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Word Integration Across Sentence Boundaries in Third and Fourth Age Adults: Evidence from Eye-Tracking during Reading

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Abstract

This study investigates how adults in the third (60–79 years) and fourth age (80+ years) integrate words across sentence boundaries during reading. Participants read two-sentence passages involving direct lexical repetition or bridging inferences. Both age groups exhibited longer reading times when bridging was required, showing that inference-making is still present despite potential cognitive declines. However, while third-age adults showed immediate sensitivity to inference demands, fourth-age participants demonstrated a delayed response, suggesting compensatory strategies. These findings highlight a key role for semantic knowledge in sustaining reading comprehension in old age. Future research with more diverse samples and longitudinal methods should clarify how age-related changes interact with linguistic resources. Interventions may target processing speeds to support reading comprehension in late adulthood.

Keywords: Reading comprehension, aging, inference making, eye tracking.

Introduction

Global population aging stands as one of the most significant demographic phenomena of the twenty-first century. Owing to medical, social, and economic advancements, life expectancy has climbed substantially across the globe, rising from an average of 46.5 years in the mid-twentieth century to about 66.0 years by the early 2000s (Mangoni, 2014; Vaupel et al., 2019). By the 2020s, life expectancy has continued to rise, reaching a global average of approximately 73.0 years as of 2023 (World Health Organization, 2023).

Critically, the fastest-growing segment of the older population comprises adults aged 80 and over, a shift that places heightened demands on healthcare systems, social services, and economies worldwide. Given these developments, it becomes increasingly important for current research and future scientific challenges to study not only the health-related dimensions of aging but also how cognitive abilities evolve in very late adulthood. Identifying factors that promote resilience and well-being during this stage of life should be a priority in future research.

A critical cognitive ability across the life cycle is reading comprehension. Indeed, it is an important component of functional literacy in older adulthood, supporting independence and overall quality of life (Martín-Aragoneses et al., 2023; Fitzhugh et al., 2019; Artuso & Belacchi, 2021; Jongman & Federmeier, 2021). In recent years, reading skills have gained even greater importance with the advent of new

technologies, such as artificial intelligence (AI), which require advanced linguistic and comprehension skills to navigate effectively. Older adults, who may already face challenges in adapting to rapidly evolving technology, are particularly impacted by this shift. Thus, a better understanding of the factors that influence reading comprehension abilities in older adulthood could help reduce the technological gap, empowering older adults to engage more fully with modern tools and platforms.

Within this demographic, researchers have recently distinguished between the “third age” (60–79 years) and the “fourth age” (80+ years). These groups differ significantly in cognitive and linguistic capacities, with the third age often characterized by higher levels of cognitive reserve and the fourth age associated with increased vulnerability to cognitive decline (Higgs & Gilleard, 2017; 2021; Rojas et al., 2023a, 2023b). Recent evidence suggests that while many older adults retain relatively strong reading comprehension abilities, those in the fourth age may experience pronounced declines. These declines are often attributed to sensory losses, slower processing speeds, and other age-related changes.

A recent study conducted by Riffo et al. (2024) offers valuable insights into age-related differences in reading comprehension. The authors carried out a cross-sectional examination comparing third- (60–79 years) and fourth-age (80+ years) adults, with the aim of contrasting reading comprehension performance between these groups and assessing how individual differences shaped groups’ results. Specifically, the study evaluated the effects of age group, sex, education level, reading habits, self-perceived reading skills, and cognitive measures (Mini-Mental State Examination and Montreal Cognitive Assessment).

Results indicated that, while older age predicted lower performance on reading tasks, strong reading habits emerged as a substantial protective factor, enabling some very old adults to maintain comparatively robust comprehension. Furthermore, the study highlighted a higher variability within the fourth-age than the third-age group, suggesting that health, schooling, and lifelong engagement in literacy may mitigate or exacerbate age-related declines.

Riffo et al. (2024) provided substantial evidence that reading comprehension tends to diminish among fourth-age adults relative to those in the third age. Nevertheless, to further clarify the mechanisms underlying these differences, it is necessary to investigate more fine-grained comprehension processes that occur during reading itself—

that is ‘online’ comprehension—rather than relying solely on ‘offline’ post-reading assessments.

