative changes with aging hinges on understanding how predictive processing mechanisms change in older adults. The central focus for investigating these changes concerns whether older readers exhibit prediction error costs and what factors influence them.

The current research proposes to employ co-registration of eye movements and EEG to investigate the mechanism of prediction error cost in older adults, examining its origins from three perspectives: parafoveal visual processing, working memory load, and language ability. Investigating changes in predictive processing during Chinese reading in older adults is significant for deepening our understanding of Chinese language processing mechanisms and constructing a lifespan developmental model of Chinese reading ability. Moreover, this research can inform effective interventions for older adults, promoting health management, continued work, and lifelong learning to actively address population aging.

2.1 Predictive Processing in Reading

Predictive processing represents a fundamental operating principle of the brain, which uses predictive coding and computes prediction errors to make accurate inferences (Clark, 2013; Schuster et al., 2021). Recent theoretical perspectives on sentence comprehension have increasingly embraced the notion of linguistic "pre-processing," conceptualizing reading as an interactive dialogue between reader and text achieved through continuous prediction (Willems et al., 2016). "Cloze probability" serves as the primary method for measuring target word

predictability in reading materials (Taylor, 1953; Zhao et al., 2021; Zhao et al., 2019). Readers complete cloze tasks by providing the first word that comes to mind based on preceding sentence context; the proportion of readers providing the target word constitutes its cloze probability. Context represents the critical factor determining lexical predictability (Balota et al., 1985). When context provides detailed, strongly constraining information (constraining context), readers are more likely to make strong predictions. Conversely, when context provides ambiguous information (non-constraining context), predictions become weaker and more random.

Eye movement research on reading has documented predictability effects, demonstrating that readers exhibit shorter fixation durations and higher skipping rates for high-predictability words compared to low-predictability words (Balota et al., 1985; Ehrlich & Rayner, 1981; Rayner & Well, 1996; Staub, 2015; Zhao et al., 2021; Zhao et al., 2019). Electrophysiological studies have similarly found that N400 amplitude increases as predictability decreases, indicating more difficult processing of low-predictability words (Kretzschmar et al., 2015).

Two primary theories explain the origins of predictability effects. The first posits that predictability effects result from "all-or-none" lexical activation, also termed lexical prediction. Correct predictions facilitate lexical processing, while incorrect predictions interfere with processing (i.e., produce prediction error cost) (Luke & Christianson, 2016). The alternative theory suggests that predictability effects arise from graded pre-activation of upcoming lexical items, where readers simultaneously activate a set of related words with activation levels proportional to their cloze probabilities (Frisson et al., 2017). The ultimate winner depends on the reader' s goals, prior knowledge, and bottom-up input (Kuperberg & Jaeger, 2016)—a mechanism termed "graded prediction."

Distinguishing between these predictive processing mechanisms hinges on examining whether prediction error cost exists. Specifically, whether encountering an unpredictable word in a constraining context incurs greater processing cost than encountering the same word in a non-constraining context. For example, in the constraining context "Today is Cheng Liang' s birthday, his mother bought him a *{_},*" *the predictable target is "cake" while an unpredictable target would be "cellphone." In the non-constraining context "What Cheng Liang didn' t expect was that his mother bought him a* {_____}," the corresponding unpredictable target is also "cellphone." If readers employ all-or-none activation, the constraining context would activate only "cake." Encountering "cellphone" as the target would create interference, making "cellphone" more difficult to process in the constraining than non-constraining context—producing prediction error cost. Conversely, if readers employ graded diffusion activation, the constraining context would activate a set of birthday-gift-related words including both "cake" and "cellphone," albeit with different strengths. Encountering "cellphone" would not produce greater interference, and processing would not differ significantly between contexts, eliminating prediction error cost.

Thus, evidence of prediction error cost in older but not young adults (across eye movement measures such as fixation duration, skipping rate, regression ratio, and fixation count, as well as EEG N400 component amplitude, peak, and latency) would indicate qualitatively different predictive processing mechanisms between age groups—a qualitative change in reading cognition. Absence of age differences in prediction error cost would suggest that older adults' reading cognition has undergone only quantitative changes.

