A Matter of Memory?
Sentence Comprehension in Healthy Aging

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A Thesis Submitted for the
Degree of Doctor of Philosophy

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August 2, 2022

Statement of Authorship

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The Candidate acknowledges the contribution of Dr Laurel A Lawyer as co-author of Studies 1, 2, and 3, and certifies authorship and publication status of the Studies presented in this thesis as follows:

– Introduction/Review of Literature: authored by the Candidate, supervised by Dr Laurel Lawyer. Published in edited and co-authored form as Van Boxtel, W.S. and Lawyer, L.A. (2021). Sentence Comprehension in Aging and Alzheimer's Disease. *Language and Linguistics Compass*, 15(6), e12430. DOI: `10.1111/lnc3.12430`

– Study 1: Authored by the Candidate, co-authored by Dr Laurel Lawyer. At the time of submission of this thesis, submitted and under review for *Language, Cognition, and Neuroscience*.

– Study 2: Authored by the Candidate, co-authored by Dr Laurel Lawyer. At the time of submission of this thesis, awaiting submission to a Special Issue on Language and Aging in *Topics in Cognitive Science*.

– Study 3: Authored by the Candidate, co-authored by Dr Laurel Lawyer. At the time of submission of this thesis, awaiting submission to a journal not yet specified.

– Study 4: Solely authored by the Candidate. At the time of submission of this thesis, awaiting submission to a journal not yet specified.

– General Discussion/Conclusions: Solely authored by the Candidate. Not awaiting submission.

Abstract

The study of sentence processing in aging has generally resulted in theories that suggest age-related declines and deficits. However, most studies of sentence processing in older adults have conflated cognitive function and memory demands with processing itself. The current project aimed to use implicit, non-declarative methods to investigate whether sentence processing declines with age. Additionally, this project examined memory and processing speed dynamics during sentence processing by recording and manipulating memory demands and taking tests of processing speed.

Three studies of syntactic priming (Studies 1, 3, and 4) and one study of relative clause disambiguation (Study 2) with older and younger adults are presented. In Studies 1 and 3, reliable syntactic priming was recorded in older and younger adults, suggesting sensitivity to syntax remains stable in older adulthood. Intact syntactic priming in older adults further suggests a non-declarative basis for syntactic priming in general, and similar mechanisms underlying syntactic and lexical effects. Study 4 reports a further analysis of syntactic priming patterns across intervening fillers, the persistence of which has important implications for theories of syntactic priming. Study 2 reports similar patterns of relative clause disambiguation in older and younger adults, and equal susceptibility to memory interference manipulations. Effects of Working Memory and Processing Speed were generally minor and did not relate to implicit processing measures.

Taken together, the presented Studies contradict traditional accounts of sentence processing and aging which have described processing impairments. Instead, this project suggests sentence processing itself remains intact with age, and observed deficits in the past are likely the result of explicit memory demands. All studies stress the value of implicit, non-declarative measures of sentence processing to research with older adults, and provide evidence for implicit causes underlying syntactic priming effects.

Contents

1 Review of Literature

1.1 Introduction

The influential author and activist Betty Friedan once described the process of aging as "a new stage of opportunity and strength", emphasising how becoming older has profound positive consequences. Nevertheless, research on linguistic aging has largely focused on drawbacks associated with increasing age. From tip-of-the-tongue phenomena where older adults experience difficulty finding even highly familiar words to problems retrieving information from longer and grammatically complex sentences, age–related linguistic declines appear widespread and could have a wide–ranging impact on daily functioning. Linguistic changes appear linked to age–related broad deteriorations in cognitive functions, including memory capacity, which have been well-attested for decades (Craik, 1994; Wright, 2016), and are thought to be the underlying cause for many of these linguistic declines (e.g. Borson, 2010; Hofer and Alwin, 2008; Soldan et al., 2017). Additionally, a general slowing of cognitive operations as aging progresses (Salthouse, 1996) has been the focus of extensive linguistic research in recent decades, and is thought to exacerbate older adults' language processing difficulties. In short, it appears that becoming older often comes with a range of linguistic challenges and difficulties.

However, not all cognitive and linguistic skills deteriorate with age, and some continue to improve. For instance, older speakers' vocabulary sizes continue to increase: older groups generally outclass younger adults on vocabulary measures (e.g. Moscoso del Prado Martín, 2017). Older adults' continued exposure to language across the lifespan further leads to their possessing higher levels of linguistic experience, which could facilitate increased sensitivity to grammar violations and other aspects of sentence processing (Farmer et al., 2017). Recent research has suggested common linguistic tests are, in fact, biased against older adults' greater vocabulary and linguistic experience: for instance, it could take someone with a greater vocabulary size longer to search their mind for a word than someone with a comparatively smaller vocabulary, leading to delayed word–finding latencies in larger-vocabulary groups; these latencies are then often interpreted as an age-related decline (e.g. Ramscar et al., 2014). Furthermore, age-related impairments on linguistic tasks appear highly dependent on the type of response participants are required to provide. Tasks necessitating declarative, explicit memory recall elicit far greater age effects than implicit processing experiments (e.g. Hardy et al., 2017; Kim et al., 2016; Wingfield et al., 2003). The majority of past studies on older adults' language have nevertheless used explicit methods, and have based conclusions of impaired language processing on these explicit tasks.

