

Inhibitory Control Processes and Their Impact on Reading Comprehension and Speed in Older Adults: A Preliminary Analytical Cross-Sectional Study

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Original Article

Abstract

Introduction: Grounded in Inhibition Theory, many age-related cognitive challenges – including text comprehension errors – are attributed to the deficient inhibition of irrelevant information. While this deficit is known to be more pronounced in older adults, few studies have exclusively compared reading comprehension and speed between younger and older populations under identical inhibitory conditions. This study aimed to investigate the impact of semantic interference on reading performance across these two age groups.

Materials and Methods: In this non-interventional analytical cross-sectional study, a total of 70 participants comprising 35 older adults (17 women and 18 men, with a mean age of 63.11 ± 3.63 years) and 35 younger adults (19 women and 16 men, with a mean age of 31.08 ± 6.31 years) were selected using a non-random convenience sampling method and participated in the research. To evaluate inhibitory processing, participants were presented with a translated version of Rainbow Passage along with two types of interfering words in three assessment situations: a control condition, a condition containing semantically related distractors, and a condition with semantically unrelated distractors. Reading speed (words per second) and text comprehension were assessed across these three assessment conditions. To compare reading speed and comprehension, the two-way multivariate analysis of variance (MANOVA) test was used at a significance level of 0.05.

Results: Multivariate analysis revealed significant differences in reading speed and comprehension between the two groups, with younger adults consistently outperforming the elderly. In the older adult group, the lowest mean reading speeds were associated with texts containing semantically related distractors, whereas the lowest comprehension scores were observed in the presence of unrelated distractors.

Conclusion: Findings suggest that aging is associated with a significant decline in inhibitory control. Specifically, semantically unrelated distractors appear to deteriorate reading comprehension, while related distractors primarily impede reading speed in older adults. These results highlight how the semantic nature of interfering information selectively impacts different dimensions of linguistic processing in the aging brain.

Keywords: Inhibition; Comprehension; Reading speed; Younger adults; Elderly

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Introduction

Aging represents a critical period of human development, where addressing its specific requirements is a societal imperative. Given the rising geriatric population, there is a global shift toward

improving quality of life (1). During the course of healthy aging, several communication modalities, language proficiencies, and cognitive functions are subject to change (2).

In addition to disorders such as Dementia or Mild

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Cognitive Impairment (MCI), age-related cognitive changes often occur in healthy individuals as well (3). These changes typically emerge in late life and are attributed to a progressive decline in information processing mechanisms (4). Cognition, cognitive changes, and their associated factors are of paramount importance for two main reasons: first, they can significantly impact the daily functioning of older adults; and second, they play a crucial role in differentiating between normal aging and pathological conditions (5, 6).

A definitive theory to justify the underlying causes of linguistic and cognitive changes in the elderly has yet to be established; however, the Inhibition Theory remains one of the prominent frameworks in the field of geriatric cognition (7). Inhibition is a core aspect of cognitive and emotional functioning, involved in various tasks and processes (8). Some scholars regard inhibition as a domain-general process in which inhibitory control serves as the voluntary suppression of information, preventing the processing of distracting data through interference control (9). The inhibitory process is essential for thoughts, verbal responses, visual processing, auditory stimuli, actions, and semantic processing. Consequently, inhibitory deficits lead to increased processing time and a diminished capacity for recognition and mental rehearsal in healthy older adults (10).

The Inhibition Deficit Hypothesis suggests that older adults exhibit weaknesses in inhibitory processes, specifically in suppressing irrelevant information, a function that is significantly less efficient compared to younger individuals (11). In these individuals, the presence of interfering factors and the failure to inhibit them can adversely affect mental rehearsal capacities (12). According to research, when examining attention-related errors, 24% of errors in healthy older adults and 67% of errors in individuals with Alzheimer's disease are attributed to a decline in inhibitory processes (13).