Alphabetic language research demonstrates that young participants show no processing cost for low-predictability words in constraining versus non-constraining contexts, indicating no prediction error cost. This suggests young adults employ graded diffusion activation rather than all-or-none lexical prediction. Graded diffusion activation represents a more efficient mechanism than all-or-none prediction (Frisson et al., 2017). As a logographic writing system distinct from alphabetic languages, Chinese imposes unique visual and lexical processing demands on readers while sharing common cognitive-neural mechanisms with other languages. Chinese reading research has consistently demonstrated predictability effects similar to alphabetic languages (Bai et al., 2011; Bai et al., 2015; Su et al., 2016; Li & Pollatsek, 2020; Rayner et al., 2005; Yao et al., 2021), indicating universal mechanisms at higher-level reading processing stages. However, direct empirical evidence for prediction error cost in Chinese reading remains necessary.

2.2 Predictive Processing and Aging

The E-Z Reader model posits that older adults rely more heavily on prior context to predict upcoming words. However, empirical research on aging effects in predictive processing during reading remains limited and inconclusive. Some eye-tracking studies examining predictive processing in older and young adults have found larger predictability effects in older adults, with longer processing times for low-predictability words, suggesting greater reliance on contextual prediction (Liu et al., 2019; Choi et al., 2017; Huettig & Janse, 2016; Zhao et al., 2021). Conversely, event-related potential studies have found delayed and reduced predictability effects in older adults, suggesting decreased reliance on predictive processing during reading (Federmeier & Kutas, 2019; Payne & Federmeier, 2018). Despite different manifestations, both methodologies reveal distinct predictability effects between age groups, suggesting that older adults' predictive processing mechanisms may have undergone qualitative changes.

Does prior context better facilitate processing of high-predictability words or hinder processing of low-predictability words in older adults? Existing studies, whether using eye-tracking or ERPs, have exclusively employed constraining contexts, leaving this question unanswered. Addressing this issue requires examining whether older and young adults generate different prediction error costs across constraining and non-constraining contexts, while employing more precise and ecologically valid co-registration methods.

2.3 Factors Influencing Predictive Processing in Aging

During reading, readers can view not only the currently fixated word but also pre-process upcoming information parafoveally. Text processing involves continuously integrating processed information with upcoming visual input. Consequently, efficient predictive processing requires coordinated participation of visual ability, working memory capacity, and language ability. The lifespan development perspective posits that aging does not equate to pure decline but rather involves dynamic changes in cognitive mechanisms alongside genuine declines in various abilities. Normal aging brings deterioration in physiological functions such as vision and cognitive abilities like working memory, while simultaneously preserving crystallized intelligence such as language ability. Wu et al. (2020) examined language ability aging mechanisms, proposing that non-specific general cognitive abilities and specific language abilities jointly contribute, with general cognitive abilities accounting for greater between-group differences between young and older adults. Therefore, investigating factors influencing older adults' predictive processing requires multidimensional examination.

With age, even healthy older adults experience visual decline, leading to reduced information processing capacity in peripheral visual fields (Li et al., 2019; Owsley, 2016). This suggests older adults' parafoveal preview processing is likely affected. However, whether parafoveal information availability influences older adults' predictive processing remains unanswered, with only indirect evidence that impaired preview processing affects older adults' oculomotor strategies (Li et al., 2018; Schotter et al., 2015; Schotter et al., 2014).

Beyond visual ability, cognitive aging represents another important influence. Age-related declines in fluid intelligence primarily manifest as reduced working memory capacity (Janse & Jesse, 2014; Stine-Morrow et al., 2010), while growth in crystallized intelligence appears in language abilities (Liu et al., 2019). Cognitive abilities exert multidimensional and bidirectional influences on information processing: the two core aspects of adult development and aging—decline in mental function during later life (fluid intelligence) and preservation or increase in language ability (crystallized intelligence)—significantly impact process-level reading operations (Stine-Morrow et al., 2010). On one hand, age-related declines in fluid intelligence may constrain reading processing. Among aging-related theories, the working memory decline hypothesis has received substantial empirical support (He, 2017). Research has found positive correlations between working memory capacity and predictive language processing; individuals with reduced working memory capacity store less contextual information and exhibit slower information integration, thereby affecting predictive processing (Janse & Jesse, 2014; Huettig & Janse, 2016). Notably, recent research suggests that semantic integration in Chinese reading cannot be explained solely by working memory decline (Zhu et al., 2019). On the other hand, habitual text exposure throughout adulthood provides older adults with greater reading experience, preserving or increasing language ability and knowledge, which may buffer age-related impacts (Liu et al., 2019; Salthouse & Timothy, 2012). Lan-

