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| RESEARCH ARTICLE

Unraveling Age-Related Declines in Syntactic Processing: Insights from Research

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| ABSTRACT

As the field of gerolinguistics receives increasing attention, research on language in older adults has expanded globally. This article explores the complexity of syntactic processing in older adults, examining studies related to language comprehension and production in the elderly. With aging, the brain undergoes a trend of developmental decline, resulting in structural changes, particularly in key regions involved in language processing. While some studies indicate that syntactic processing remains relatively intact with age, others suggest declines in performance, including slower response times and increased error rates. Methodological advances using functional magnetic resonance imaging (fMRI) and event-related potentials (ERP) have revealed the neural substrates underlying age-related changes in syntactic processing. Despite facing numerous challenges, compensatory mechanisms play a significant role in maintaining language comprehension in older adults. The article concludes by outlining future research directions, emphasizing the necessity of interventions to enhance syntactic processing abilities in older adults. By employing interdisciplinary approaches and advanced neuroimaging techniques, researchers can better understand the dynamic nature of language processing across the lifespan, ultimately contributing to promoting healthy cognitive aging and improving the quality of life for older adults.

| KEYWORDS

Older adults, aging effect, syntactic processing.

| ARTICLE INFORMATION

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1. Introduction

The aging of the population has brought significant pressure on various aspects of society, including social, medical, and financial domains. Consequently, research on the elderly has seen substantial growth worldwide. Since Cohen (1979) first introduced the concept of "gerolinguistics," studies on the language of the elderly have rapidly expanded. Domestic and foreign scholars have carried out a lot of research on language and cognitive aging, semantic processing, and related topics. As individuals enter the aging stage, the brain undergoes a "development-decline" trend. Normal aging results in gradual shrinkage of the brain volume (this shrinkage occurs in the cerebral cortex), the contraction of the hippocampus, the reduction of brain volume, and other changes, especially the changes in the frontal lobe and the medial temporal area. (Raz, 2004). While aging leads to brain atrophy and various neurophysiological changes, it also impacts language-dependent brain regions and basic cognitive abilities such as information processing speed, attention processes, and inhibition control. Research has found that syntactic processing is believed to involve the perisylvian regions of the left hemisphere, including the left inferior frontal gyrus (IFG), left middle temporal gyrus (MTG), and posterior regions such as the angular gyrus and inferior parietal lobule (Dronkers et al., 2004.) Building of automatic phrase structures, and processing of syntactically complex sentences are supported by two different neural networks. Local phrase structure building involves a frontotemporal network connecting the anterior temporal lobe and the frontal operculum via the ventral pathway including the uncinate fascicle (UF), whereas the processing of complex hierarchical syntactic structures involves a network connecting the posterior portion of Broca's area (BA 44), to the posterior temporal lobe via a dorsal pathway including the superior longitudinal fascicle (SLF) and the arcuate fascicle (Friederici et al., 2005). The involvement of Broca's area, in particular

BA 44, and the posterior temporal cortex for the processing of complex sentences has been shown in a number of studies. Interestingly, older individuals often exhibit stronger knowledge and vocabulary, providing them with an advantage in constructing mental representations (Madden and Dijkstra, 2010). However, in terms of semantic processing, behavioral and neural results showed that the semantic processing of the elderly showed a declining trend. That is, previous research has found that semantic processing shows an age-related decline. However, whether syntactic processing declines with age in the same way semantic processing does is controversial; this paper aims to delve into the syntactic abilities and processing of the elderly, exploring scholars' research on language processing among older adults. Through this exploration, a deeper understanding of how aging impacts language processing, particularly syntactic abilities, can be gained.

2. Older Adults Maintain Syntax Processing Abilities

Some studies indeed indicate that the syntactic processing in older adults is comparable to that of younger individuals. There are two explanations: first, the neurological system in older adults has not deteriorated; second, the elderly brain has undergone neural compensation.