During the aging process, the decline in inhibitory phenomena is not generalized but rather highly selective, with distinct neural pathways being activated for each type (14, 15). From a neurological perspective, research indicates that inhibitory processes are associated with neural control systems, particularly within the prefrontal regions, the subthalamic nuclei, the inferior frontal gyrus of the right hemisphere, and the pre-supplementary motor area (16).

Neuropsychological and behavioral evidence consistently indicates that inhibitory control deficits are prevalent in older adults, young children, and individuals experiencing fatigue or emotional stress. Three primary functions have been attributed to this

mechanism: 1) controlling access to the focus of attention; 2) deleting and suppressing irrelevant information from attention and working memory; and 3) inhibiting prepotent/inappropriate responses (17).

In cognitive science, inhibitory control is considered a fundamental mechanism essential for the regulation of thoughts, actions, and memory operations (18). Furthermore, regarding age-related cognitive changes, memory impairment is a pervasive issue; one prominent theoretical explanation for this decline is the dysfunction of inhibitory control (19). Impaired inhibition leads to attenuated selective attention and working memory capacity, subsequently resulting in less effective encoding and retrieval strategies. The inhibitory process serves a crucial regulatory role, gating the flow of information entering and exiting working memory. Consequently, in older adults, the inefficiency of these inhibitory processes prevents the clearance of irrelevant information from working memory, thereby generating significant interference (20).

Current research conceptualizes inhibition as a memory-linked process, identifying three primary inhibitory functions during information processing: 1) access inhibition, which precludes the entry of irrelevant information into the focus of attention; 2) deletion inhibition, whereby irrelevant or no-longer-relevant information is suppressed and removed; and 3) prevention inhibition, in which prepotent responses triggered by familiar cues are withheld to prevent their execution (21). A prominent paradigm for investigating the impact of inhibition on memory is Retrieval-Induced Forgetting (RIF). In these tasks, specific information must be maintained in memory for subsequent retrieval. Evidence suggests that inhibitory capacities exert a direct influence on the ability of healthy older adults to effectively regulate memory content and information (22-24).

Inhibitory dysfunction in older adults is evident across various domains, including perception, language, and motor processing, as well as in the suppression of visual distractors during reading (25). Such inhibitory deficits account for numerous perceptual impairments in the elderly; for instance, older adults exhibit greater perceptual difficulties in the presence of background noise, distractors, or phonological similarity between words (26).

In language comprehension, the inhibitory process serves two pivotal roles: 1) gating inappropriate information to prevent its entry into working memory, and 2) deactivating irrelevant or redundant information that has been sustained in working memory. According to this perspective, the activation of irrelevant information interferes with the processing of relevant data, thereby compromising comprehension (27).

This framework also extends to language production deficits; for example, older adults tend to produce more off-topic or irrelevant information (28). Research suggests that difficulties encountered by the elderly with low-frequency words or words with high lexical neighborhood density stem from an inability to inhibit high-frequency words or phonologically similar competitors, leading to processing bottlenecks. Ultimately, the failure to inhibit distractors and superfluous information impairs accurate processing and the execution of diverse tasks (29). Consequently, a decline in processing resources—characterized by reduced working memory capacity, diminished processing speed (defined as the rate of cognitive operations and motor responses, which begins to decline in the third decade of life), and impaired inhibitory control—collectively explains the shifts in expressive language throughout the aging process (29-31).

In light of various causal factors, inhibitory decline in healthy older adults is characterized by diminished performance on *Stroop tasks and negative priming paradigms, prolonged reaction times when presented with irrelevant stimuli—particularly as distractor density increases—and reduced flexibility in acquiring new task rules compared to younger cohorts. Furthermore, increased interference from irrelevant information during text perception and a diminished capacity to inhibit overlearned/well-established responses in favor of novel response patterns further exacerbate inhibitory failures and cognitive interference (32).

Inhibitory deficits are also manifest in the early stages of Alzheimer's disease (AD) (33, 34). Evidence from studies analyzing error patterns, word reading, and selective attention in individuals with early-stage dementia indicates that irrelevant information significantly interferes with information processing. This leads to the perseveration of responses and the occurrence of intrusion errors (characterized by the failure to produce the target word and its substitution with a synonym or related item), both of which are attributed to compromised inhibitory control (35).