guage ability has been shown to relate to predictive processing, with studies comparing adults with high versus low language ability finding weaker predictive processing in those with lower ability (Huettig & Brouwer, 2015). Recent research indicates that older adults with larger vocabularies process language more similarly to young adults, suggesting vocabulary serves a compensatory role (Xu et al., 2020).

Parafoveal preview effectiveness, working memory load, and language ability preservation may all influence predictive processing mechanisms in older and young adults, and these influences may not operate independently. However, existing research has not confirmed how these three factors contribute to prediction error cost. Therefore, investigating changes in older adults' predictive processing mechanisms must consider visual decline, fluid intelligence such as working memory, and crystallized intelligence such as language ability. Additionally, other non-specific cognitive factors may influence language ability aging (Wu et al., 2020), including reduced processing speed in older age (Salthouse, 1996) and decreased ability to inhibit irrelevant information (Campbell et al., 2020). Educational background and daily reading habits also affect older adults' language ability.

2.4 Application of Co-registration Technology in Reading

Most electrophysiological reading research employs the Rapid Serial Visual Presentation (RSVP) paradigm, which has provided substantial evidence for predictive processing but has potential limitations: unnatural stimulus presentation (Frisson et al., 2017; Schotter et al., 2014). On one hand, words presented at fixed rates typically remain visible longer than natural reading fixation durations. On the other hand, this paradigm forces serial, unidirectional processing without allowing parafoveal preview or regressive saccades present in natural reading. Sereno and Rayner (2003) first proposed combining eye-tracking with ERP techniques to simultaneously record eye movement indices and fixation-related brain potentials (FRPs) during normal reading, enabling synchronous measurement of behavioral oculomotor performance and EEG signals during reading comprehension.

Both eye movements and EEG signals possess high temporal resolution. The key to successful co-registration lies in ensuring identical sampling rates for both systems (typically 1000 Hz), which better detects neural processing during fixations (Baccino, 2011). Synchronization is achieved through two computers connected in parallel: Computer A presents stimuli and collects eye movement data while Computer B collects EEG data. Experiments can be configured so that Computer A sends synchronous TTL pulses to Computer B when presenting stimuli, achieving synchronized recording. During offline analysis, TTL pulses provide accurate time markers for data alignment (with EEG segmentation based on fixation onset and offset times). Notably, since EEG recording typically excludes ocular artifacts, co-registration requires artifact correction. Two viable methods exist: Independent Component Analysis (ICA) (Henderson et al., 2013), which

identifies ICA components using EOG, determines their scalp distribution, uses meta-analysis to establish the proportion of current density from eye position, and finally subtracts ocular artifact components from raw EEG data. Alternatively, the Multiple Source Eye Correction (MSEC) method (Dimigen et al., 2011) requires participants to complete 120 saccade calibrations in four directions and 40 voluntary blinks before the main experiment, then uses Principal Component Analysis (PCA) to define artifact topographies for each type of eye movement before correction (Li & Liu, 2017).

Co-registration studies have found that predictability affects both eye movement and EEG measures: high-predictability words show higher skipping rates, fewer regressions, and shorter fixation durations, along with reduced N400 amplitude (Kretzschmar et al., 2015). To date, no Chinese reading research has employed this cutting-edge co-registration method to investigate predictive processing, yet this approach can examine the critical question of prediction error cost in more natural reading contexts.