2.1 Preservation of the Elderly Neurological System

Syntactic processing, often conceptualized as an input process operating in a "modular" fashion, has been traditionally considered immune to the effects of aging, according to seminal works by Fodor (1983) and Frazier (1987), as well as arguments put forth by Caplan and Waters (1999). Some studies indeed suggest that syntactic processing performance between elderly and young individuals is comparable, potentially indicating preserved neurological system function in older adults. Campbell and colleagues (2016) adopt a systems-level perspective to dissect processes specific to language comprehension from those related to general task demands while examining age differences in functional connectivity within and between these systems. Using functional magnetic resonance imaging (fMRI), subjects spanning ages 22 to 87 engaged in natural listening and explicit task versions involving sentence comprehension. Independent components analysis revealed that while task-free language comprehension activated auditory and frontotemporal (FTN) syntax networks, performing a simple task with the same sentences recruited additional networks. Importantly, FTN functionality remained consistent across age groups, with no differences in within-network connectivity or responsivity to syntactic processing demands, despite age-related gray matter loss and reduced connectivity to task-related networks. This suggests no evidence for reduced specialization or compensation with age, with overt task performance maintained across the lifespan. The syntactic ability of older people to produce language has also been studied. Glosser and Deser (1992) found that middle-aged adults (ages 43-61) and older adults (ages 67-88) showed no significant differences in the complexity of syntax and the number of syntactic omissions (such as subjects, main verbs, function words, and grammatical morphemes), despite a non-significant decreasing trend in complexity with increasing age. Bates and colleagues (2014) provided evidence regarding the impact of normal aging on complex syntax. The study found no significant differences between older and younger individuals, although older adults do tend to produce fewer complex structures overall. Older adults prefer using two separate sentences, while younger individuals tend to utilize shorter but more complex syntactic structures. However, no differences were observed between older and younger individuals in terms of syntactic diversity and the fit between grammar and discourse. Although older adults produce fewer complex syntactic structures, their ability to use these structures correctly is as strong as that of younger individuals. Therefore, research suggests that aging may be associated with reduced accessibility to structures that are less frequent or more complex.

2.2 Neural Mechanisms and Compensation in Syntactic Processing

However, more research has found that although older people perform as well as younger people, this is because older people use potential compensatory mechanisms to compensate for syntactic processing. Kemmer and colleagues (2004) explored age-related changes in simple syntactic processing with normal aging. They observed that while digital violations caused P600 responses in both young and old individuals, the brain's response to simple syntactic violations remained relatively unchanged in timing or amplitude despite age-related decrements in accuracy and speed of grammaticality judgments. However, the brain's processing of these violations did engage somewhat different brain regions as a function of age, indicating a qualitative change rather than a simple quantitative one. Nonetheless, while Kemmer suggested that older individuals retained syntactic processing capabilities, it's noteworthy that the comprehension accuracy of older individuals in comprehension tasks was significantly lower than that of younger individuals. Wingfield and Grossman (2006) found that despite declines in various activities and functions among elderly individuals, their language comprehension abilities remain intact. During syntactic processing, age-related increases in activation in the right frontal regions occur, leading to compensatory recruitment of these right hemisphere areas to some extent, thereby preserving the nature of compensatory recruitment of new brain regions observed in performance-matched older adults in understanding sentences compared to younger individuals. This neural plasticity of recruitment contributes to the stability of language comprehension in the aging brain. Furthermore, Tyler and colleagues (2010) study the mechanisms by which adults maintain language understanding. The study involved young adults and older adults. The experiment had three verbal stimuli: normal sentences (NP), anomalous sentences (AP), and unstructured strings of words (RWO), and subjects pressed buttons when they heard the target words. The study found that performance was preserved in the older group despite age-related gray matter loss in the network of neural regions typically involved in syntactic aspects of language comprehension. Also, this study found evidence for age-related neural compensation, where increased right hemisphere frontotemporal activity was associated with age-related neural atrophy in the left hemisphere frontotemporal network activated in the younger group. this shift toward a bilateral functional language network underpins preserved syntactic processing functions in the older group. Christianson and colleagues (2006) investigated the reliance of younger and older adults on "good-enough" interpretations for garden-path sentences. In their first experiment, 24 young adults and 24 older adults were tasked with reading garden-path and non-garden-path sentences containing OPT or RAT verbs and answering comprehension questions. Results indicated that older adults were more inclined than younger adults to maintain transitive interpretations of sentences containing OPT verbs, regardless of whether they were garden-path or non-garden-path sentences. However, this age difference was not observed in sentences containing RAT verbs. The discrepancy in responses to OPT verb sentences among older adults might stem from semantically based inference, which could be one of several heuristics older adults employ while interpreting garden-path sentences to compensate for age-related declines in working memory. Such inferences likely arise from a strategy of relying on propositions constructed during the parse of complex sentences rather than the verbatim content. Boxtel and Lawyer (2023) explored the neural correlates of syntactic priming in older adults' comprehension. Their experiment involved 20 young adults and 18 older adults engaging in a self-paced reading and event-related potential paradigm. Both priming and lexical boost effects were evident on ERP measures, although age-related differences in topography were observed. The expected centroparietal P600 component exhibited a frontal topography, particularly front-left in younger adults, while verbal N400 was captured in a broad parietal topography in both groups. While differences between older and younger adults were not found in reading times except for measures of lexis-only overlap, older adults were not facilitated in this regard. Nonetheless, ERP measures revealed robust syntactic priming patterns in both age groups. Some researchers provided evidence supporting the idea that functional connectivity within the frontotemporal syntax network remains consistent across age groups, indicating preserved specialization for syntactic processing. However, other researchers have found evidence suggesting that while older individuals may perform syntactic processing tasks as well as younger individuals, they may rely on compensatory mechanisms or different brain regions to achieve comparable performance. Overall, while some aspects of syntactic processing may remain intact with age, the literature suggests a combination of preserved function, compensatory mechanisms, and qualitative changes in neural processing among older adults.