During online reading, as comprehension unfolds, several component skills come into play (Gough & Tunmer, 1986; Oakhill et al., 2014; Scarborough, 2001). One of these fundamental processes is inference-making, which allows readers to bridge gaps in the text by connecting words and ideas to the preceding linguistic context. It has been proposed that bridging inferences (Singer & Ferreira, 1983) are essential for constructing a coherent mental model of the situation described in the text (Kintsch, 1998). Recent online word-to-text integration studies have provided robust support for these ideas, showing that readers actively integrate new information into their ongoing mental representations. Through this integration, they form bridging inferences that maintain coherence and enhance comprehension (Kintsch, 1998; Guerra & Kronmüller, 2020, 2024; Perfetti, 2012; Yang et al., 2007).

For instance, Guerra & Kronmüller (2020) investigated how readers handle discourse continuity by contrasting a “Repetition” condition—where a target word is repeated across sentences—with an “Inference” condition—where readers must infer the link between context and the target word across sentences boundaries without direct lexical repetition. Using a self-paced reading paradigm in adults, they observed a clear contrast in reading times: participants read more slowly when they had to generate bridging inferences (Inference condition) compared to when the same word was repeated (Repetition condition). Interestingly, vocabulary level had a modest but reliable impact, smoothing out the additional cost of inference-making, whereas other cognitive factors such as working memory and decoding did not significantly modulate this difference.

In a more recent study, the same design was applied in a larger sample of adolescents (Guerra & Kronmüller, 2024). Participants showed distinctly longer reading times in the Inference condition relative to the Repetition condition, highlighting the additional cognitive load of integrating lexical information across sentence boundaries in this population, as well. The authors also reported that vocabulary played a role in easing inferential processing. By replicating the fundamental pattern—slower reading for inference-based word integration—the study suggested that the burden of generating bridging inferences is consistent across developmental stages yet can be partially offset by robust lexical knowledge.

Building on these self-paced reading findings in adults and adolescents, it is reasonable to ask whether older adults exhibit a similar inference cost associated with online bridging inferences or whether they require a different cognitive mechanism for text comprehension. As individuals transition into the third and, particularly, the fourth age, they face potential declines in processes that sustain fluid intelligence, such as processing speed, working memory, and attentional control—factors that may amplify the cost of generating bridging inferences. However, older adults often benefit from enriched semantic networks and broader life

experiences, which can facilitate text integration through the maintenance of crystallized intelligence (Burke & Shafto, 2008; Rizzo et al., 2024). Thus, studying word-to-text integration in older populations may therefore shed light on how these contrasting factors interact during reading comprehension and influence cognitive strategies in late adulthood.

The present study

We adapted the word-to-text paradigm to an eye-tracking experiment and tested both third- (60–79 years) and fourth-age (80+ years) adults, using standard eye-movement indices to examine their real-time processing costs. Specifically, we collected first-pass reading times (the sum of all fixations on a word or region from first entry until exiting to the right), regression-path duration (including any regressive fixations back into the target region before participants’ gaze moved to the right of the word), and total reading times (the aggregate of all fixations on a region throughout the trial). These measures offer a fine-grained view of online reading behavior, capturing both initial lexical processing and any subsequent revisits that reflect integrative or corrective strategies (Rayner, 1998, 2009; Gordon et al., 2016).

We hypothesized that if cognitive processes supporting reading abilities change significantly after the age of 80—due to losses in fluid intelligence and increased reliance on crystallized intelligence—fourth-age adults would exhibit slower inference effects. Alternatively, if these abilities begin to decline, we would observe larger inference-related costs compared to their third-age counterparts.

Method

Participants A total of 150 monolingual older adults volunteered to participate in this research study. Recruiting people over the age of 60, particularly those over the age of 80, is challenging due to factors such as health problems, mobility limitations and availability constraints. Despite these difficulties, we successfully recruited 150 participants who met strict inclusion and exclusion criteria, consisting of 86 people in the third age group (60–79 years) and 64 people in the fourth age group (80+ years). Although larger sample sizes are generally advantageous to increase statistical power, studies focusing on these specific age groups often operate with smaller samples due to similar recruitment challenges (e.g., Martín-Aragoneses et al., 2023; Rojas et al., 2023a, 2023b).