The preservation or deterioration of sentence processing specifically is also the topic of significant controversy. Traditional research has generally found reduced accuracy on sentence comprehension measures in older adults and longer latencies to experimental tasks (for a review, see DeDe and Flax, 2016). Sentence processing has frequently been tied to memory ability, specifically Working Memory – given that memory declines strongly with age, dominant accounts of sentence processing and aging suggest this deterioration of the memory system leads to impaired processing. Moreover, some recent research provides evidence for the notion that syntax processing declines even when memory effects are eliminated (Poulisse et al., 2019). Generally, however, much like the aforementioned effects, sentence processing declines do not seem universal, and studies finding preserved sentence processing with age are becoming more frequent (e.g. Hardy et al., 2017, 2020b). This is particularly the case in studies using implicit or non-declarative rather than explicit or declarative methods.

The urgency and relevance of research on older adults' sentence processing is greater than ever before. There is now a greater aging population on the planet than at any time in human history (Eurostat, 2020; United Nations, 2013), and with life expectancies across the globe still rising (Keyfitz et al., 1991; Kinsella and Velkoff, 2001), a larger-than-ever older contingent of the population is having to function in a rapidly-changing and information-heavy society. If older adults' sentence processing is indeed impaired, companies and policymakers must be aware of the challenges this brings to including older groups in business, politics, and society at large.

In short, the study of sentence processing and aging currently leaves a large body of questions unanswered. First of all, it is still unclear whether processing itself declines or whether the effects observed in the past are due to explicit task demands or confounding memory issues. Relatedly, the extent of memory effects and declining speed of processing on sentence comprehension has not been extensively explored from an implicit, non-declarative viewpoint. The present project aims to contribute to this discussion by directly comparing older and younger groups on several different sentence processing measures, focusing on implicit rather than explicit paradigms.

1.2 Aging, Language, Memory

The most prevalent complaint in aging populations is one concerning memory problems. Memory issues in aging appear to stem from a general deficit in the ability to create new episodic and spatial memories, as well as decreased capacity for contextual details and difficulties retrieving information from memory (Leal and Yassa, 2019). For instance, although older adults may recollect the salient details of events accurately, it becomes increasingly harder for them to remember the context in which events take place, and gradual impairments in discriminating between, for example, several different faces of strangers, become more widespread. Although situations such as forgetting where one has left the car keys only to find them already in one's pocket seem innocent enough, memory complaints therefore have wider cognitive consequences. For instance, Kim et al. (2016) found that advertisements targeting older people are often too complex for them to understand. Kim et al. (2016) uncovered little to no differences in comprehension accuracy between older and younger readers when sentences were short and simple. However, age-related declines began to emerge as stimuli complexity and length increased, leading the authors to suggest the increasingly limited memory capacity in older adults cause impairments in the interpretation of sentences. Given that average life expectancy has been growing for decades and a larger part of the population is expected to age (Eurostat, 2020; United Nations, 2013), the relevance of sentence processing research in aging is now greater than ever before.

The rate at which cognitive skills decline appears to be dependent on a large amount of intrinsic and extrinsic variables, including but not limited to educational and occupational attainment, history of (cardio-)vascular conditions, dietary restrictions and caffeine consumption, exercise, and sleep patterns (Geda et al., 2010; Leal and Yassa, 2019), highlighting how heterogenous the process of aging can be. Adults with a healthy lifestyle and regular sleep cycle are less susceptible to severe cognitive decline, a kind of resistance which appears boosted by regular cognitive and physical exercise (Barnes, 2015).

As summarised in Section 1.1, language is among the many skills that undergo changes during the process of aging. On the surface, older adults may exhibit difficulties with word-finding, resulting in an increase in so-called tip-of-the-tongue experiences (Ouyang et al., 2020); generally, speech rates are also slowed and it may take older adults more time to correctly process and interpret written and spoken language (Salthouse, 1996). Furthermore, abundant evidence suggests older adults' sentivity to and attention for semantic informaton changes drastically. For instance, Zhu et al. (2019) found that older adults show a disadvantage compared to younger groups when attempting to integrate semantically incongruous stimuli into wider discourse. Conversely, semantic abilities have also been put forward as potential compensation mechanism for memory declines or syntactic processing impairments (e.g Poulisse et al., 2019), especially in sentence processing studies.

1.2.1 Working Memory, Aging, and Language

Working Memory has frequently been cited as one of the most crucial cognitive functions predicting sentence comprehension. The term Working Memory (hereafter WM) refers to a limited-capacity system used for the temporary storage, processsing, and subsequent retrieval of informational cues (Baddeley, 2010). WM differs from Long-Term Memory in that WM does not permanently store information, and from Short-Term Memory in that there is concurrent processing of information involved in WM retention. Thus, while hearing a phone number and writing it down half a minute later while scrambling for a pen and paper is a task involving Short-Term Memory, writing down the same phone number in reverse order involves concurrent processing and therefore includes a WM component. In a linguistic context, there are three crucial cognitive operations necessary for successful use of WM: first, the *encoding* or storage of linguistic cues in the memory system; second, the *maintenance* of those cues, even under conditions where those cues are subject to concurrent processing; and third, the *retrieval* of cues at the right time (see Lewis et al., 2006, for a discussion). This implies that the processing of some grammatical structures (which require more and more extensive memory operations) places greater demands on the WM system than others, something which will be discussed extensively below.

