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# Sentence comprehension in ageing and Alzheimer's disease

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**Abstract**

The ability to correctly interpret complex syntax and long sentences is gradually impaired as people age. Typical ageing is characterised by working memory deficits, which are thought to play an important role in determining whether syntax can be comprehended correctly, and neurodegenerative conditions such as Alzheimer's disease (AD) are thought to exacerbate these limitations. Furthermore, declines in processing speed appear to cause increasing difficulty in the proper allocation of cognitive resources necessary for sentence processing. Typically ageing adults may compensate for these deficits successfully when interpreting sentences using semantics or intact cognitive functions, but AD patients may exhibit deficits too severe for this to occur. The causes of syntax comprehension deficits in Alzheimer's are still contested, and may consist of language-specific impairments or deficits in general cognition impacting linguistic behaviour. In this review, we aim to give an overview of the main markers of cognitive ageing and AD in the domain of sentence comprehension, as well as discuss potential underlying factors that may affect sentence comprehension in older speakers and Alzheimer's patients.

# 1 | INTRODUCTION

Human cognition changes throughout the lifespan. While typical childhood development is associated with the development of cognitive skills, further ageing is characterised by progressively deficient cognitive abilities. From a general slowing of cognitive operations as ageing progresses (Salthouse, 1996) to reductions in the efficacy of inhibitory and attentional processes (Hofer & Alwin, 2008, ch. 7), to general deteriorations in memory capacity (Wright, 2016, p. 7); becoming older often comes with a range of challenges and difficulties. The question of how these general cognitive changes affect linguistic behaviour has been a topic of academic research for decades (e.g., Whitaker, 1976), yet much remains unclear about what linguistic deficits characterise ageing, and what causes them. Research into neurodegenerative diseases such as Alzheimer's Disease (hereafter AD) provides a window into the cognitive processes underlying linguistic behaviour, and how these may be impaired. These questions are made all the more relevant by the increasing age of the general population and the increasing prevalence of AD. There is a larger aged population on the planet now than there ever has been in world history (United Nations, 2013), and the number of Alzheimer's patients in the United Kingdom alone is set to grow from 850,000 in 2019 to over 1.5 million in 2040 (Wittenberg et al., 2019); research on topics in ageing and neurodegeneration will therefore become ever more important as time progresses (Börsch-Supan, 2003, p. 6).

This review aims to give an overview of the sentence comprehension deficits seen in ageing and AD and discuss potential explanations for these impairments that have been put forward over time. Sentence comprehension is particularly suited for the study of ageing and Alzheimer's in relation to language due to the variable memory demands involved in comprehending sentences, which disproportionately affect older and impaired speakers (DeDe & Flax, 2016). The paper will start with a description of sentence comprehension changes seen in typical ageing, along with a discussion of relevant working memory (WM) and processing speed theories. Potential causes and compensation strategies are also discussed. Declines in WM and processing speed appear to be key to understanding observed changes in older adults' language, especially in the domain of syntax. Sentence comprehension deficits in AD and potential causes thereof are the topic of the second half of this review. Deficits in this type of dementia may be seen as an exacerbation of the effects of ageing, although severe impairments in other cognitive domains such as inhibition, and an increasing inability to successfully compensate for declines in syntax processing, may also affect sentence comprehension in this population. Finally, suggestions are made for future research topics into this field and their potential impact.

# 2 | AGEING, MEMORY, AND LANGUAGE

## 2.1 | Sentence comprehension in ageing populations

The process of ageing is characterised by negative changes to cognitive abilities. This increased "cognitive frailty" (Park & Festini, 2017, p. 82) has been the topic of extensive research for decades. One of the most frequently reported complaints in ageing populations, and the one that has arguably drawn the most attention from linguistic researchers, is one concerning memory problems (e.g., Kausler, 1994; Nilsson, 2003). The ability to generate new episodic and spatial memories, as well as memory capacity for contextual details, appears to gradually become impaired as the ageing process progresses (Leal & Yassa, 2019). Older adults also become increasingly unable

to discriminate highly similar events in memory, an impairment potentially related to deficits in inhibitory control and suppression (e.g., Hu et al., 2018). Reduced memory capacity and progressively less efficient memory operations have effects on older adults' language comprehension, both in terms of semantic access and syntax. This section will discuss some of these effects and offer potential causes for them.