Recruitment was carried out through the ‘*Más Adultos Mayores Autovalentes*’ program, sponsored by the Chilean government. The inclusion criteria for participation were as follows: participants must be 60 years of age or older, have at least six years of formal education, have normal (or corrected) hearing and vision, live in urban areas, and complete the reading comprehension task within a maximum of two weeks. To ensure the health status of participants, it was imperative that their medical records were up to date. Exclusion criteria were established to ensure the integrity of the study and included: a history of cerebrovascular disease,

a diagnosis of any neurodegenerative disorder, the presence of depression or other psychiatric illness, and a risk score on any of the following psychometric assessments: Mini-Mental State Examination (MMSE score < 23 points; Folstein et al., 1975), Montreal Cognitive Assessment (MoCA score < 21 points; Delgado et al., 2019), or Geriatric Depression Scale-15 (score > 11 points; Ortega et al., 2007). Approximately 210 older people were invited to participate in the study. The sample size was set at a minimum of 3000 data points. Among those who expressed interest, older adults who did not meet the inclusion and/or exclusion criteria were subsequently excluded from participation.

Prior to participation, all older adults were required to read and sign an informed consent form approved by the ethics committee of the sponsoring university. The aims and details of the study were communicated to the authorities of each participating senior citizens' club. Interested older adults underwent cognitive (MMSE and MoCA) and emotional (Geriatric Depression Scale-15) assessments. Finally, selected participants were invited to the university's specialized laboratory or the office of the program for independent living for older people to complete a reading comprehension test and a questionnaire on reading habits and self-perceived reading difficulties in older adults.

Materials & Design Following Guerra & Kronmüller (2024), we employed a set of 80 experimental two-sentence passages in Spanish. Each passage was constructed with the specific purpose of eliciting either a “Repetition” or an “Inference” condition (see table 1). In the Repetition condition, a critical word appeared both at the end of the first sentence and near the start of the second sentence, enabling direct lexical continuity. Conversely, in the Inference condition, the same concept had to be inferred: the critical word itself did not appear in the first sentence, requiring readers to bridge the second sentence back to an implied reference in the first. All passages were kept as short as possible—typically not exceeding 25 words in total—and were matched for syntactic complexity and lexical frequency to avoid unintended differences. The critical word consistently appeared as the second word of the second sentence, allowing us to capture clear eye-movement measures around word boundaries where inference-making was expected to be most salient. Alongside these experimental items, we included filler passages of similar length and style, interspersed throughout the trials to minimize predictability of the conditions.

We employed a within-subjects design similar to that of Guerra & Kronmüller (2024), with each participant reading both Repetition and Inference items in a randomized order. However, rather than administering a self-paced reading task, we used an eye-tracking protocol to gather continuous data on participants' reading behavior. Specifically, we recorded first-pass reading times (the sum of all fixations on the critical region before the gaze moved on), regression-path duration (capturing any immediate regressions into the critical region), and total reading times (the sum of all fixations over the entire

course of reading) for each sentence region. Participants completed practice trials to familiarize themselves with the procedure, followed by the experimental set and fillers in random order. By incorporating eye-tracking measures, we sought to capture the precise timing of inferential processing, expecting that Inference passages would elicit longer reading durations relative to Repetition passages, especially around the critical word. This paradigm was adapted to two age groups—third-age (60–79 years) and fourth-age (80+ years)—to investigate whether additional processing time and regressions would be particularly pronounced among older readers, thereby extending the findings of Guerra & Kronmüller (2024) to a sample of adults in advanced old age.

Table 1: Examples of experimental materials.

Condition	Example
Repetition	<i>“A medida que se acercaba al área rival, el delantero apuntó al arco y pateó el balón.”</i>
Inference	<i>“A medida que se acercaba al área rival, el delantero apuntó al arco y pateó.”</i>
Target	<i>“El balón fue golpeado tan fuerte que casi rompe la red.”</i>
English Translation: ‘As he approached the opponent’s area, the striker took aim at the goal and kicked / the ball. The ball was hit so hard that it almost broke the net’.	

Procedure Participants sat comfortably approximately 60–70 cm from the computer screen. We use an EyeLink 1000 system (SR Research) to record participants eye movements at a sampling rate of 500 Hz. Before the experiment began, a 9-point calibration and validation were performed to ensure accuracy. In addition, calibration was checked before each new trial block, and recalibrations were conducted if participants moved excessively or if the eye-tracking signal drifted.