Early research on WM proposed various hierarchical models of the memory system, including sub-systems that underlie the three operations necessary for successful WM use. Conversely, linguistics-based research involving WM is often less concerned with formal modelling of the WM system, but rather takes a functional approach, making predictions of how linguistic effects may be manipulated by WM in general. The remainder of this section discusses some of these formal and functional models in turn.

Arguably the most influential model of WM is that of Baddeley and Hitch (1974). Recent versions of this model propose four main components: (1) the central executive, a mechanism controlling attentional capacity, which is subserved by three 'slave' systems: (2) the phonological loop, which rehearses auditory input and holds verbal and acoustic information, (3) the visuospatial sketchpad, which maintains visual, spatial, and kinaesthetic (body movement) information, and (4) the episodic buffer, accounting for temporary storage and interaction between the different slave systems and, importantly, between WM and long-term memory (see further Baddeley, 2000). The central executive is thought to arrange the attentional resources dedicated to these two slave systems, and act as the locus where cues from one system inform and combine with information from another. Thus, with four main components and an extensive network of interacting cognitive functions, the Baddeley and Hitch (1974) model has found extensive application across neuropsychology, education, psychiatry, and importantly, linguistics (Baddeley, 2010). A visualisation of the model is given in Figure (1).

Turning from formal cognitive modelling to linguistic applications, vigorous academic debate rages between competing WM-based explanations of language-specific findings. In a seminal study, King and Just (1991) investigated the role of WM capacity in the interpretation of object relative sentences, such as *"The reporter that the senator attacked admitted the error"*. The authors hypothesised that the large amounts of information that need to be retained in WM while interpreting sentences such as this should cause problems for low-memory (or *low-span*) readers: upon encountering *'that'*, NP1 (*'the reporter'*) must be stored and maintained while the relative clause is read; furthermore, the verbs *'attacked'* and *'admitted'* must be connected to the correct NPs, *'the senator'* and *'the reporter'*, respectively. Finally, the demands of storing NP1 (*'the reporter'*) as the subject of *'admitted'*, but as the object of *'attacked'*, was thought to tax WM capacities even further. King and Just (1991) drew contrasts between these complex object relatives and the highly similar subject relative, as in *"The reporter that attacked the senator admitted the error"*. In this sentence, the only WM retention required is that of *"the reporter"*, which is resolved at the end of the relative clause. King and Just (1991) presented high- and low-span participants with pairs of these

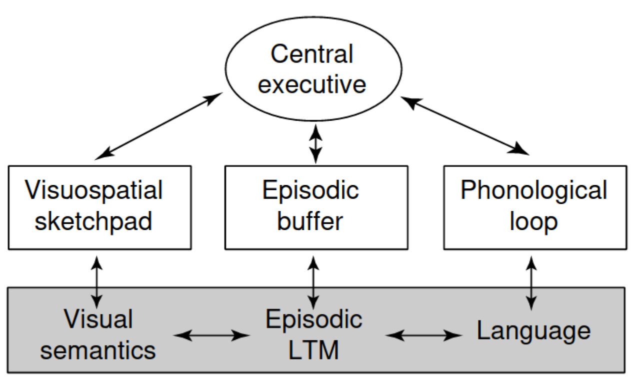


Figure 1 – Baddeley and Hitch's revised model of WM (Baddeley, 2010)

constructions to investigate the receptive effects of WM.

Although high-span readers were found to comprehend all sentences better than low-span participants, span effects were significantly larger for object relatives as opposed to subject relatives, such that low-span readers processed object relatives disproportionately slower than subject relatives. By-word reading times for low-span readers on object relatives increased at the point at which all dependencies are resolved (in the above example, at the verb *admitted*), while high-span readers did not show such effects (King and Just, 1991). This suggested that low-span readers required far more time to integrate the various dependencies created in object relatives compared to subject relatives, but that high-span readers did not show such differences. Figure 2 illustrates these reading time results.

This groundbreaking evidence was then formalised into a capacity-based theory of language comprehension by Just and Carpenter (1992). This theory claims that WM deficits are one of the main sources of differences in sentence comprehension speed and accuracy due to an *activation mechanism*. Items are retained in WM by means of memory resources *activating* informational cues, increasing their salience and prominence in memory in preparation for retrieval: sufficient activation is necessary for successful retrieval at the correct stage. Low-span readers, following this account, have insufficient resources in their activation pool to successfully interpret highly complex sentences. An activation-focused model has important implications for the current project, as one of the main theories of syntactic priming implicates activational resources as the central underlying cause for priming effects. These accounts are discussed further in Section 1.4. The Just and Carpenter (1992) model of WM proposes a single, unified system of activational resources underlying all of WM, and therefore differs from the Baddeley and Hitch (1974) model. Rather than accrediting differences observed between functions of WM or different types of WM task to various WM sub–systems, Just and Carpenter (1992) consider these effects the result of the WM system allocating varying levels of activation to different tasks (Just and Carpenter, 1992).