3. Decline in Syntax Processing Abilities of Older Adults

In addition, more studies suggest that the syntactic ability and processing of the elderly are inferior to that of the young. Some studies have revealed that older individuals encounter challenges in language processing, exhibiting slower and less accurate responses compared to their younger counterparts. Numerous studies on language processing in older adults have shown a range of impairments in language processing in older adults, including protracted response times, heightened error rates in syntactic structure utilization, limitations in working memory impacting both comprehension and production and a diminished capacity to imitate and formulate complex sentences. These findings underscore the nuanced regression in linguistic faculties as individuals age.

3.1 Syntactic Abilities and Aging: Insights from Behavioral Studies

For instance, Kynette and Kemper (1986) scrutinized spontaneous language usage among adults aged 50 to 90 years. They examined sixteen distinct measures encompassing syntactic structure, verb tense, form class, lexical utilization, and disfluency. The study unearthed that individuals aged 70 and 80 committed more errors in employing simple syntactic structures, including omissions of obligatory grammatical morphemes such as complementing entities and relative pronouns. Moreover, older adults displayed higher frequencies of errors like incorrect past tense inflections, subject-verb mismatches, and omissions of articles and possessive markers. Compared to younger adults, older adults refrained from utilizing complex structures incorporating the first relative clause of a sentence or the complement of a noun phrase, nor did they use structures that included multiple embedded clauses. In addition, Kemper (1986) conducted experiments where both older adults (70-89 years) and younger adults (30-49 years) imitated complex sentences containing embedded gerunds, wh-clauses, that-clauses, and relative clauses. The elderly adults encountered difficulties in imitating or paraphrasing sentences with long, sentence-initial embedded clauses, while they accurately imitated or paraphrased sentences with short, sentence-final embedded clauses.

Similarly, Kemper has studied the shortcomings of generative language in older adults. Kemper and colleagues (2003) employed the constrained output task, prompting subjects to construct a sentence using a predetermined set of words displayed on a computer screen until they spoke, thereby compelling subjects to plan their utterance using the entire list of target words. The study revealed that elderly participants exhibited slower response rates and higher error rates compared to their younger counterparts. Additionally, when older adults incorporated more words into their sentences or utilized complementing verbs, they produced shorter, simpler sentences with reduced information and encountered greater difficulty in sentence production. One limitation of the study, however, is that subjects were rarely able to name the kind of complex multi-clause structures that have been the focus of naturalistic language research. Consequently, Kemper and colleagues (2004) investigated subjects' ability to compose complex structured sentences under controlled conditions. They modified the sentence generation task utilized by

Kemper and colleagues (2003) to encourage participants to craft complex sentences. The research discovered that older adults, irrespective of the stem type or the number of additional words, exhibited slower response times for the left branch compared to the right branch. This outcome suggests that the increased memory load associated with the left branch and additional words hindered older adults' capacity to generate effective responses. Moreover, the syntactic complexity of the main stem did not influence the responses of older adults. These findings align with Kemper's (2003) observations that limitations in working memory processing place a "ceiling" on the production of complex sentences among older adults, constraining their length, complexity, and content. Combined with the above research findings, not only is there a reduction in the number of different grammatical forms, syntactic structures, and verb tenses spontaneously produced by elderly adults, but there is also a loss in the ability of elderly adults to imitate and paraphrase complex syntactic structures.