In summary, this research proposes to use co-registration of eye movements and EEG to focus on high-level information processing mechanisms related to aging in Chinese reading, examining whether differences between older and young adults represent quantitative or qualitative variations. The key issue concerns whether older adults exhibit prediction error cost during reading. For predictive processing in Chinese reading, the study will examine effects of age-related changes in physiological function, fluid intelligence, and crystallized intelligence from three perspectives: parafoveal visual processing, working memory load, and language ability. Processing speed, inhibitory ability, educational background, and daily reading habits will be included as covariates in the model for data mining and integration to construct a lifespan developmental model of Chinese reading.

3 Research Plan

This research will employ co-registration of eye movements and EEG (FRPs) to examine cognitive mechanism changes in predictive processing during Chinese reading with age and their influencing factors. The core scientific question addresses whether differences between older and young adults during reading represent merely quantitative differences or also qualitative differences, encompassing three aspects: (1) whether older and young adults generate different prediction error costs and employ different predictive processing mechanisms in constraining versus non-constraining contexts; (2) how parafoveal information availability, working memory load, and language ability preservation lead to different predictive processing mechanisms between older and young adults; and (3) whether factors influencing general language ability aging—such as processing speed, inhibitory ability, educational background, and daily reading habits—affect predictive processing mechanisms, how these factors operate and their time courses across predictive processing stages, and how individual differences among older adults modulate these effects.

Addressing these three scientific questions, the research will conduct three studies: Study 1 will use co-registration of eye movements and EEG (FRPs), manipulating contextual constraint conditions with multiple eye movement and EEG measures as dependent variables to examine whether prediction error cost emerges in older versus young adults during Chinese reading, investigating whether predictive processing mechanisms undergo qualitative changes with age.

Study 2 will use co-registration of eye movements and EEG (FRPs), manipulating contextual constraint conditions with multiple eye movement and EEG measures as dependent variables to examine why older adults exhibit prediction error cost, focusing on parafoveal preview, working memory, and language ability. Before all experiments, participants will complete assessments of visual ability (foveal acuity test), educational background, recent reading experience, processing speed (digit and color naming tasks), working memory (digit span forward and backward), inhibitory ability (STROOP task), and lexical ability (vocabulary subtest of Wechsler Intelligence Scale). These data will be used for data mining integration in Study 3 to comprehensively examine potential influences.

Experiment 1 will apply the boundary paradigm with varying parafoveal preview conditions to examine whether prediction error cost differs between older and young adults when parafoveal visual information is available versus unavailable, exploring the influence of visual physiological ability on predictive processing mechanisms.

Experiment 2 will employ the gaze-contingent text masking paradigm to examine whether prediction error cost changes under normal versus increased working memory load, investigating how working memory integration affects predictive processing mechanisms.

Experiment 3 will divide older adults into high and low language ability groups based on language ability scores to examine whether prediction error cost differs between older adults with different language abilities and young adults, exploring how preserved language ability influences predictive processing mechanisms.

Study 3 will use linear mixed-effects modeling to include all factors from Study 2 as covariates, examining their influence on predictive processing patterns. Additionally, survival and distribution analyses will be conducted on EEG components and eye movement indices to investigate the time course of these influences and individual difference effects.

3.1 Study 1: Effects of Aging on Prediction Error Cost in Chinese Reading

During reading, readers can predict upcoming words based on their knowledge and prior text information, with word predictability influencing dynamic text processing. Eye movement research demonstrates that cloze probability

measures word predictability, with high-predictability words receiving shorter fixations and higher skipping rates than low-predictability words (Staub, 2015). Electrophysiological research provides converging evidence that predictability facilitates text processing: the N400, a negative ERP component occurring approximately 400ms post-stimulus, shows increased amplitude under low-predictability conditions (DeLong, Quante, & Kutas, 2014).

Regarding the causes of predictability effects in reading, we previously introduced two competing theories—graded diffusion activation and lexical activation—which represent the key to understanding the cognitive mechanisms of predictive processing. The critical distinction lies in examining whether a reading time cost occurs when encountering an unpredictable word in a constraining context compared to the same word in a non-constraining context—that is, whether prediction error cost exists. If prediction error cost exists, it indicates that in high-constraint contexts, readers expect a specific high-predictability target word. When the actual word matches expectations, processing is facilitated; when mismatched, processing is disrupted, producing prediction error cost. Conversely, absence of prediction error cost suggests readers do not maintain all-or-none expectations for specific words but instead engage in graded diffusion activation of a set of related words. Alphabetic reading research has demonstrated that young adults tend to employ graded diffusion activation for predictive processing. Based on the unique characteristics of the Chinese writing system, Chinese reading exhibits particularities while potentially showing cross-linguistic consistency in high-level predictive information processing.