Aging and the associated reduction in WM resources can, following this capacity-based

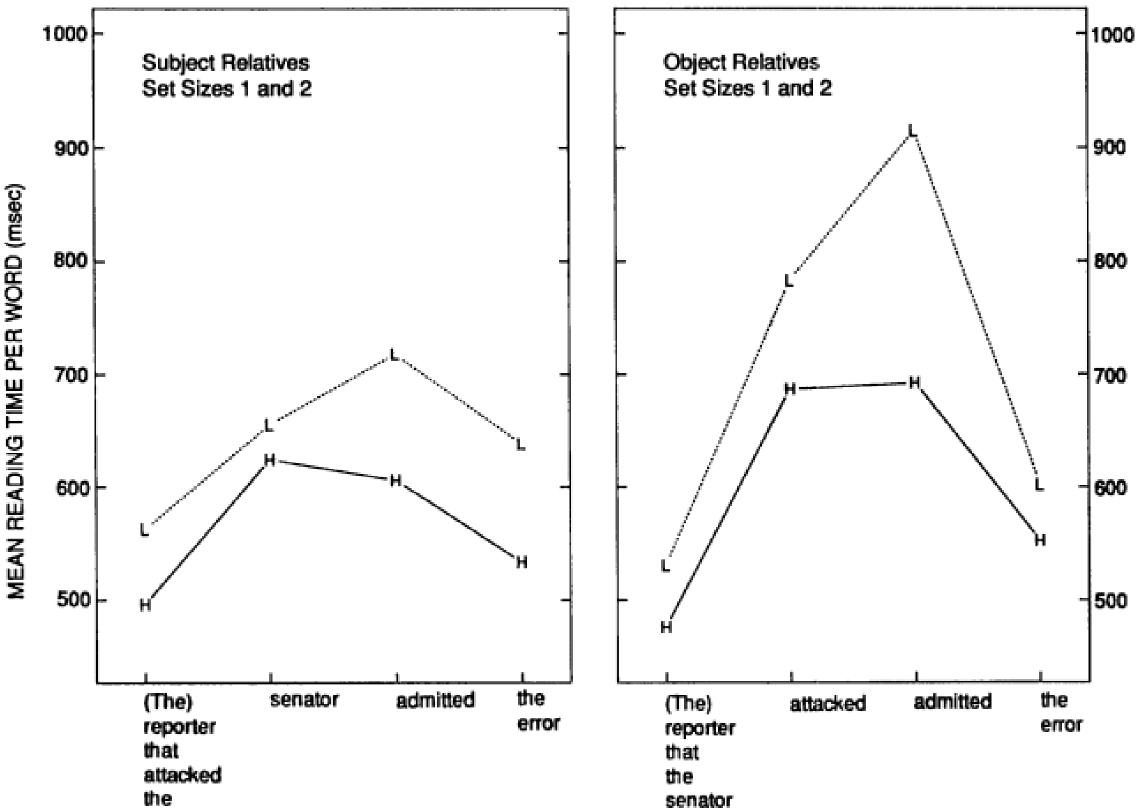


Figure 2 – Reading times by sentence region in King and Just (1991)'s first experiment, showing clear differences between low-span (marked with "L") and high-span groups (marked with "H") on reading times for object relatives (right pane) especially.

theory, be boiled down to a gradual reduction in available activation levels as aging progresses. Indeed, Just and Carpenter (1992) consider language impairments generally to be the result of WM-limitations rather than any language-specific deficits. For instance, the case is made that aphasia, a type of language impairment often resulting from traumatic brain injury, may instead be a WM-related deficit. The huge symptomatic variability and the non-linguistic implications of aphasia are made possible in the capacity-based theory by the single WM component underlying all of cognition.

This single WM monolith, however, came under severe scrutiny some time after the capacity-based theory was presented. Specifically, Waters and Caplan (1996a) heavily critiqued the capacity-based model, claiming that Just and Carpenter (1992)'s data was insufficient for the formulation of a full model, that the statistics used were poor and incorrectly done, and that the capacity-based theory fails to account for a large amount of neurpsychological evidence. In particular, Waters and Caplan (1996a) critique the notion that one WM system underlies all linguistic tasks and that many language impairments actually stem from WM-related issues. To support this critique, Waters and Caplan present large amounts of evidence which show very weak correlations between different measures of WM, such as digit span (remembering and recalling an incrementally increasing number of digits) and reading span (remembering the final words of incrementally increasing numbers of sentences). Waters and Caplan (1996a) approach WM from a modular perspective, claiming the lack of correlations between span measures must mean that separate WM systems underlie WM processes.