The reduced discriminatory ability in ageing mentioned above has distinct effects on verbal fluency abilities of older adults. For example, Taler et al. (2019) studied a large sample ($n = 12{,}686$) of older adults with a verbal fluency task, which asks participants to name as many items of a given criterion as possible (e.g., *animals*). Accessing the correct items in a verbal fluency task involves a search through semantic memory, the part of the memory system where knowledge about objects, actions, and words is stored. Generally, Taler et al. (2019) concluded greater age was found to be associated with fewer produced items overall. Furthermore, older participants produced more frequent, less diverse, and orthographically and semantically more similar items. Although the changing ability of older adults to select and produce items from semantic memory is a well-attested development (e.g., Bowles & Poon, 1985; Pistono et al., 2019; Suzin et al., 2019), Taler et al. (2009) suggest this may not necessarily be indicative of a semantic *impairment*, as older adults' greater linguistic experience may partially account for slowed access of semantically appropriate items compared to younger adults. Searching through semantic memory for category-appropriate words takes older adults longer, not just because their cognitive abilities are slowed, but because they have a greater volume of semantic memory to search through. The suggestion that semantic access is slowed, but semantic abilities themselves are not impaired, is consistent with the robust finding of greater vocabulary size in older adults (e.g., Hardy et al., 2017; Hartshorne & Germine, 2015; Zhu et al., 2019) and, importantly, with the notion that an absence of semantic content in sentences increases older adults' sentence processing difficulties (Poulisse et al., 2019). The study by Poulisse et al. (2019) found stronger age-related declines on agreement error detection measures for pseudoverbs compared to real verbs, suggesting that semantics may act as a type of compensation mechanism for impaired syntax processing.

In short, although ageing causes observable changes in the domain of semantics, it is not immediately clear as to in what way syntax processing may change or become impaired with age, and how changes in semantic abilities may interact with syntax. Age-related impairments in syntax processing appear to be linked to memory demands: in a recent advertisement comprehension study, in which participants were asked questions about the content of length-manipulated adverts, Kim et al. (2016) found little to no differences between older and younger adults when stimuli sentences were short and simple. However, declines began to emerge in the older group when demands on WM were increased, leading the authors to imply progressively decreasing WM capacity as the main predictor of performance. If it is possible for semantic information to compensate for sentence processing declines, as the study by Poulisse et al. (2019) suggests, this may be dependent on memory-related factors. The following section discusses the potential impact of WM limitations on sentence processing in older adults.

## 2.2 | Working memory and linguistic ageing

By WM, we refer to a limited-capacity system used for temporarily storing, processing, and retrieving informational cues (Baddeley, 2010). WM does not store information in the long-term and is therefore different from long-term memory (LTM), and information maintained in WM is processed concurrently, making WM different from short-term memory (STM). While hearing a

phone number and writing it down is an STM task, writing down the same number in reverse order involves changing the order and shape of the information, and is therefore a WM-based task. Further evidence suggesting that WM is at the centre of the comprehension deficits in ageing comes from Norman et al. (1992), who presented younger and older adults with WM tests as well as multiple-choice comprehension questions relating to short passages. The study manipulated syntactic complexity in these passages by varying the number of left-branching sentences, which include a large amount of information preceding the grammatical head. Examples of left- and right-branching sentence types are given in (1 and 2). Overall, left-branching sentences were read more slowly than right-branching sentences. Furthermore, performance on the comprehension questions was found to correlate positively with measures of WM, indicating that participants with lower WM scores may face sentence comprehension problems.

(1) Since it reminded him of the 3 years he had lived in the neighbourhood as a child, the man walked down the road (*left-branching, information precedes head*).
(2) The man walked down the road in the neighbourhood in which he had lived for 3 years as a child (*right-branching, information follows head*).