Participants were asked to read each two-sentence passage for comprehension at a natural pace, with no additional secondary tasks. They were told, however, that occasional comprehension statements might appeared on-screen in True/False format, focusing on content from the preceding sentences; participants responded by pressing ‘p’ for true or ‘q’ for false. Upon finishing a passage, they pressed a spacebar on a keyboard to proceed with the next trial. At least three short breaks were offered during the session, allowing older adults sufficient rest to minimize fatigue. Overall, the procedure took around 30 minutes per participant.

Each list featured an equal number of inference-based and repetition-based passages, interspersed with fillers to reduce predictability. Specifically, if a given item appeared in the Inference condition in List 1, it appeared in the Repetition condition in List 2, ensuring that across participants, each item was read in both conditions. Sentences were presented one at a time, with the critical word consistently located at the start of the second sentence to isolate the bridging inference effect. Eye movements were recorded continuously throughout the experiment. After reading each passage (and providing a True/False response, if prompted), participants

progressed to the next item. All participants provided written informed consent before beginning the task and were thoroughly debriefed on the study's aims and procedures upon completion.

Data Analysis Following standard practices in eye-movement research (Rayner, 1998, 2009), we first merged contiguous fixations shorter than 80 ms if they fell within one character space of another fixation, treating them as part of a single continuous look. Any isolated fixations shorter than 80 ms that could not be merged, as well as fixations exceeding 1200 ms, were deleted from the dataset. For each stimulus passage, the region of interest was the second word of the second sentence (the “critical word”), which marked the point where either the Repetition or Inference manipulation took effect. Although we recorded eye movements across the entire passage, analyses here focus on first-pass reading time, regression-path duration, and total reading time within this critical region.

Prior to inferential tests, reading-time data for the critical region were log-transformed to address skewness and approximate a normal distribution. We then fitted linear mixed-effects regression models in the lme4 package of the R software, enabling us to include crossed random effects for participants and items (Baayen et al., 2008; Barr et al., 2013). We conducted separated regression analysis for each dependent variable and group. All models had the experimental condition (Repetition vs. Inference) as fixed effect. All random slopes justifiable by our design were included. We obtained p-values using the Satterthwaite approximation of the lmerTest package. This approach allowed us to systematically account for variability in reading times across participants and items.

Results

We fit separate linear mixed-effects models for each of the three eye-movement measures—first-pass reading time, regression-path duration, and total reading time—using

group (third- vs. fourth-age) and condition (Repetition vs. Inference) as fixed effects, with sum contrast coding for both factors.

First-Pass Reading Time The model revealed a significant main effect of condition (Estimate = -0.02846 , SE = 0.01246 , $t = -2.28$, $p = .0252$), indicating that participants, on average, read more slowly in the Inference condition relative to the Repetition condition. The main effect of group was marginal (Estimate = 0.12231 , SE = 0.06383 , $t = 1.92$, $p = .0602$). Crucially, the interaction between group and condition reached significance (Estimate = -0.04001 , SE = 0.01984 , $t = -2.02$, $p = .0480$), suggesting that the magnitude of the inference-related slowdown differed between third- and fourth-age adults.

Regression-Path Duration For regression-path duration, there was again a significant main effect of condition (Estimate = -0.04276 , SE = 0.01269 , $t = -3.37$, $p = .0013$), with Inference sentences eliciting longer regression paths than Repetition sentences overall. The main effect of group was not reliable (Estimate = 0.06767 , SE = 0.06566 , $t = 1.03$, $p = .3069$), and the interaction with condition approached but did not reach conventional significance (Estimate = -0.03661 , SE = 0.02100 , $t = -1.74$, $p = .0866$).

Total Reading Time Finally, total reading time showed a significant main effect of group (Estimate = 0.18571 , SE = 0.07246 , $t = 2.56$, $p = .0130$), indicating generally longer reading times among the fourth-age adults compared with the third-age group. Condition was also significant (Estimate = -0.04151 , SE = 0.01392 , $t = -2.98$, $p = .0041$), aligning with the pattern of slower reading in the Inference condition. However, the group $\times$ condition interaction was not significant (Estimate = -0.01961 , SE = 0.02396 , $t = -0.82$, $p = .4167$), implying that while older participants overall spent more time reading, the difference between Inference and Repetition conditions did not vary reliably by age group for total reading time.