More specifically, Waters and Caplan (1996a) argue that although one resource pool is available to WM systems, clear distinctions must be made between those tasks relying on *conscious* (also known as *declarative*) processing and those relying on *unconscious* (or *non-declarative*) processing. In this sense, unconscious processing includes, for instance, sentence processing, and instantaneous lexical access during production. Examples of conscious processes include an active search through semantic memory for a word or answering a comprehension question about a recently read paragraph. This distinction between conscious and unconscious, explicit and implicit, linguistic tasks, appears crucial to the linguistic aging literature — the vast majority of paradigms finding impaired sentence processing in older adults used explicit tasks, such as comprehension questions. Moreover, WM is a clear measure of explicit capacity, as all span tasks require the active regurgitation of information. It could therefore be the case that implicit sentence processing is affected differently by aging than explicit measures. The current project therefore places a large emphasis on implicit measures of sentence processing in an effort to uncover whether processing *itself*, the absence of declarative demands, is impaired with age.

Both the Just and Carpenter (1992) and Waters and Caplan (1996a) models assume that WM *capacity* is the main source of individual language processing differences, despite varying proposals of what form this capacity takes. However, this is not the only conceptualisation of WM that has been put forward. MacDonald and Christiansen (2002) consider WM in a completely different light: MacDonald and Christiansen suggest making a functional distinction between WM and linguistic ability (i.e. hypothesising that one can predict the other) is fundamentally wrong: their *connectionist* approach stresses the mutual and constant interaction of speakers' ccognitive abilities and linguistic experience. This interaction results in the individual differences observed in earlier studies. MacDonald and Christiansen (2002) stress the importance of linguistic experience to processing: experience is thought to stem from the amount of reading done in childhood, or how much a child was read to, as well as the linguistic situations readers have found themselves in throughout the lifespan (e.g. those with professions in psycholinguistics have different linguistic experiences compared to those working in literary criticism).

MacDonald and Christiansen (2002) also claim that span tasks do not test WM in particular since no such construct as WM exists in their view. Instead, they propose that these tasks test processing skills, and as such any correlations made between span tasks and language processing tasks are, effectively, meaningless. Indeed, there is controversy in the literature about what WM tasks genuinely tap into WM and which use only STM or attentional processes. Forwards digit span tasks, where a sequence of numbers must be stored and recalled in the same order, does not appear to require any processing of numbers in itself, and has therefore been described as a task measuring short-term memory and attentional ability (Cullum, 1998). Reading span, which requires the storing and retrieval of words from sentences that must be rated for grammaticality or appropriateness, and subsequent recall of those words, appears to involve much more processing and has therefore been used extensively as a WM measure (Daneman and Carpenter, 1980).

The approach taken by MacDonald and Christiansen (2002), however, appears to jar with the finding that older speakers usually show greater linguistic experience, especially on tasks of verbal fluency and vocabulary size. Following the connectionist model, this should give older adults an advantage on WM-related tasks rather than the commonly observed disadvantage. MacDonald and Christiansen do not discuss this apparent conflict with their theory, however they refer to the observed general slowing theory of Salthouse (1996) as the main reason why older adults may show different linguistic behaviour to younger groups. This account is discussed extensively in section 1.7 below.

Relating individual differences in WM to language comprehension is not always straightforward. Apart from the necessity for any recorded sample to exhibit individual variation in predictor measures, the statistical techniques used to relate a predictor measure to a dependent variable have, in past research, been lacking or even non-existent (refer to the discussion of Just and Carpenter, 1992; Waters and Caplan, 1996a, below). Perhaps more poignantly, it is often not completely clear what individual differences on a predictor measure actually mean (e.g. Daneman and Hannon, 2007; Salthouse, 1992). Lower scores on a digit span task may reflect WM declines, but speed of processing, motivational aspects, and extrinsic factors such as physical health all affect these scores. In particular when studying something as multifaceted as aging in particular (for a review, see Lara et al., 2015), the limitations of a correlational approach such as that taken by past studies of language processing and aging, as well as the current project, must be acknowledged. With this considered, this project includes visualised distributions of its individual difference measures in the presented studies and used statistical techniques that do not rely only on correlation of measures. The General Discussion (Chapter 6) returns to this debate further.

Relatedly, debate exists around the most effective measure of WM to employ for individual difference research (e.g. Daneman and Hannon, 2007; Friedman and Miyake, 2004, 2005). In particular, what separates WM from Short-Term Memory is, as summarised above, the concurrent processing and storage of information in WM. Short-term memory involves only temporary storage, with little to no concurrent processing requirement. Considering popular WM tasks used in linguistic research, digit span (where a sequence of numbers must be recalled in the same order in which it was presented) requires virtually no concurrent processing, and is therefore more suited to a test of Short-term memory. Reverse digit span, where the sequence of numbers must be recalled in reverse order, involves comparatively more processing. *Complex* span tasks, such as Reading and Operation span, require the resolution of a short task (such as the rating of a sentence for appropriateness in Reading span or the calculation of a maths equation in Operation span) while, concurrently, informaiton from those tasks must be remembered and recalled subsequently (Redick et al., 2012). Complex span tasks therefore tap WM resources more directly than simpler tasks such as digit span, and these were therefore used in this project. Given that the majority of literature related to language, aging, and WM has focused on the Reading Span Task, this is the task selected for this project.