WM was also among the most significant predictors for older adults' language performance in a study by DeCaro et al. (2016), who used a sentence comprehension task involving the gender naming of actors (i.e., asking whether the agent was male or female). DeCaro et al. (2016) manipulated the complexity of sentences with object- and subject-relative structures, and the length by adding optional prepositional phrases between the subject and object of the relative clauses. Object relatives (as in (4)) have generally been found more difficult to comprehend than subject-relatives (as in (3)) (e.g., Caplan et al., 2007; Garraffa & Grillo, 2008). This may be due the additional processing operations required to parse object relatives, including the need to store the subject of the relative clause (in (4), "the woman") in WM (Gibson, 1998).

(3) The butcher that attacked the woman was arrested.
(4) The butcher that the woman attacked was arrested.

In the DeCaro et al. (2016) study, accuracy scores on the gender naming comprehension task were significantly lower in object relative compared to subject-relative sentences, while clause length effects were significant only on the more complex object relative structures (DeCaro et al., 2016, p. 7). Importantly, effects of WM span accounted for variance across conditions, sentence lengths, and syntactic manipulations. Age was found not to be a significant predictor after effects of WM were controlled for. This indicates that WM effects are an extremely important predictor for performance on linguistic tasks in older adults.

Various hypothesised structures of the WM system make different predictions about older adults' performance on linguistic tasks. As an amendment to the Baddeley and Hitch (1974) multipart model of WM, King and Just (1991) introduced the notion that "individual differences" in the amount of resources to which the WM system has access are a major cause of performance deficits on linguistic tasks. These resources, King and Just (1991) argue, take the form of an "activation pool", and successful access to and retrieval of information stored in WM is dependent on sufficient activation of these informational cues. One pool of activation is thought to underlie all of cognition, and linguistic operations share this pool with other cognitive tasks such as inhibition and conflict monitoring. In highly complex grammatical sentences, more activation is often

required, as cues must be maintained in WM for longer, or more cues may need to be active at the same time (Cunnings, 2017, p. 661).

Older adults' consistently poorer performance on WM tasks compared to younger adults (for a review, see Bopp & Verhaeghen, 2005) may therefore be down to a progressively decreasing amount of available activation. Likewise, older adults face problems with the use of inhibitory control, the ability to suppress irrelevant information, causing problems with the effective use of activational resources for linguistic tasks as cues that are not relevant to sentence processing are not repressed (e.g., Campbell et al., 2020).

This notion is consistent with evidence from older adults' performance on linguistic tasks less dependent on activational resources than class sentence comprehension or reading speed paradigms. One such task is syntactic priming, where responses to one grammatical structure are facilitated by the presentation of the same grammatical structure earlier in the trial sequence (e.g., Tooley et al., 2019). Although syntactic priming was previously thought to rely on lingering activation of syntactic representations (Pickering & Branigan, 1998), recent evidence converges on an *implicit learning* mechanism, by which the syntax processor "learns" to parse a grammatical structure, facilitating faster processing of that structure in the future (Chang et al., 2012; Yan et al., 2018). If syntactic priming is dependent on an implicit learning mechanism rather than on activation, older adults should exhibit normal syntactic priming effects.

Hardy et al. (2017) investigated syntactic priming and effects of lexical repetition (termed the "lexical boost") in older speakers with a scripted dialogue task in which the experimenter read out cards with either active or passive sentences and prompted the participant to respond. They concluded both syntactic priming and lexical boost effects are highly robust in both younger and older adults, and that underlying syntactic representations are therefore intact in elderly speakers. These findings were corroborated with other priming studies by Hardy et al. (2019) and Hardy et al. (2020), with a general conclusion that minimal syntactic processing differences were observed between younger and older groups. These findings are in stark contrast to older studies using other paradigms such as Norman et al. (1992) and Kim et al. (2016), where significant differences between older and younger adults were observed. More research on this activation distinction is needed.