Given the aforementioned considerations and the burgeoning elderly population, there is a critical need to investigate the factors affecting communicative competence and quality of life in this cohort. Identifying factors that contribute to cognitive decline is of paramount importance, as these may serve as precursors to the early diagnosis of Alzheimer's disease. Early screening and timely diagnosis can substantially mitigate treatment costs and enhance the quality of life for older adults (36, 37).

Current literature indicates that inhibitory processes have been extensively studied within the domains of

memory—specifically working memory—and attentional tasks (38-40). However, although inhibitory control is vital for auditory comprehension and daily interpersonal interactions requiring high-level information exchange, it has been relatively under-investigated in language processing, particularly language comprehension. To the best of the researcher's knowledge, only two studies have explored the effects of inhibition on comprehension (33, 34). One study focused on the impact of interfering factors on sentence comprehension, while the other examined text comprehension; notably, both were conducted on patients with Alzheimer's disease and did not provide a direct comparison between younger and older adults.

Investigating this phenomenon in younger populations is equally essential, as evidence suggests that the decline of certain cognitive processes, such as processing speed, commences as early as the third decade of life (41). It is highly probable that inhibitory functions follow a similar trajectory. Therefore, the present study aims to compare younger and older adults while also conducting an intra-group analysis within the younger cohort to provide preliminary evidence regarding the presence or absence of inhibitory deficits. This will elucidate whether inhibitory decline, like other cognitive processes, begins in early adulthood.

Furthermore, the precise impact of distractors with varying levels of complexity during reading tasks on inhibitory control remains poorly understood. This study employs text reading and comprehension tasks, as research indicates that these paradigms are the most effective for evaluating inhibitory control. Such tasks allow for the simultaneous integration of multiple interfering variables—including semantic, lexical, orthographic, and visual factors—at varying levels of difficulty (34).

Consequently, the present study compares inhibitory processes in younger and older adults during reading tasks, while simultaneously examining their impact on text comprehension. Given that—to the best of the researcher's knowledge—no prior domestic or international studies have addressed this specific intersection, this research aims to elucidate the relationship between inhibitory control, text comprehension, and reading speed across both younger and older populations.

Materials and Methods

Participants: A total of 35 older adults (aged 60-79 years) and 35 younger adults (aged 20-39 years) volunteered to participate in this study. Participants were categorized into three educational levels based on the Iranian educational system: primary education (8 years), high school diploma (12 years), and higher

education (more than 13 years). The two groups were matched based on their educational background. Given the potential influence of education on the assessed variables, a statistical comparison was conducted, which revealed no significant difference between the two groups ($P > 0.05$). All participants were native speakers of Persian and reported no history of hearing or visual impairments, cognitive disorders, brain injury, or psychiatric conditions. At the outset, all participants provided written informed consent, as approved by the Ethics Committee of Isfahan University of Medical Sciences. The demographic characteristics of the participants are summarized in Table 1.

Instrumentation and Procedure: "To investigate inhibitory effects in both older and younger adults, the Persian version of the 'Rainbow Passage' was utilized. This passage consists of seven sentences and is the Persian equivalent of the original Rainbow Passage, adapted to align with the phonological and linguistic features of the Persian language. The text comprises 92 words and 207 syllables (42). The topic was selected to be culturally and socially neutral to ensure consistent reading patterns across all participants.

In the first assessment session, a printed version of the passage was presented to the participants in an appropriate font size, without any distractors. Participants were instructed to read the text aloud while their voices were recorded; subsequently, comprehension questions were administered. After a two-week interval, the participants performed the second assessment. In this stage, two modified versions of the Rainbow Passage were presented. One version contained 18 semantically related words, and the other included 23 unrelated words, serving as interfering distractors to activate the inhibitory system. These distractors were embedded within the text at intervals of one to six words, distinguished from the main text by a different font format. Participants were required to reread the passage while actively ignoring and inhibiting the irrelevant words.