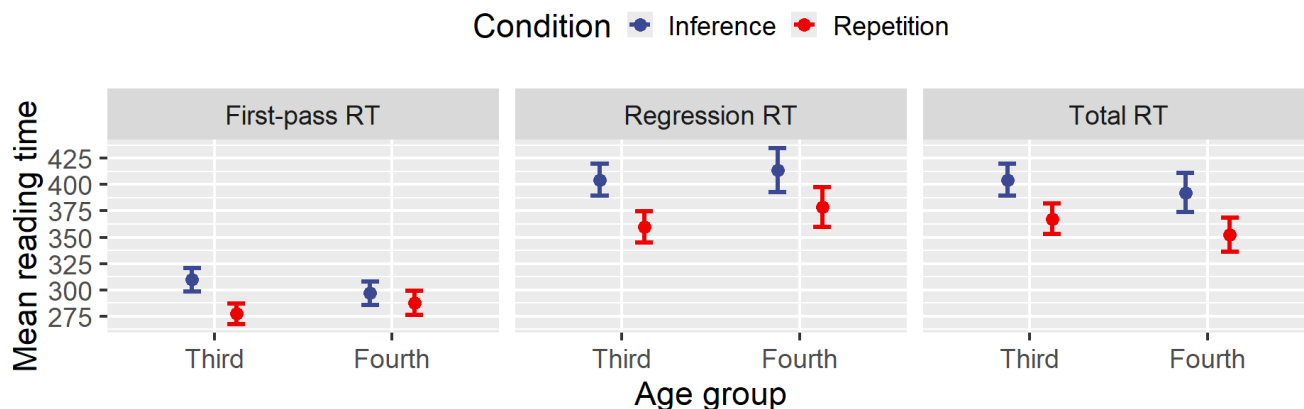


Figure 1: Mean reading times as a function of experimental condition (Inference vs. Repetition), Age group (Third- vs. Fourth-age) and reading measure (First-pass reading times, Regression path-duration, Total readings times). Error bars represent 95% confidence intervals adjusted for within-subject design.

Table 2. Summary of results from the regression models

Measure	Effect	β	se	t	p	
First Pass Reading Time	(Intercept)	5.5	0.0	156.2	0.001	***
	Group	0.1	0.1	1.9	0.060	#
	Condition	0.0	0.0	-2.3	0.025	*
	G $\times$ C	0.0	0.0	-2.0	0.048	*
Regression Path Duration	(Intercept)	5.8	0.0	155.3	0.001	***
	Group	0.1	0.1	1.0	0.307	
	Condition	0.0	0.0	-3.4	0.001	**
	G $\times$ C	0.0	0.0	-1.7	0.087	#
Total Reading Time	(Intercept)	5.7	0.0	142.1	0.001	***
	Group	0.2	0.1	2.6	0.013	*
	Condition	0.0	0.0	-3.0	0.004	**
	G $\times$ C	0.0	0.0	-0.8	0.417	

***= $p < .001$; **= $p < .01$; *= $p < .05$; #= $p < .1$

General Discussion

This study investigates how adults in the third (60–79 years) and the fourth age (80+ years) integrate lexical information across sentence boundaries while reading. Drawing on findings from previous online reading research (e.g., Guerra & Kronmüller, 2020, 2024) and recent work on reading in older adulthood (Riffo et al., 2024), we hypothesized that fourth-age adults would show different processing demands relative to third-age adults. Using eye-tracking reading measures, we tested whether advanced age would heighten the costs associated with bridging inferences compared to direct lexical repetition.

The results indicate that both age groups experience higher reading costs when bridging inferences are required compared to when lexical repetition is provided, suggesting that both groups engage in inferential processing during reading. However, the temporal dynamics of these costs differed. The third-age group showed early sensitivity to inference-making (in first-pass), suggesting immediate word-to-text integration through bridging inferences (Guerra & Kronmüller, 2024; Perfetti, 2012; Yang et al., 2007). This sensitivity persisted across later measures, indicating sustained engagement with the text and the maintenance of coherence throughout the reading process. In turn, the fourth-age group exhibited a delayed effect, appearing only in later reading stages (particularly in total reading times). This delay suggests that while fourth-age adults engage in inferential processing, they may require more time to integrate new information into their mental model of the text. This might reflect a less immediate or less efficient online integration. Such findings converge with earlier accounts of age-related slowing in cognitive functions (Burke & Shafto, 2008; Schubert et al., 2020) yet also underscore older readers' capacity to adapt their reading strategies given sufficient time.