However, even on non-priming tasks, not all evidence directly implicates WM in linguistic declines, and instead suggest syntax processing itself is deficient in ageing: as mentioned above, Poulisse et al. (2019) studied older adults' language with stimuli that kept WM demands to a minimum by limiting sentences to two words (e.g., "I cook"). Agreement errors (e.g., "I cooks") were included in the stimuli and pseudoverbs ("I spuff") were compared to real verbs. The participants' task was to detect the agreement errors as rapidly as possible. Poulisse et al. (2019) found that even on short sentences older adults' speed and accuracy on this error detection measure declined compared to younger controls. Furthermore, the decline in speed was larger for pseudoverbs, suggesting that an absence of semantic content caused greater declines, and that semantic cues may provide a means of compensating for declines in the interpretation of syntactic structure. The findings of Poulisse et al. (2019) are noteworthy given that processing declines were observed while WM load was kept to a bare minimum. The implications of these findings are twofold: first, declines in older adults' language may not be WM-dependent under all circumstances; and second, it is therefore possible that older adults are able to compensate for cognitive declines by using information from other sources.

Furthermore, Additional evidence suggests the effects of WM declines on sentence processing may be mitigated by other processing mechanisms. For instance, Payne et al. (2012) examined effects of print exposure (how much people read and are read to, see Mol & Bus, 2011) on

older adults' vocabulary size and WM, as well as on a sentence reading task involving stimuli manipulated for length and word frequency. Print exposure was associated with faster word reading, and effects of print exposure even compensated for memory declines in participants with poor WM scores (Payne et al., 2012, pp. 166–167).

## 2.3 | Conscious task demands and processing speed

Apart from WM declines, there are several important factors at play in ageing and sentence comprehension that impact whether task performance is impaired or not. The first is a distinction between conscious and unconscious processing. Waters and Caplan (2001) hypothesise that different linguistic tasks may be subserved by different parts of WM, citing a general lack of correlations between different measures of WM as evidence for a multipart WM system. Tasks that yield findings of syntactic impairments in older adults have usually been quite complex, Waters and Caplan argue, and rely too much on conscious processing, which Waters and Caplan consider far more impaired than unconscious processes. This hypothesis appears to corroborate with findings of intact syntactic priming, as mentioned above, which is a generally unconscious (or implicit) process, and with impaired performance on the tasks used in Kim et al. (2016) and Norman et al. (1992), which both involved passage reading and answering of comprehension questions, and therefore included a far greater conscious element. The distinction, therefore, between conscious and unconscious, implicit and explicit processing, appears critical in understanding linguistic changes with age.

The second important factor that comes into play during sentence comprehension in older adults is processing speed. Salthouse (1996, inter alia) extensively worked on the notion that cognitive (and linguistic) deficits in ageing may largely be the result of a general slowing of cognitive functions. A large body of evidence suggests declines in processing speed may be a major cause of age-related processing deficits (e.g., Bezdicek et al., 2016; Bott et al., 2017; Ebaid et al., 2017). The Processing Speed Theory of cognitive ageing (Salthouse, 1996) stipulates that in a sequence of cognitive operations, if it takes older adults longer to perform the basic, early operations, not enough time is left for them to perform later stages of the operational sequence (Salthouse, 1996, p. 404). Furthermore, information processed in the earlier stages of processing may be lost by the time it is needed for later processing. These two deficits naturally interact, such that the extra time needed for early stage operations can lead to a loss of information later on in the processing sequence. Salthouse (1996) predicts that the implications of this impaired state include longer latencies to processing operations and greatly increased error levels. To give a linguistic example of this theory at work, a linguistic task assessing discourse coherence interpretation usually consists of the reading of several sentences of text, followed by at least one judgement of acceptability and/or a comprehension question. According to the Processing Speed Theory, it is highly likely much of the information processed at the start of the stimuli items will have been lost in older adults by the time the comprehension question needs answering. This could then lead to the critical information necessary for finding the correct answer to these questions already having faded from memory in older adults.