1.2.2 Testing WM Effects: Relative Clause Disambiguation

A task that has been used extensively in the study of WM and language is sentence disambiguation. In sentences such as (1), it is ambiguous whether the referent of the relative clause "that looked old" is the "owner" (NP1) or the "house" (NP2). Conversely, in (2), clause attachment is biased to *high* attachment, to the "owner", as it is implausible the house had a moustache. Finally, *low* attachment is illustrated in (3), with the plausible option being attachment to the "house". Native English speakers have been found to generally prefer NP2-attachment, a strategy known as *recency* (e.g. Altmann et al., 1998; Frazier and Rayner, 1982).

(1) The owner of the house that looked old appealed for help.

(2) The owner of the house that had the moustache appealed for help.

(3) The owner of the house that needed renovation appealed for help.

Various authors have determined an impact of WM on attachment preferences, in line with Just and Carpenter's (1992) individual differences theory. For instance, Felser et al. (2003) studied attachment ambiguity preferences in children with high and low WM spans, as well as adults who were not tested for WM, using a self-paced listening experiment. Their results suggested adults were generally biased towards an NP1 preference, while children's bias varied along WM lines. High-span children showed similar attachment preferences to adults, while low-span children showed an NP2 bias. In Felser et al.'s view, low-span participants had insufficient memory capacity to store NP1 and NP2 concurrently, leading to more defined *Recency* strategies in low-span children.

Swets et al. (2007) tested the Recency principle and its relationship to WM directly by presenting 247 Dutch- and English-speaking adults with externally-segmented sentences. Swets et al. hypothesised that by forcing participants to insert a prosodic break in between NP1 and NP2, the salience of either NP (and therefore, the activational WM resources dedicated to them) might be affected, leading to different attachment preferences. For instance, the sentence in (1) would be segmented as "The owner of the house // that looked old // appealed for help." Swets et al. (2007) found attachment patterns directly contradicting Felser et al. (2003): low-span participants attached preferentially to NP1, which Swets et al. put down to NP1 being stored in WM earlier than NP2. Notably, presenting sentences in chunks biased high-span readers to attach to NP1 along with their low-span counterparts – the increased salience of NP1 in high-span readers' WM was forwarded as the main cause for this effect (Swets et al., 2007).

Traxler (2009) tested this chunking hypothesis in an eye-tracking study, and although some indications were found for high-span readers preferring NP1 attachment, this result was only apparent in one of several eye-tracking parameters and its effect size was minor. Traxler (2009) therefore suggest that any influence of WM capacity on attachment preferences is small, at least during implicit reading. This links back to the distinction made by Waters and Caplan (1996a), suggesting that explicit linguistic tasks may be more directly subserved by WM than implicit tasks. Traxler's (2009) stimuli were chunked across several lines, following the Swets et al. (2007) account, which resulted in a general NP1 rather than NP2 bias, further suggesting that chunking of information can affect disambiguation preferences.

Importantly, chunking effects are genererally increased with age, leading older readers to group words into smaller syntactic blocks during reading (Stine-Morrow and Miller, 2009; Stine-Morrow et al., 2010). This has important implications for attachment preferences, which may therefore change with age. Payne et al. (2014) recognised how findings from attachment ambiguity and chunking in aging may be tied together, and conducted a WM-based study of disambiguation in in older adults. If greater age results in increased chunking, older adults should be more biased towards NP1 attachment. Contradicting this hypothesis, Payne et al. (2014) found that both younger and older participants experienced more processing difficulty on NP1 biased sentences, as evidenced by self-paced reading times. However, offline comprehension biases, measured by questions presented after sentence reading, were modulated by WM span, such that low-span older adults showed offline biases towards attaching to NP1.

There are, therefore, some indications that age may affect attachment preference, however the extent to which this is the case is still unclear. Some evidence from disambiguation studies favours Just and Carpenter's (1992) individual differences account, especially evidence based on offline judgements (e.g. Swets et al., 2007). However, WM capacity may not be as influential on online biases, as demonstrated by Traxler (2009) and Payne et al. (2014). The aforementioned limitations on the scope and reliability of WM span measures further suggests that alternative angles of viewing WM may be worthwhile: accounts such as MacDonald and Christiansen's (2002), which does not view the memory system as purely capacity-based, would suggest that WM span measures would naturally suffer from low predictive power in linguistic experiements. Instead, another branch of research has looked into what effects the *quality* of WM operations might have on attachment preferences. The next section discusses some of these studies.

1.2.3 Similarity-based Interference

Traditional views which see WM as a limited-capacity system that can overload during language comprehension have led to the conclusion that WM-impaired comprehenders suffer difficulty when interpreting long and complex sentences. Additionally, low-span readers are thought to be predisposed to different syntactic interpretations compared to high-span readers. However, Van Dyke and McElree (2006) considered this may not paint an accurate picture of the nature of WM, what information is maintained therein, and how that information is organised and interacts with other pieces of information. Van Dyke and McElree therefore concur with MacDonald and Christiansen's (2002) view that capacity-based theories of WM are incomplete, and other factors must be at play that explain WM-related variance on linguistic tasks. Specifically, Van Dyke and McElree (2006) proposed that interference of cues with other cues may cause many WM-based effects which were traditionally attributed to capacity limitations.