Have older adults' predictive processing mechanisms in reading undergone qualitative changes compared to young adults? This question first requires considering whether predictability effects show different patterns in older adults. ERP studies examining predictive processing differences between older and young adults have found delayed and reduced context constraint effects in older adults, suggesting reduced reliance on predictive processing during reading comprehension (Federmeier & Kutas, 2005; Wlotko & Federmeier, 2012). In contrast, eye-tracking studies suggest older adults show larger predictability effects than young adults, indicating greater dependence on predictive processing (Choi et al., 2017; Huettig & Janse, 2016). According to E-Z Reader model predictions, older adults utilize prior context more extensively to predict upcoming words, compensating for slower lexical processing (McGowan & Reichle, 2018; Rayner et al., 2006). Given changes in visual physiological function and cognitive abilities, older adults may employ predictive processing mechanisms different from young adults. Therefore, examining whether older adults exhibit prediction error cost in predictive processing can reveal whether different cognitive mechanisms underlie predictive processing across age groups.

Thus, Study 1 will use co-registration of eye movements and EEG (FRPs), manipulating contextual constraint and target word predictability levels to record participants'eye movement trajectories and EEG responses during reading. This will examine whether prediction error cost emerges in older versus young adults

during Chinese reading and investigate whether predictive processing mechanisms undergo qualitative changes with age.

Experimental materials are configured as shown in Table 1:

Example of experimental condition configuration

Context Type	Example Sentence	Target Word	Condition
Constraining	Today is Cheng Liang' s birthday, his mother bought him a cake as a gift.	cake	Predictable (CP)
Constraining	Today is Cheng Liang' s birthday, his mother bought him a cellphone as a gift.	cellphone	Unpredictable (CU)
Non-constraining	What Cheng Liang didn' t expect was that his mother bought him a cellphone as a gift.	cellphone	Unpredictable (NU)

Sixty young and sixty older adults participated in material norming studies without participating in subsequent eye movement experiments. In constraining contexts, predictable target words (CP) had an average cloze probability of 78.2%, while unpredictable targets (CU) averaged 1.8%. In non-constraining contexts, corresponding unpredictable words (NU) averaged 0.8% cloze probability. Paired-sample t-tests on cloze probabilities revealed that CP words were significantly more predictable than CU words ($p < 0.001$). Critically, for testing prediction error cost, unpredictable target words in high versus low constraint contexts (CU vs. NU) did not differ significantly in cloze probability ($t < 1$). Predictable and unpredictable target words were carefully matched on visual complexity and word frequency. No significant differences existed between the two age groups' ratings ($ts < 1$). Predictable and unpredictable target words appeared in identical sentence frames. Note that the (un)predictable classification is conceptually based on constraining contexts; corresponding unpredictable targets in non-constraining contexts also maintained low cloze probabilities.

All participants completed assessments of visual ability (foveal acuity test), educational background, recent reading experience, processing speed (digit and color naming tasks), working memory (digit span forward and backward), inhibitory ability (STROOP task), and lexical ability (vocabulary subtest of Wechsler Intelligence Scale) to ensure within-group homogeneity. These test scores will be included as covariates in the final study' s analyses.

Hypotheses: (1) If experimental material controls are effective, typical predictability effects should be observed, manifesting as shorter fixation durations

and higher skipping rates for predictable versus unpredictable target words in constraining contexts. (2) If older and young adults employ different predictive processing mechanisms in Chinese reading, young adults should not show prediction error cost—processing times for unpredictable targets should not differ between constraining and non-constraining contexts. In contrast, older adults may exhibit prediction error cost, with unpredictable targets in constraining contexts disrupting their processing.