Some research (e.g., Chevalère et al., 2020; DeDe, 2014) suggests that declines in processing speed are themselves a compensation mechanism for working with limited resources in older age. The potential reasons for this are manifold: older adults have fewer available cognitive resources to dedicate to a task, and may choose more selectively where to dedicate these resources and when to avoid an overload of cognitive demand (Brébion, 2003; Hess, 2014). However, recent

evidence presented by Malyutina et al. (2018) casts doubt on this possibility. Malyutina et al.'s experiment tested accuracy on multiple-choice comprehension questions in response to self-paced and externally paced sentences with both complex and simple grammar. The authors expected older adults to strategically slow their relative reading speeds compared to younger adults, and to find changes in comprehension accuracy dependent on external presentation rate (Malyutina et al., 2018, p. 27). Manipulations included comparing canonical and non-canonical word order, subject and object relatives, and the inclusion of reflexive pronouns. Malyutina et al. (2018)'s experiment resulted in slower reading times for older adults across the board, but no interaction between age and presentation rate on comprehension measures. Thus, no evidence was found that older adults were differentially affected by presentation rate increases compared to younger adults, and conscious acceleration or deceleration of reading speed therefore appears unlikely following this study. However, more research into the notion of strategic slowing is warranted to reach a definite conclusion.

These potential compensation strategies are the third major factor that explains variable performance on linguistic tasks by older adults (e.g., Rabaglia & Salthouse, 2011). These mechanisms can take a variety of different forms. Kemper et al. (1992) formulated an early hypothesis of cognitive compensation based on a model of linguistic modularity. In this model, the syntax processor is a separate cognitive module to other language processing centres, such as that which processes semantics. The natural interaction between these modules implies that older adults can compensate for impaired syntactic processing by prioritising semantic information. Older adults' greater semantic knowledge and vocabulary size (Hartshorne & Germine, 2015; Zhu et al., 2019) are, in this view, used to balance out WM issues in sentence comprehension. Evidence for this position was found by Poulisse et al. (2019), as mentioned earlier, who discovered increased deficits and poorer performance on stimuli with an absence of semantic content (in this case, pseudowords) compared to real words. This suggests semantics may act as a "buffer" which compensates for poorer performance on the syntax element of processing.

To summarise, general cognitive and memory impairments in ageing appear to have a tangible impact on the sentence processing capacities of older language users. Compensation mechanisms involving semantics or processing speed may successfully counteract impairments up to a point, but abundant evidence suggests these mechanisms do not compensate for all linguistic deficits that are seen in ageing adults. In particular, WM has been forwarded as a key cognitive factor responsible for declines in syntax processing with age, and, when paired with increasingly slowed speeds of processing, this appears to be responsible for many of the linguistic effects observed. The following sections will extend the preceding discussion to AD, which appears to exacerbate the memory and processing speed issues seen in typical ageing and can offer a further window into what processes are key to the successful interpretation of sentences.

## 3 | ALZHEIMER'S DISEASE

AD is a type of neurodegenerative dementia progressively affecting most everyday cognitive functions. The condition is currently without cure and is thought to affect between 5% and 10% of the population (Moorhouse & Fisher, 2017; Stahl & Morrissette, 2019). Generally, early markers for the condition include occasional forgetfulness and the inability to recall names for objects and people, though the condition often worsens swiftly and the average outlook for an Alzheim-

er's patient is only 4 to 8 years post-diagnosis (Alzheimer's Association, 2020). Many patients pass away due to ageing and AD-related complications such as infections, pneumonia, or blood clots; those who do not finally reach a vegetative state where a complete inability to perform basic actions is seen and no language is produced.