Each of the three text conditions was accompanied by six comprehension questions. Consequently, inhibitory control was evaluated across three distinct conditions: the control text, the text containing semantically related distractors, and the text containing unrelated distractors. The interfering words, phrases, and comprehension questions were developed with the assistance of two linguists. These distractors were

embedded within the text at intervals of one to six words, distinguished by a different font and color.

To ensure the validity of the materials, the two versions containing distractors and the associated comprehension questions were pilot-tested on ten healthy individuals (mean age: 61.75 years for the older group and 30.20 years for the younger group) who did not participate in the subsequent stages of the study. Following this, the two linguists reviewed all items, and six questions were finalized for the final version of the texts. The assessment procedure consisted of three stages: the baseline control stage, followed by the related-distractor condition, and concluding with the unrelated-distractor condition. The experimental flow is illustrated in Figure 1.

"Participants were evaluated individually. Each text was presented to the participants, and they were instructed to read it aloud once to become familiar with the material, as the study specifically aimed to assess reading speed and comprehension during oral reading. Subsequently, they responded to the examiner's questions. A score of one was assigned to each correct answer and zero to each incorrect response; the total comprehension score for each individual was derived from the sum of these points. During the task, each participant's voice was recorded using Praat software to determine the exact onset, offset, and total duration of the reading. To calculate reading speed, the total number of words read was divided by the time elapsed, and the result was expressed as words per minute (WPM). This process was conducted by two researchers, achieving an inter-rater reliability of over 95%.

All statistical analyses were performed using IBM SPSS Statistics (version 23). A two-way multivariate analysis of variance (MANOVA) was employed to compare reading speed and comprehension across the three text conditions and between the two age groups (younger vs. older). For tests involving a single outcome variable, a two-way ANOVA was used. Furthermore, Duncan's post-hoc test was applied for pairwise comparisons of the means. The significance level for all tests was set at $p < 0.05$.

Results

The mean scores for text comprehension and reading speed across the different assessment conditions for each group are summarized in Table 2.

Table 1. Demographic characteristics of the participants, categorized by age group

Participants group	Age (years)	Sex [n (%)]		Education [n (%)]		
		Male	Female	Elementary	Diploma	Higher education
Elder Group	63.11 ± 3.22	18 (51.4)	17 (48.6)	9 (25.7)	11 (31.4)	15 (42.9)
Young Group	31.08 ± 6.36	16 (45.7)	19 (54.3)	6 (17.1)	10 (28.6)	19 (54.3)

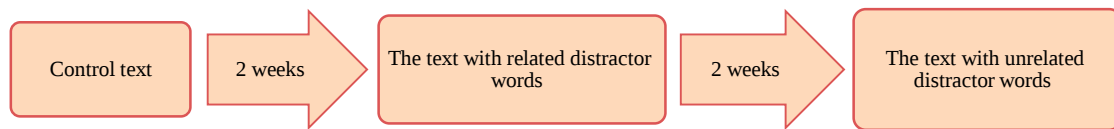


Figure 1. Sequences of experimental phases

The MANOVA results revealed a significant interaction effect between Group $\times$ Text Type on reading speed and text comprehension (Wilks' $\Lambda = 0.954$, multivariate $\eta^2 = 0.469$, $P = 0.047$). Further analysis using a 2 (Group) $\times$ 3 (Text Condition) ANOVA for reading speed (words per second) showed a significant main effect for Group ($F_{(1,204)} = 232.607$, $\eta^2 = 0.469$, $P < 0.001$), indicating that reading speed significantly decreases with age (Mean = 147.85 for the younger group vs. Mean = 118.42 for the older group). However, the main effect of Text Type (control, semantically related distractors, and unrelated distractors) was not significant ($F_{(2,204)} = 3.027$, $\eta^2 = 0.029$, $P = 0.051$), and reading speed did not differ significantly across the control, related, and unrelated conditions ($M = 133.63$, $M = 129.48$, and $M = 136.04$, respectively). Additionally, there was no significant *Group $\times$ Text interaction for reading speed ($F_{(2, 204)} = 0.717$, $P = 0.489$), suggesting that the reduction in reading speed was solely attributable to age rather than the type of text.