3.2.1 Experiment 1: Effects of Parafoveal Information Availability on Prediction Error Cost in Older and Young Adults

Sentence comprehension emerges from integration of prediction and preview processing. Separating predictive effects from parafoveal preview effects requires sophisticated experimental design and high temporal resolution measurement (DeLong, Quante, & Kutas, 2014; DeLong, Troyer, & Kutas, 2014; Kutas et al., 2011). The boundary paradigm (Rayner, 1975) represents the most common method for investigating parafoveal preview processing in reading research. In this paradigm, an invisible boundary is set before the target word, with different preview conditions presented to the right of the boundary. When readers fixate left of the boundary, they parafoveally process different preview information; when their eyes cross the boundary, the preview information changes to the target word. For example, the target word "chair" can be parafoveally previewed as the word itself, masked symbols (##), or an unrelated word (e.g., "light").

Balota et al. (1985) first used this technique to manipulate parafoveal preview for high and low predictability target words, finding that predictability-related facilitation occurred only when preview words were identical or visually similar to targets. Subsequent research has confirmed the interaction between predictability and preview, clearly demonstrating that predictability effects depend on effective parafoveal preview availability (Juhasz et al., 2008; White et al., 2005). Bayesian belief models explain this phenomenon by suggesting that invalid preview produces costs that eliminate predictability effects. During sentence reading, readers maintain multiple hypotheses about potential meanings, updating them according to Bayesian rules as each new word is encountered. Word processing time functions as a measure of required belief updating, with invalid preview representing unexpected input that shifts beliefs away from initially predicted targets, thereby eliminating target predictability (Levy, 2008; Norris, 2006; Parker et al., 2017).

How this interaction between top-down predictive processing and bottom-up preview processing affects older adults' reading remains unclear. Older adults exhibit substantially reduced parafoveal preview processing capacity yet still show predictability effects, possibly because they employ all-or-none lexical prediction. Experimentally eliminating parafoveal visual information for both age groups could reveal how preview availability influences predictive processing

strategies. Therefore, this experiment will use the boundary paradigm, building on Study 1 materials to create valid preview (target word presented as preview) and invalid preview (※ symbols presented as preview) conditions. Using co-registration, we will examine: (1) whether parafoveal preview availability influences predictability effects in older and young adults; and (2) whether parafoveal preview availability affects prediction error cost emergence in both groups. Preview conditions are illustrated in Figure 1 [Figure 1: see original paper].

[Figure 1: see original paper] Schematic diagram of preview condition configuration for Experiment 1

All participants will complete assessments of visual ability, educational background, recent reading experience, processing speed, working memory, inhibitory ability, and lexical ability to ensure within-group homogeneity. These scores will be included as covariates in the final study' s analyses.

Hypotheses: (1) If parafoveal preview influences predictive processing, both older and young adults should show larger predictability effects under invalid versus valid preview conditions, with young adults showing smaller effects and older adults' effects remaining unchanged. (2) If parafoveal preview leads to different prediction error costs across conditions, young adults may show prediction error cost under invalid preview but not under valid preview, while older adults may exhibit prediction error cost under both preview conditions.

3.2.2 Experiment 2: Effects of Working Memory Load on Prediction Error Cost in Older and Young Adults

Reading requires processing continuously appearing new information while storing processed information, retrieving existing knowledge, and integrating current with prior information. Working memory, as a system for temporary storage and manipulation of information, is crucial for this complex process (Yang, 2015). Research indicates that semantic information processing and maintenance are affected by working memory capacity; individuals with different cognitive abilities store varying amounts of contextual information and show different speeds of information transformation and updating, potentially exhibiting different levels of predictive processing. Working memory correlates positively with language predictive processing and forms the spatiotemporal foundation of language processing (Huettig & Janse, 2016; Janse & Jesse, 2014).