From a theoretical perspective, these findings refine our understanding of aging and discourse processing by revealing that the mechanisms of bridging inference are present even in very advanced old age, albeit with slower deployment. As processing speed and memory declines (Burke & Shafto, 2008; Lindenberger, 2014; Klencklen et al., 2017), older readers do not appear to engage in immediate inference-making; instead, they appear to reach comparable comprehension outcomes through extended processing epochs. This aligns with claims that older adults retain expansive semantic knowledge bases, which can compensate for diminished speed and working memory (Stine-Morrow et al., 2016; Riffo et al., 2020). Consequently, discourse comprehension theories must account for such compensatory mechanisms, emphasizing the continuing role of inference-making beyond the typical “young–old” comparisons more common in the literature.

These results support and extend cognitive-reserve and discourse-processing models by demonstrating that even fourth-age readers deploy inference mechanisms that capitalize on crystallized semantic knowledge to offset declines in processing speed and working memory. Riffo et al. (2024) showed that sustained reading practices in older adults buffer against cognitive decline, indicating that robust semantic reserves facilitate the construction of situation models despite slower online processing. Likewise, Guerra and Kronmüller (2020) found that vocabulary richness directly modulates the speed of word integration in bridging inferences, implying that high-quality lexical representations underpin inferential comprehension. Consistent with this, Guerra and Kronmüller (2024) reported in adolescents that extensive vocabulary not only accelerates overall reading but also reduces the cognitive cost of generating real-time inferences. Together, these findings underscore the central role of semantic reserves as compensatory mechanisms in aging and call for processing theories that explicitly integrate interactions among speed, working memory, and prior knowledge.

Practically, our results underscore the importance of designing reading materials and interventions that consider slower initial processing. Interventions might incorporate staggered presentation of new information or embedded cues to assist in bridging textual gaps. Educational programs or cognitive training for older adults could focus on fostering active inference strategies, allowing fourth-age readers to leverage their semantic and experiential knowledge. Such strategies might offset age-related declines in processing speed, ultimately supporting functional literacy and maintaining engagement in daily tasks that rely on comprehension including the interactions with novel technologies such as AI.

Some limitations are worth noting. First, our sample, while representative of individuals who self-select for reading studies, may exclude less literate or less cognitively intact older adults. Future work should incorporate more heterogeneous samples to generalize the findings beyond relatively healthy readers. Second, the cross-sectional design

offers only a snapshot of age-related differences, leaving open questions about whether changes in reading profiles reflect individual aging trajectories. Third, we focused on a single aspect of inferential processing—bridging words—whereas text comprehension involves multiple layers of inference, including predictive and elaborative processes.

Further research might expand to additional inference types or examine interactions with vocabulary, memory span, and executive control. Similarly, longitudinal designs that track individual participants over time could clarify the developmental pathways that lead some older adults to retain near-full reading efficiency and others to experience sharper declines. Moreover, integrating more sensitive neurocognitive measures (e.g., event-related potentials) could offer deeper insight into how inferential processes unfold moment to moment. By further dissecting the interplay between maintained semantic knowledge and decreased speed, researchers and practitioners can foster strategies to bolster text comprehension throughout later life.

Several limitations of the present study suggest avenues for future work. Incorporating neurophysiological measures (e.g., ERP) would enable a finer-grained mapping of the temporal dynamics underlying inference generation and yield direct evidence of compensatory activation in older readers. Moreover, extending the investigation to include predictive and elaborative inferences—beyond the bridging inferences examined here—would clarify whether the observed slowdown in the fourth-age group reflects a process-specific effect or a general inferential delay. Finally, a longitudinal design tracking the same participants as they transition from the third to the fourth age cohort would illuminate how semantic reserves and reading strategies evolve over time and inform the development of targeted interventions to support comprehension in advanced age.

Conclusion

Our findings provide evidence that older adults remain capable of drawing bridging inferences to maintain coherence during reading, despite age-related changes in processing speed and potential declines in working memory. The fact that fourth-age readers displayed a delayed but still successful inferential process underscores the resilience of semantic and experiential knowledge in supporting comprehension, even in advanced old age. Our results suggest an interplay of compensatory strategies and aging, likely to be linked to changes in both fluid and crystallized intelligence in late adulthood. These insights may inform future research on discourse processing in aging populations, as well as the development of targeted interventions to sustain reading comprehension. Ultimately, our results add to the growing literature that views aging not solely through the lens of inevitable decline, but rather as a dynamic phase in which older adults adapt their cognitive strategies to maintain coherent text understanding.

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