Regarding text comprehension, the 2 $\times$ 3 ANOVA revealed significant main effects for both Group ($F = 63.475$, $\eta^2 = 0.237$, $P < 0.001$) and Text Type ($F_{(2, 204)} = 12.906$, $\eta^2 = 0.112$, $P < 0.001$). Overall, comprehension scores decreased with age (Mean = 4.27 for younger adults vs. Mean = 2.89 for older adults). Furthermore, comprehension scores differed significantly across text conditions ($M = 4.15$ for control, $M = 3.51$ for related, and $M = 3.08$ for unrelated distractors). The highest mean comprehension scores were observed in the control condition, while the lowest scores were associated with the text containing semantically unrelated distractors. Notably, a significant Group $\times$ Text interaction was observed ($F(2, 204) = 3.916$, $\eta^2 = 0.037$, $P = 0.021$), indicating that the decline in text comprehension is a function of both age and text

type. Post-hoc analysis revealed that the lowest mean comprehension score belonged to the older group in the unrelated distractor condition (Mean = 2.057). Finally, results showed that text comprehension in the younger group did not vary significantly across the three text conditions ($P = 0.181$).

Discussion

The growth of the elderly population is a global phenomenon. Consequently, Speech-Language Pathologists (SLPs) must possess comprehensive knowledge regarding this demographic and their challenges across various linguistic domains, including speech production and comprehension (43). While inhibitory control significantly influences auditory comprehension—a vital component of daily interactions and information exchange requiring high levels of understanding (44)—inhibitory deficits in certain areas of language processing, particularly comprehension, have been somewhat overlooked. This study aimed to provide evidence regarding the relationship between inhibitory processes, reading speed, and text comprehension in both younger and older adults.

Our findings indicate that aging significantly affects inhibitory control, text comprehension, and reading speed. When interfering distractors are introduced, the ability of older adults to suppress irrelevant information diminishes. These results suggest that elderly individuals exhibit more pronounced inhibitory deficits, failing to suppress distractors effectively. Consequently, this irrelevant information interferes with their working memory, leading to a decline in reading proficiency. This is consistent with the findings of Amieva et al. (19), who reported that inhibitory deficits in older adults lead to impaired language comprehension during reading. Similarly, our results align with Connelly et al. (46), who demonstrated lower reading speed and comprehension in the elderly.

Table 2. Mean scores for reading speed and text comprehension, categorized by age group

Text type	Variables					
	Reading Speed (word per second)			Reading Comprehension		
	Young Adults	Older Adults	Total	Young Adults	Older Adults	Total
Text 1 (control)	149.61	122.47	136.04	4.62	3.68	4.157
Text 2 (related distractor)	146.11	112.84	129.48	4.08	2.94	3.514
Text 3 (unrelated distractors)	147.85	119.42	133.64	4.11	2.05	3.085
Total	147.85	118.24	-	4.27	2.89	-

Table 3. Results of MANOVA and ANOVA 2 (Group) $\times$ 3 (Text)

Source	Dependent Variable	F	P-value	Eta Squared
Group	Speed & Comprehension	F=104.66, (Λ =0.492)	< 0.001	0.508
Text		7.528, (Λ =0.867)	< 0.001	0.068
Group * text		2.431, (Λ =0.954)	0.047	0.023
Group	Reading speed	180.404	< 0.001	0.469
	Comprehension	63.475	< 0.001	0.237
Text	Reading speed	3.027	0.051	0.029
	Comprehension	12.906	0.000	0.112
Group * text	Reading speed	0.717	0.489	0.007
	Comprehension	3.916	0.021	0.037

Deaton et al. (47) also found that age-related declines in inhibitory processes result in lower comprehension scores due to increased error rates.