Regarding maintenance mechanisms for language in working memory, researchers propose that readers must re-engage attentional focus to retrieve and activate memory traces. Due to interference and time-based decay, information in working memory gradually disappears when attention shifts, but can be reactivated through attentional refocusing before disappearing completely. The "time-based resource-sharing model" represents a prominent theoretical account (Camos & Barrouillet, 2018). Reading and aging research has found that older adults make numerous regressions during reading, possibly reflecting

increased attentional refocusing processes adopted to compensate for working memory decline and enable effective reading. This suggests older readers may self-regulate information input, pausing more frequently for conceptual integration to effectively utilize prior context for predictive processing (Stine-Morrow et al., 2010). Notably, recent research indicates that semantic integration in Chinese reading cannot be explained solely by working memory decline (Zhu et al., 2019). Thus, how increased working memory load affects predictive processing mechanisms in older versus young adults remains unresolved.

Therefore, this experiment builds on Study 1 materials using the gaze-contingent text masking paradigm. Under masking conditions, previously read content is masked with ※ symbols, preventing attentional refocusing and increasing working memory load. Using co-registration, we will examine: (1) whether working memory load influences predictability effects in older and young adults; and (2) whether working memory load affects prediction error cost emergence. Figure 2 [Figure 2: see original paper] illustrates the experimental condition configuration.

[Figure 2: see original paper] Schematic diagram of increased working memory load condition for Experiment 2

All participants will complete assessments of visual ability, educational background, recent reading experience, processing speed, working memory, inhibitory ability, and lexical ability to ensure within-group homogeneity. These scores will be included as covariates in the final study' s analyses.

Hypotheses: (1) If working memory load influences predictive processing, both older and young adults should show larger predictability effects under high versus normal working memory load, with young adults showing smaller effects and older adults showing larger effects. (2) If increased working memory load leads to different prediction error costs across conditions, young adults may show no prediction error cost under low load but exhibit cost under high load, while older adults may show prediction error cost under both loads, with greater cost under high working memory load.

3.2.3 Experiment 3: Differences in Prediction Error Cost Between Older and Young Adults with Different Language Abilities

Research demonstrates that habitual text exposure throughout adulthood increases knowledge and may buffer age-related effects. Age-related increases in language ability can effectively enhance language processing (Liu et al., 2019; Salthouse & Timothy, 2012). Language ability (reading skill) and predictive capacity are closely related, with studies comparing different participant groups –such as high versus low literacy individuals, children, dyslexic adults, and college students–showing that dyslexic adults exhibit poorer predictive processing than normal adults (Huettig & Brouwer, 2015). Recent research indicates that

older adults with larger vocabularies process language more similarly to young adults, suggesting vocabulary serves a compensatory role (Xu et al., 2020).

Older adults possess richer reading experience and accumulating crystallized intelligence. However, how accumulated language ability contributes to changes in older adults' predictive processing mechanisms remains unresolved. Therefore, this experiment uses Study 1 materials, dividing participants into high and low language ability groups based on verbal intelligence scores. Using co-registration, we will examine whether prediction error cost differs between older adults with different language abilities and young adults, investigating how preserved language ability influences predictive processing mechanisms.

All participants will complete assessments of visual ability, educational background, recent reading experience, processing speed, working memory, and inhibitory ability (excluding lexical ability used for grouping) to ensure within-group homogeneity. These scores will be included as covariates in the final study' s analyses.

Hypothesis: If language ability influences older adults' predictive processing, low language ability older adults should show larger predictability effects than high ability older adults, manifesting as greater difficulty processing low-predictability words and larger prediction error cost. However, even high language ability older adults should still show larger predictability effects and prediction error cost compared to young adults.

3.3 Study 3: Data Mining Integration to Construct a Predictive Processing Model for Older Chinese Readers

Language represents one of humanity' s most complex psychological behaviors. Researchers investigating language comprehension are concerned with its psychological processes, relationships with basic cognitive components, and connections to the cognitive system. Three primary theories explain how non-specific factors influence language ability aging: processing speed theory posits that slowed cognitive processing in older age reduces language processing speed (Salthouse, 1996); working memory theory suggests working memory impairment explains age-related language ability deficits (He, 2017; de Beni et al., 2007); and inhibitory deficit theory proposes that reduced ability to inhibit irrelevant information importantly contributes to language ability impairment (Campbell et al., 2020). Wu et al. (2020) examined language ability aging mechanisms, proposing that non-specific general cognitive abilities and specific language abilities jointly contribute, with regression analyses indicating both significantly predict young-old group differences, though general cognitive abilities contribute more.