Van Dyke and McElree (2006) suggested that this interference creates an overload of associations between cues in WM, which causes information to become entangled and far less easy to selectively retrieve when necessary. To test this, Van Dyke and McElree (2006) presented participants with memory conditions in a self-paced reading task: no memory load, where participants read sentences without having to store any additional information in WM; non-interfering load, with participants asked to maintain three words (semantically unrelated to the stimulus sentence) and recall them after reading; and interfering load, where the words to recall bore semantic similarity to the stimulus items. For instance, for the item *"It was the boat that the guy who lived by the sea sailed in two sunny days"*, interfering words might include *"navy—captain—sink"*, compared to non-interfering words such as *"dancer—fireman—truck"* (Van Dyke and McElree, 2006). The non-interfering load condition was found to elicit significantly more accurate responses on the comprehension questions after reading, and reading was slowed in the regions where interfering words semantically matched content in the sentences. Van Dyke and McElree (2006) concluded that being able to distinguish between alternatives in WM, even in the face of this *'similarity-based interference'*, appears key to successful language understanding, perhaps more so than the capacity of the WM system.

This idea of similarity-based interference was further explored by Gordon et al. (2006), who conducted multiple studies to examine the effects of linear proximity (the distance between the point at which a cue is encoded and at which it is retrieved), proper v. common nouns, and transitivty on interference. Although reading slow-downs caused by similarity-based interference were widespread, these interference manipulations were found to elicit no effects at all when the stored NP was fully integrated into surrounding discourse before interference could occur – directly evidencing that this type of interference exists if two similar cues are present in memory at the same time, but not when cues have already been integrated. Similarity-based interference has not been explored in older adults' language comprehension. Despite this, connecting similarity-based interference to linguistic research with older adults' has the potential to inform theories of WM, uncover whether linguistic preferences change with age, and whether these changes are affected by decreased quality of WM operations.

In sum, the most appropriate way from which to approach WM appears to be difficult to determine, and what specific impact WM may have on sentence processing is even more unclear. Accounts of the structure of WM range from models including various different components that subserve different (linguistic) functions, such as the Baddeley and Hitch (1974) and Waters and Caplan (1996a) models, to accounts emphasising the shared, underlying nature of the WM resource pool which is accessible by all linguistic tasks (Just and Carpenter, 1992), to models which do not accept the traditional separation between knowledge on the one hand and WM capacity on the other, and instead prefer to put performance differences down to individual differences in neural architecture and experience (MacDonald and Christiansen, 2002). Considering WM from not only a capacity-based, but also a quality-based perspective has proven effective in past research, although this angle has not hitherto been applied to research with older adults. Generally, however, it is clear from research finding varying reading performance that is not predicted by WM (e.g. Traxler, 2009), that memory cannot be the only factor that affects sentence processing performance in older adults. The following section discusses some of these potential factors.

1.3 Age-Specific Sentence Processing Declines

Rather than implicating memory deficits as the cause of observed age-related declines on sentence processing, some early studies considered impairments the result of some undefined language deficit. Obler et al. (1991) set out to investigate the impact of various cognitive functions on sentence processing in older adults, including inhibition (the suppression of irrelevant information), WM, and attention span. Obler et al. (1991) asked participants to read sentences with varying syntactic complexity and word length, and to answer a comprehension question after each sentence. Error patterns in the older group showed performance affected by sentence type and length, with complex sentences such as double embedded and double negative sentences eliciting the most errors (examples of these types are given below, from Obler et al., 1991). Notably, each of the cognitive functions Obler et al. recorded only had minimal explanatory power on the error rates obtained, suggesting errors are the result of aging itself.

(4) The doctor who helped the patient who was sick was healthy. (Double embedded)

(5) The bureaucrat who was not dishonest refused the bribe. (Double negative)

The older group was, however, slower to respond to comprehension questions across sentence types. Obler et al. (1991) hypothesise this general slowing of cognitive performance may be found across the language faculty and beyond. Section 1.7 discusses the processing speed theory of aging in more detail. Furthermore, Obler et al. (1991) also discovered that implausible sentences (where the semantics had been manipulated in such a way that the sentence was grammatical but nonsensical) caused greater difficulties in the older population, which is suggestive of semantic abilities acting as a type of shielding to syntactic impairment. These types of possible compensation mechanisms in older populations are discussed more extensively in section 1.8. The Obler et al. (1991) study thus made three main important discoveries: (1) the possibility exists that a syntactic impairment is part of the aging process; (2) a general slowing of reaction times and cognitive performance is likely in aging; (3) compensation mechanisms may be at play which allow for fairly accurate behavioural performance in some linguistic domains. The remainder of this review discusses each of these points in turn.