Language ability and a severe deterioration thereof is one of the earliest and clearest markers of the onset of AD. Patients developing AD generally show an increasing inability to name familiar objects or people, reflecting the rapid deterioration of semantic memory associated with the condition (Jokel et al., 2019). Problems with pronunciation also develop due to increasing difficulties with swallowing and tongue movements, caused by an underlying motor impairment (Moorhouse & Fisher, 2017). The disintegration of semantic memory and large declines in processing speed further result in serious pragmatic impairments: AD patients are generally reported to have problems taking turns in conversation and maintaining topics, and people with AD often break off conversations unexpectedly (Moorhouse & Fisher, 2017; Stahl & Morrissette, 2019). Furthermore, AD patients present with increasingly impaired inhibitory (Martyr et al., 2019) and attentional (Huntley et al., 2017) functioning, suggesting a widespread deterioration of cognitive faculties in the condition. Both in terms of general cognition and language impairment, then, symptoms of AD are far more intense and widespread than problems associated with typical ageing.

## 3.1 | Language and Alzheimer's

The modern study of language and Alzheimer's, and syntax in particular, began with Whitaker (1976), who performed a case study with a single patient diagnosed with late and severe dementia. Virtually no language was produced, but the patient sang when cued to do so and appeared to have excellent pronunciation. Furthermore, when asked to repeat sentences read to her, the patient appeared to correct grammar issues intuitively. This led Whitaker (1976) to suggest that AD may target only non-automatic aspects of language, such as most instances of production, but that automatic processes may be spared. This automaticity distinction is one previously made with regards to WM by Waters and Caplan (1996) and concerning activational resources by (Hardy et al., 2017, 2020), as mentioned above. The apparent dichotomies between intact and severely impaired language features led to the fairly long-lasting assumption that syntax comprehension, an automatic part of sentence processing, is unimpaired in AD (for an early review, see Bayles, 1982).

Quantitative studies later began to paint a clearer picture of the language impairments associated with dementia. Kempler et al. (1987) set out to investigate whether syntax processing is truly unimpaired in AD by analysing samples of spontaneous speech recorded from different patients. Transcripts were coded along lines of syntactic complexity, including simple sentences (*"I was just talking."*), conjoined types (*"They're interesting and they're nice."*), as well as various types of complex syntax such as passive and topicalised structures (*"This is handled by the whatchacallit."*). Kempler et al. (1987) found no differences in syntactic complexity between AD patients and controls, and when combined with results obtained from a cue differentiation task involving semantic and syntactic judgements, the authors concluded that AD patients show significantly more difficulty than controls on semantic tasks, but that syntax does not appear impaired. These findings were then tied to the supposedly modular nature of the language system in which syntactic processing and production comprise individual centres which are selectively non-impaired (Kempler et al., 1987, p. 347).

However, not all research supports this conclusion. Grober and Bang (1995) applied methodology from the extensive literature on aphasia to AD patients and discovered syntax may well suffer under certain task demands. Using a sentence-picture matching task it was discovered that while patients' interpretation of standard, non-reversible, active sentences (such as (5)) was near-perfect, reversed passive items (as in (6)) elicited deficient results. Grober and Bang (1995) considered their finding of deficient interpretation of reversed passives in the light of then-recent results of WM-related research (e.g., Just & Carpenter, 1992; King & Just, 1991), which had sparked an interest in WM as a potential predictor of language-related performance. Passives such as (5) are more taxing on the WM system as the canonical sentence structure of English, Subject-Verb-Object, is reversed, and the Object of the structure (in (6), "the butcher") must be maintained in WM until the sentence is resolved. Grober and Bang (1995) suggest WM, which is highly impaired in AD, may significantly influence AD patients' linguistic behaviour to the point where differences between patients and typically ageing adults are highly robust.

(5) The baker assaulted the butcher.
(6) The butcher was assaulted by the baker.