Study 2 focused on predictive processing mechanisms in Chinese reading, manipulating three factors to examine how visual physiology, working memory, and language ability influence age-related changes in predictive processing mechanisms. Visual decline may prevent older adults from effectively processing

upcoming stimuli, meaning graded diffusion activation would likely fail to utilize preview information to inhibit other activated options. Working memory decline may cause older adults to regress frequently to refocus attention, increasing working memory burden if employing graded diffusion activation. Language ability preservation may enable older adults to continue predictive processing. Multiple factors collectively lead older adults to exhibit predictability effects and prediction error cost, adopting a less efficient but more conservative all-or-none predictive processing strategy.

To comprehensively examine other potential influences, all studies will include assessments of visual ability (foveal acuity test), educational background, recent reading experience, processing speed (digit and color naming tasks), working memory (digit span forward and backward), inhibitory ability (STROOP task), and lexical ability (vocabulary subtest of Wechsler Intelligence Scale). These scores will be included as covariates in the final study' s analyses. Aging encompasses highly complex, interactively influencing factors that must be considered comprehensively to build a predictive processing model for older Chinese readers. What are the relative weights of these factors? What are their time courses? How do substantial individual differences among older adults modulate these effects? These questions remain unanswered. Therefore, Study 3 will include all these factors as covariates in linear mixed-effects models to examine their weight in influencing older adults' predictive processing mechanisms. Survival analysis will investigate how these factors operate across different stages of predictive processing, while distribution analysis will examine effects of individual differences among older adults.

Hypotheses: If these factors operate jointly rather than independently, model fit with all factors simultaneously included will be superior to models with individual factors. If these factors have different time courses, survival analysis will reveal different divergence points. If individual differences among older adults have effects, distribution analysis will show no differences in location parameters but significant differences in scale parameters.

4 Theoretical Construction and Innovation

Examining changes in reading behavior and underlying cognitive mechanisms during older adulthood requires more than simply modifying parameters in existing eye movement control models (McGowan & Reichle, 2018; Rayner et al., 2006; Rayner et al., 2013). Current reading models posit that combining experiential knowledge with current context to predict and pre-activate upcoming information is crucial for effective language processing (McGowan & Reichle, 2018; Li & Pollatsek, 2020). This research proposes that examining whether older adults exhibit prediction error cost during reading can determine whether their predictive processing mechanisms have changed. Using co-registration of eye movements and EEG, the research focuses on the mechanism of prediction error cost in older adults, examining why reading processing mechanisms change dynamically from three perspectives: parafoveal visual processing, work-

ing memory load, and language ability. Based on existing research and anticipated findings, we propose to construct a mechanism model of predictive processing changes with age in Chinese reading, as illustrated in Figure 3 [Figure 3: see original paper].

[Figure 3: see original paper] Mechanism model of predictive processing changes with age in Chinese reading

The innovation of this research is manifested in three ways: First, it focuses on high-level information processing mechanisms related to aging in Chinese reading using co-registration, providing both neurophysiological evidence for oculomotor behavior and employing a more ecologically valid method that aligns with natural reading habits to explore EEG changes during reading. Investigating whether cognitive processing mechanisms undergo qualitative changes with age under natural conditions places this research at the forefront of lifespan developmental reading studies.

Second, the research creatively proposes that addressing this key question requires examining prediction error cost in older adults' reading, further investigating why reading cognitive mechanisms change dynamically from three perspectives: parafoveal visual processing, working memory integration ability, and language ability. This approach demonstrates strong innovation and pioneering spirit.

Third, the research innovatively employs data mining techniques using multicovariate modeling, survival analysis, and distribution analysis to propose how age-related visual and working memory declines interact with preserved language ability, examining their time courses and individual difference effects. By constructing a lifespan developmental model of Chinese reading, this research will ultimately provide reference for improving reading efficiency and spiritual-cultural life quality among Chinese older adults, effectively addressing population aging.

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Note: Figure translations are in progress. See original paper for figures.