In addition to syntactic defects in language generation, the elderly also have poor syntactic processing performance. Further insights into age-related language processing disparities were gleaned by Kemtes and Kemper (1997), who utilized an online reading paradigm to assess the processing of main verb and relative clause sentences among older and younger adults. The study disclosed that older individuals exhibited significantly slower sentence reading times and were less accurate in responding to complex and ambiguous queries compared to their younger counterparts. However, the decline in syntactic processing prowess wasn't universal among elderly individuals, suggesting pronounced interindividual differences in syntactic processing among the elderly. To assess the effects of age on reading subject-relative and object-relative constructions, Elizabeth (2000) engaged 34 elderly individuals and 39 college students. The study found no disparity in accuracy between older and younger individuals for subject-relative structures, whereas younger participants exhibited higher accuracy for object-relative structures. Moreover, both age groups exhibited deceleration in the critical region while reading both types of relative clause constructions, with only younger individuals exhibiting slowdowns for object-relative sentences. Unlike their younger counterparts, older readers seemed to struggle in allocating resources to thematic role assignment, thereby impeding effective integration of thematic role information to construct meaning representations of object-relative sentences. Moreover, in a sentence-picture matching paradigm involving sentences of increasing syntactic complexity, Antonenko and colleagues (2013) discovered superior syntactic performance in younger compared to older adults. The paradigm comprised sentences with three different levels of syntactic complexity, ranging from no hierarchical embeddings to one or two subordinate clauses. Correct picture matching decisions necessitated a full understanding of sentence structure. Older adults exhibited lower accuracy and slower response times compared to younger adults, although the effect of syntactic complexity did not differ between age groups. Behavioral results were correlated with brain function and structure, as the syntactic abilities of young adults were associated with functional coupling in a mainly left hemispheric syntax network. In contrast, the syntax network of older adults included additional frontal and parietal regions supporting working memory and semantic processing. Poulisse (2019) delved into age-related disparities in syntactic comprehension among young and older adults. The study enlisted college students and older adults to gauge elementary syntactic comprehension by presenting minimal sentences designed to minimize the impact of working memory, incorporating both real and pseudo verbs. Results indicated that older adults exhibited slower and less accurate responses in detecting syntactic agreement errors across both real and pseudo verb sentences, indicating an age-related decline in syntactic comprehension. Notably, the decline in accuracy was less pronounced for pseudo verb sentences, while the reduction in speed was more substantial, suggesting that syntactic comprehension decline is more pronounced in the absence of semantic information, leading older adults to deliberate longer for more accurate decisions. This study furnishes evidence that basic syntactic processing abilities wane with healthy aging. The findings suggest that aging impacts the allocation of cognitive resources during syntactic processing, particularly in tasks requiring thematic role assignment and integration of syntactic and semantic information. Moreover, the decline in syntactic comprehension appears more pronounced in tasks devoid of semantic context, highlighting the importance of semantic cues in mitigating age-related declines.

Age-related constraints on working memory resources have also been cited in research on syntactic processing. Studies have found that the difficulties and slowness older adults experience when processing syntactically complex language materials are not specific to language. Norman and colleagues (1991) found that age was associated with working memory capacity for recalling sentences involving center-embedded clauses but not for recalling simpler single-clause sentences. The research suggests that the reduction in working memory resources limits older adults' ability to fully process more complex syntactic structures. Kemper and Herman (2006) investigated the impact of memory load on syntactic processing in both young and older individuals. The study comprised 31 young adults and 30 older adults who were asked to recall noun phrases (NP) while reading sentences of differing syntactic complexity. The memory load consisted of two types of NP: proper names or explicit descriptions related to occupations or roles, which could either match or not match the NP used in the sentences. The research revealed that syntactic processes rely on working-memory resources shared with other non-syntactic processes. Older adults exhibited a general reduction in online processing due to the demand placed on working memory by the memory-load task, but they did not encounter additional memory interference from the similarity of the NP. In contrast, young adults experienced heightened complexity when memory interference arose from matching NP in both the sentence and memory load. However, for older adults, memory-load interference remained consistent across varying sentence complexities and matches between memory loads and sentence NP. These findings suggest that the memory load induced a general reduction in processing capacity among older adults, whereas the alignment between memory loads and sentence NP caused a more specific form of interference affecting young adults' online processing.