Recent research has considered this proposal in depth. Marková et al. (2017) studied a large ($n = 77$) group of native Slovak-speaking mild and moderate AD patients using a sentence-picture matching task involving a wide variety of structures. Moderate AD patients were found to perform significantly worse than controls on all sentence types, while those with mild AD were impaired only on object-verb-subject (OVS) and centre-embedded sentences, both of which are fully grammatical in Slovak due to the language's very rich inflectional morphology. Interestingly, no effects for sentence length were reported in any group, suggesting a significant grammaticality issue is at play. Marková et al. (2017) also found that sentences involving a relatively large number of grammatical morphemes elicited more correct responses than those without, lending credence to the hypothesis that morphology can assist impaired speakers during syntactic interpretation (a facet of the Competition Model; see MacWhinney, 1987). Similar findings were obtained in two studies of Hebrew-speaking AD patients by Kavé and Levy (2003, 2004), the first using spoken descriptions of the commonly used Cookie Theft Picture, and the second examining AD patients' sensitivity to existing and non-existing morphemes in a reaction time paradigm. These studies showed AD patients are as sensitive to morphology as older adults, in turn suggesting the possibility that morphological compensation mechanisms may be at play in some languages that cannot develop in English. Given that a critical absence exists of linguistic studies of non-English-speaking AD patients, this review calls for a greater number of cross-linguistic studies into the linguistic effects of dementia and AD.

## 3.2 | Causes of linguistic declines in Alzheimer's

The most common explanation for behavioural AD linguistic deficits is one involving impaired WM. As discussed above, WM is thought to subserve various linguistic processes. AD patients are generally impaired on WM compared to healthy controls (Baddeley et al., 1991), in line with the general reduction in cognitive function seen in the condition. It may be hypothesised, then, that serious reductions in the capacity of WM cause the deficits summarised

above, which include impaired interpretation of non-canonical sentence structures and potential length effects. This is one of the most commonly cited explanations and one for which ample evidence exists (Jokel et al., 2019). Following this hypothesis, language impairments in AD can be seen as a more severe type of the declines often observed in typical ageing, though exacerbated by a reduced inhibitory control faculty and a highly impaired attention span (Ober and Shenaut, 1988).

However, an impaired WM explanation still leaves various questions unanswered, the first of which is what is understood by impaired WM. This could take the form of a general capacity limitation, in that fewer cues can be actively maintained in the system (an explanation favoured by, for instance, Carpenter et al., 1994); but alternatively, the quality of specific WM operations might be considered. The storage, maintenance, and accurate retrieval of cues from WM, as well as processes involved in syntactic parsing, are operations which must be performed at speed and with high accuracy (Martorell et al., 2020; Niharika & Prema Rao, 2020), and it is highly likely these processes are impaired in AD due to the significant memory impairments seen in the condition (Baddeley et al., 1991; Zokaei & Husain, 2019). Furthermore, not all studies have found WM to be a highly significant predictor of task performance in AD. For instance, Croot et al. (1999) did not find a strong association between measures of WM and AD patients' performance on the Test for the Reception of Grammar (TROG). Furthermore, there was no relation between the number of words in a sentence and performance, suggesting length effects were virtually absent in their data. Croot et al. (1999) hypothesise that linguistic processing itself is selectively impaired as a feature of AD.

There is also abundant evidence to suggest that a specific semantic deficit, at least, is part of the AD pathology. Ober (2002) reviews research on semantic priming in AD, and concludes that deficits or differences in priming patterns occur frequently in AD patients. Significantly greater-than-normal priming effects have been recorded in tasks involving AD patients, an effect known as *hyperpriming*. This phenomenon is consistent with a degradation of semantic networks in AD, allowing activation to spread quickly over less intact semantic nodes (Ober, 2002, p. 889). Furthermore, results of hyperpriming suggest AD patients are increasingly impaired in distinguishing one set of semantic properties from another: Martínez-Nicolás et al. (2019) claim the progressive loss of attribute distinction in AD causes these hyperpriming effects, since patients begin to confuse what semantic nodes have what attributes attached. When paired with the notion that semantic abilities may compensate for impaired sentence comprehension in typical ageing (see Section 2), it could be the case that highly impaired semantics fail to successfully compensate for declined syntax comprehension in AD patients.