According to ERP studies investigating N400 waves, semantic processing in older adults is disrupted by interfering factors, thereby altering their comprehension (48). From a neuroanatomical perspective, aging is associated with structural changes in regions such as the prefrontal cortex, subthalamic nuclei, inferior frontal lobe, and the supplementary motor area (SMA), all of which play critical roles in inhibitory processes. A reduction in cellular and synaptic volume within these regions can lead to inhibitory deficits, ultimately impacting reading speed and comprehension. Conversely, younger adults, who have not yet undergone such structural brain changes, exhibit superior performance in comprehension and reading tasks that require high levels of inhibitory control (49, 50).

Consequently, it can be inferred that structural brain changes in the elderly may be a primary factor contributing to the decline in reading performance. Another objective of the present study was to examine the impact of inhibitory processes by presenting control texts, texts with unrelated distractors, and texts with related distractors. Accordingly, in younger adults, reading speed remained consistent across both control and distractor conditions; however, their comprehension scores decreased in the presence of both related and unrelated distractors. This suggests that inhibitory control in younger individuals remains precise and has not yet undergone significant age-related degradation. According to Deaton (47), while the processing of inhibitory or distracting information may appear similar across age groups, younger adults maintain a superior ability to distinguish between information sources (target vs. distracting information) during comprehension.

In contrast, older adults exhibited significantly lower comprehension scores in the presence of unrelated distractors and slower reading speeds in the presence of related distractors compared to their

younger counterparts. One explanation for this finding is that during text comprehension, a higher density of irrelevant information increasingly disrupts the retrieval of relevant data (33). In other words, according to *Inhibition Theory, the inhibitory process in older adults is compromised; thus, in texts containing unrelated distractors, irrelevant information infiltrates working memory, subsequently interfering with the accurate processing required for comprehension.

During the comprehension process, a competition occurs between correct (relevant) and incorrect (irrelevant) information, potentially leading to the selection of incorrect data. Numerous models of language comprehension focus on the online regulation of information, where inhibitory and facilitatory mechanisms modulate how information is activated, thereby explaining the underlying processes of language understanding (51, 52). Individuals with lower comprehension potential struggle to suppress irrelevant information because they fail to effectively utilize contextual cues to enhance understanding (32).

Regarding reading speed, as opposed to comprehension, semantically related distractors significantly increased the time required for reading in older adults, thereby reducing their overall reading speed. This may be attributed to the fact that semantically related words share semantic nodes. When target nodes are activated, related nodes are simultaneously triggered—a process that increases processing time and subsequently impacts reading speed. Connelly similarly demonstrated that reading time is more substantially affected when factors semantically related to the text are present, leading to a marked decrease in reading speed (53).

Limitations

The primary limitation of this study was the relatively small sample size. Based on power analysis using GPower software**—assuming an effect size of 0.5, an alpha level of 0.05, and a power of 80%—the required sample size was calculated to be 64

participants per group. However, due to the protracted duration of the study and challenges in recruiting elderly participants, the sample was limited to 35 individuals per group. Therefore, the findings of this study should be interpreted as preliminary. Another notable limitation was the discrepancy in the number of related and unrelated distractors, which resulted in an unequal total word count across the three experimental texts."

Recommendations

Future research should involve larger sample sizes to enhance the generalizability of the findings. Additionally, it is suggested that working memory be formally assessed to explore the complex interplay between working memory capacity, text comprehension, and reading speed across control, related, and unrelated distractor conditions."

Conclusion

In summary, it can be concluded that inhibitory control remains precise in younger adults, meaning that the presence of distractors does not significantly alter their reading speed. In contrast, aging is associated with a decline in inhibitory performance. Specifically, the presence of semantically unrelated distractors tends to impair text comprehension, while semantically related distractors primarily impact reading speed. Thus, the semantic nature of the information embedded within a text significantly influences the reading speed and comprehension performance of older adults.

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Authors' Contribution

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Conflict of Interest

The authors did not have a conflict of interest.

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