3.2 Neural Mechanisms in Syntactic Processing

Beyond the statistical findings from behavioral experiments, insights from studies employing ERP and fMRI techniques shed light on age-related declines in syntactic processing among older adults, uncovering alterations in brain activation patterns and elucidating potential mechanisms underlying diminished language comprehension and integration. Peelle and colleagues (2010) scrutinized the cortical network underpinning speech comprehension in healthy aging, employing short sentences varying in syntactic complexity and processing demands manipulated through speech rate. Utilizing fMRI, subjects were tasked with discerning the gender of the performing action character in object relative clauses or subject relative clauses. Young adults exhibited significantly greater activity than older adults in the left ventral IFG when processing syntactically complex object-relative sentences. The left ventral IFG is consistently implicated in the processing of grammatically intricate sentences, indicating an age-related decline in the ability to leverage specialized language processing regions. Potential contributors to this decline may include reductions in gray matter thickness, diminished white matter pathway integrity, or compromised coordination of activity across regions. Moreover, the study noted a reduction in coordinated activity in relevant brain regions essential for supporting sentence comprehension among older adults. Zhu, Hou, and Yang (2018) explored syntactic processing in older individuals. In their experiment, 26 young adults and 20 older adults assessed sentences and judged their semantic acceptability across congruent sentences, sentences with semantic violations, and sentences with combined semantic and syntactic violations. ERP results revealed significantly delayed latency periods in older adults, coupled with a reduced amplitude of the N400 effect during semantic analysis compared to younger adults. In the syntactic analysis, while the amplitude of the P600 effect was similar between groups, correlation analysis unveiled that a larger P600 effect amplitude was associated with poorer syntactic performance, exclusively in older adults. Reduced N400 effect in older adults has been linked to inefficiencies in pre-activating semantic features of forthcoming words and integrating them into context. Additionally, fMRI studies among older adults have unveiled under-recruitment in left frontal-temporal regions in poorer readers or older adults compared to their younger counterparts. The correlation pattern suggests dedifferentiation between congruent and incongruent sentences in older adults, implying a reduced ability to predict forthcoming words and integrate them into context, leading to delayed peak latency and diminished N400 amplitude. Conversely, the larger P600 in older adults may stem from ineffective utilization of syntactic information during reading. In conclusion, research employing ERP and fMRI techniques provides valuable insights into age-related declines in syntactic processing among older adults, revealing alterations in brain activation patterns and potential mechanisms underlying diminished language comprehension and integration.

4. Conclusion and Future Direction

Currently, debates persist regarding the extent of age-related declines in syntactic abilities. While more studies tend to show poorer performance in older adults compared to younger individuals, indicating impairment in both syntactic abilities and processing, some research suggests that older adults perform as well as younger individuals. Considering the overall body of research, it appears that aging can impair processing mechanisms in older adults. Older adults generally exhibit lower accuracy rates and slower response times compared to younger individuals, and fMRI studies have revealed brain region damage and disruptions in connectivity between regions in older adults. However, regardless of whether older adults perform worse or similarly to younger individuals, compensatory mechanisms exist to help older adults recruit additional resources for language comprehension. Moreover, syntactic processing in older adults may involve qualitative changes in brain activation patterns, indicating neural reorganization. The reviewed literature underscores the multifaceted nature of language processing in older adults. While some studies suggest that aging may lead to declines in syntactic processing abilities, others highlight the presence of individual differences and potential compensatory mechanisms employed by older adults to maintain performance levels. Importantly, methodological advancements in neuroimaging techniques, such as ERP and fMRI, have provided valuable insights into the neural mechanisms underlying age-related changes in language processing. By elucidating alterations in brain activation patterns and functional connectivity, these studies contribute to our understanding of the neural basis of age-related changes in language comprehension and integration. Moreover, the exploration of syntactic priming effects and the reliance on heuristic strategies in older adults' language comprehension highlight the adaptive nature of cognitive processes across the lifespan. Older adults may leverage their accumulated knowledge and cognitive resources to navigate complex linguistic structures, compensating for age-related declines in certain cognitive domains.