A final explanation for linguistic problems in AD is the "post-interpretative processing" account (favoured by, for instance, Kempler et al., 1998). This hypothesis extends the theory that WM is responsible for comprehension issues by involving other general cognitive processes as a post-interpretation stage. These processes can include impaired meta-linguistic awareness, inhibition, and the use of linguistic information to answer comprehension questions (Peelle, 2019). This position is evidenced by studies showing that AD patients "are capable of processing the forms of language at the sentential level" (Caplan & Waters, 2000, p. 75) but fail to use linguistic cues effectively to perform tasks due to deficits in various cognitive domains. However, there is a lack of clarity whether these post-interpretative processes can be dissociated from effects of task demands and WM, and due to the high heterogeneity within AD patient groups, identifying specific post-interpretative processes that cause linguistic impairments has proven difficult.

## 4 | CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Ageing and neurodegeneration have serious consequences for cognition and language ability (Cabeza et al., 2016; Peelle, 2019). Changes in semantic categorisation and the ability to search through semantic memory gradually become evident as the ageing process continues. Furthermore, memory issues, which appear to be at the forefront of the language problems exhibited in ageing, cause declines in older groups' ability to quickly and correctly interpret complex and longer sentences. A gradual decline in processing speed across adult cognition appears to lead to difficulties in sentence comprehension, such that older adults spend more time performing early stage, basic sentence processing operations, and fail to maintain necessary information in WM for late-stage processing. Task complexity and whether processes rely on conscious or unconscious memory operations furthermore appear to have a significant impact on older adults' performance on linguistic tasks: conscious processing seems far more impaired than unconscious processing.

Various compensation strategies mitigate the negative impact of cognitive decline on sentence comprehension. Evidence suggests that the use of semantic information may counteract memory declines, and that an absence of semantic content may exacerbate sentence processing deficits (e.g., Poulisse et al., 2019). Another potential source of compensation includes strategic slowing, where older adults' slower processing speed (Salthouse, 1996) is seen as a strategy to selectively deploy the reduced cognitive resources available to older adults (e.g., Chevalère et al., 2020). Whether these compensation mechanisms play a significant role, and to what extent they account for older adults' performance on linguistic tasks, as well as the question whether they apply similarly to all languages, is a necessary topic for future investigation.

In AD, significant impairments in semantics and syntax have been discovered. Comprehension of complex and long sentences declines rapidly in AD populations and compensation mechanisms do not appear to successfully counterbalance the effects of memory declines. Importantly, however, this may not be the case to the same degree across languages: as indicated by Marková et al. (2017), frequent inflections in morphologically complex languages could assist AD patients in sentence processing and help compensate for memory impairments. Effects of declines in the quality of WM operations, inhibitory control, and meta-linguistic awareness also contribute to the linguistic disease profile in AD. Much remains unclear about the specific sentence comprehension deficits in AD and their causes, and further research into this area is needed.

In summary, despite decades of research into linguistic impairments in ageing and AD, many questions about the role of syntax and sentence comprehension, and to what extent these are affected by cognitive declines, remain unanswered. Future studies on language, ageing, and AD should focus on the aforementioned apparent distinction between conscious and unconscious, implicit and explicit memory, using paradigms such as syntactic priming. Furthermore, older adults' and AD patients' susceptibility to semantic memory interference, and to what degree such interference affects sentence comprehension, is another topic that needs elucidating.

An informative angle in the study of ageing and syntactic processing could also include predictive processing, which has generated significant attention in the past (e.g., Payne & Silcox, 2019; Wlotko et al., 2012). The anticipation of upcoming information plays a large role in language comprehension, and while some evidence suggests the use of contextual information to predict upcoming cues is affected by age, it is still unclear what the exact mechanisms behind these issues are (see Dave et al., 2018). Integrating manipulations of prediction into experiments on ageing and syntactic processing therefore has the potential to elucidate the exact nature of processing deficits further.

Finally, the locus of linguistic deficits in AD, whether syntax impairments are caused by memory declines, other general cognitive deficits such as inhibition, processing speed declines, or AD-specific pathological causes, remains uncertain. Future studies in this field have the potential to impact psycholinguistic theories of sentence processing as well as memory theory, and ultimately, may contribute to strategies and clinical practice that mitigate older adults' and AD patients' linguistic declines.

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