Although the existing research has made significant progress in the understanding of grammatical processing in the elderly, there are still some limitations. First, many studies involve complex syntactic structures. However, the interpretation of complex syntactic structures may not rely solely on grammar; instead, it may require additional comprehension mechanisms, including semantic and pragmatic processing. Therefore, the study of complex syntactic structures as an independent process of grammatical understanding and processing may not fully reflect the syntactic ability of the elderly. Complex syntactic structures can place a greater burden on working memory, as long-distance linguistic dependencies need to be retained in working memory to successfully integrate syntax and meaning. This dependence may show a more significant effect in older people, as their working memory ability typically declines with age. Second, research mostly focuses on cross-sectional designs, lacking long-term tracking of changes in syntactic processing abilities over time. Since the syntactic processing abilities of older adults may change with age, long-term tracking studies are crucial for understanding the changes in older adults' syntactic processing abilities. The lack of long-term longitudinal studies limits our comprehensive understanding of how grammatical processing skills change over time in older adults. In addition, the age groups of study participants are generally broad and lack a detailed breakdown of age groups. This lack of compartmentalization may result in critical periods of decline in grammatical comprehension not being accurately identified. Finally, despite the importance of language rehabilitation and intervention for older adults, there are relatively few studies on intervention and training targeting syntactic processing abilities. The lack of targeted interventions may limit the improvement and rehabilitation of syntactic processing abilities in older adults. Current research has focused primarily on describing the performance of older adults in terms of aspects of grammatical processing, with relatively little research on how to improve these performances through interventions. This limitation limits our understanding of how to enhance language skills in older adults through active intervention.

Future research should aim to overcome the above limitations to gain a more comprehensive and in-depth understanding of the syntactic processing ability of older adults. First, research should attempt to separate the effects of syntactic, semantic, and pragmatic processing to gain a clearer understanding of the ability of older adults in pure syntactic processing. Experiments can be designed to control and separate these variables to ensure that the research results accurately reflect the true situation of syntactic processing. This will help to clarify the specific characteristics of the syntactic ability of older adults without being confounded by other language processing mechanisms. Second, future research should adopt more longitudinal designs to track the changes in the syntactic processing ability of older adults over time. By tracking the syntactic processing ability of the same group of participants over a long period of time, we can better understand the evolution of the syntactic ability of older adults and identify key periods of change. Detailed division of age groups to more accurately identify the critical period of decline in syntactic comprehension ability in older adults will help develop targeted interventions. In addition, future research should focus on developing and evaluating interventions aimed at enhancing the syntactic processing ability of older adults. Based on the principles of cognitive training and neurorehabilitation, these interventions have the potential to slow down age-related decline and promote cognitive vitality in late life. By leveraging the principles of neuroplasticity and lifelong learning, interventions can help older adults maintain language skills and cognitive resilience to cope with challenges associated with aging. Researchers can design various training programs, such as grammar training working memory training, and evaluate their effects on the syntactic processing ability of older adults. Finally, Future studies should combine multidisciplinary approaches and use advanced neuroimaging techniques, such as event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI), to further elucidate age-related changes in language processing. These techniques provide brain activity data with high temporal and spatial resolution, enabling detailed observation and analysis of the neural mechanisms of language processing in the elderly. By revealing changes in brain activation patterns and functional connectivity, these studies will not only help us understand the neural basis of language comprehension and integration in the elderly but also identify the synergy of different brain regions in language processing. Studies combining ERP and fMRI techniques will provide a more comprehensive perspective, revealing the time course and spatial localization of language processing. This multi-level research approach will not only help reveal the neural basis of language processing in the elderly but also help identify possible compensatory mechanisms; that is, the elderly may use resources from other brain regions to maintain language comprehension ability when faced with grammatical complexity.

In conclusion, by overcoming the limitations of existing studies, future studies will help us understand the syntactic processing ability of older adults more comprehensively and provide new intervention strategies and theoretical support for improving the language ability and quality of life of older adults.

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