First, following Obler et al.'s (1991) results, which indicated no relationship between WM measures and sentence processing errors, research shifted towards uncovering whether WM affects all, many, or just some processing measures in older adults. Waters and Caplan (2001) set out to investigate this relationship further using a self-paced listening paradigm, measuring reaction times and comprehension accuracy. Older adults generally scored lower on WM span measures than younger adults, but there was no evidence that older listeners were differentially affected by syntactic complexity on listening times. There was, furthermore, only weak evidence of a relationship between age, WM, and scores on comprehension questions. Waters and Caplan (2001) consider these findings in light of Just and Carpenter's (1992) theory that WM is one of the main predictors of linguistic performance, especially in aging, and conclude their study offers no evidence for this. Additionally, Waters and Caplan's (2001) findings again stressed the distinction between implicit and explicit processing. While explicit measures may be sensitive to WM-related declines in some cases, Waters and Caplan consider implicit processing to be independent from WM effects. This is an important notion which this project aims to address.

The Waters and Caplan (2001) findings were complemented by Caplan and Waters (2005) and Caplan et al. (2011), whose results again indicated only a very minor relationship between sentence comprehension and WM measures, especially on implicit processing. However, Caplan et al. (2011) found severely lower comprehension accuracy in older adults, as well as significantly longer processing times at demanding points in complex sentences. Specifically, Caplan et al. found slowdowns around verbs contained in relative clauses in cleft sentences (such as *"It was the movie that terrified the child"* or *"It was the child that the movie terrified"*), which are generally considered hard to process. Greater age was also associated with longer reading times on these complex sentences compared to simple control items, but this effect was not related to WM scores or speed of processing (Caplan et al., 2011, Experiment 1). This suggests an age-specific decline in syntax processing independent of WM or processing speed.

Aiming to explore the relationship between WM and syntax processing further, Poulisse et al. (2019) investigated a large sample ($n = 100$) of older and younger readers in a grammaticality judgement test involving the shortest possible sentences, consisting of only two words (e.g. *"I cook"*). Agreement errors (*"I cooks"*) were included in the stimuli and pseudoverbs (*"I spuff"*) were compared to real verbs. Poulisse et al. (2019) found that even on short sentences older adults' speed and accuracy on grammaticality judgement measures declined compared to younger controls. Furthermore, the decline in speed was larger for pseudoverbs, suggesting that an absence of semantic content (which may help compensate for slower processing; see Section 1.8 below) caused greater declines. Poulisse et al.'s (2019) findings are noteworthy given that declines were observed while WM load was kept to a bare minimum; the addition of pseudowords also provides an insight into possible compensation mechanisms at play in older readers, something which will be expanded on below. Poulisse et al. conclude that older adults show impaired sentence comprehension even when processing items involving no demands on WM at all.

However, as emphasised by Waters and Caplan (1996a), Caplan and Waters (2005), and Caplan et al. (2011), a large dissociation exists between older adults' implicit and explicit performance on sentence processing measures. Poulisse et al.'s (2019) conclusions of WM-independant impaired comprehension were based on agreement error detection, an explicit measure. Obler et al.'s (1991) findings, which also pointed to an age-specific sentence processing impairment, were similarly the result of explicit tasks. The possibility therefore exists that the demands of active memory searches required for explicit tasks are associated with age-related declines, but implicit processing, and therefore, non-declarative performance, is not.

1.4 Implicit Comprehension and Priming

An informative angle from which to approach older adults' sentence comprehension therefore involves implicit, unconscious tasks, which do not require active memory recall. One such task that has recently been applied to aging populations is syntactic priming.

Syntactic priming occurs when the reading or hearing of a syntactic structure facilitates the comprehension or production of the same structure later. Priming of this sort can occur in production, where speakers preferentially use structures they have used before to describe similar events, or in comprehension, where sentences of similar structure to previous items may be processed faster than sentences with different word orders (Yan et al., 2018). Debate exists around whether syntactic priming reflects persistent activation of syntactic representations, implicit learning, a combination of both, or involvement of other related cognitive functions (for reviews, see Mahowald et al., 2016; Tooley and Traxler, 2010).

Bock (1986) first formulated the principle that speakers align along the dimension of syntactic structure in normal speech. Priming had been relatively well-attested in semantics (e.g. Collins and Loftus, 1975; Sperber et al., 1979), subcategorisation (e.g. Blaxton and Neely, 1983; Higgins et al., 1985), and phonological-orthographical domains (e.g. Bowles and Poon, 1985), but syntactic priming had up to that point scarcely been documented. Bock (1986) asked participants to view and repeat active (*"One of the fans punched the referee"*), passive (*"The referee was punched by one of the fans"*), prepositional (*"A rock star sold some cocaine to an undercover agent"*) or double object sentences (*"A rock star sold an undercover agent some cocaine"*) before presenting them with a semantically unrelated drawing to describe. This simple yet highly effective experiment demonstrated robust priming effects: participants were up to 23% more likely to use a structure when they had been primed with that structure, indicating that participants were significantly influenced in the structure they used to describe the unrelated picture by the sentences they had just repeated. Bock already speculated this effect appeared to occur independently from lexical overlap between prime and target, however this was not conclusively demonstrated until well over 30 years after the publication of her paper.

While Bock's (1986) experiment focused on productive syntactic priming, the same phenomenon in comprehension appeared harder to determine, especially when primes and targets did not share any lexical elements. In a study of prepositional phrase attachment, Branigan et al. (2005) found participants were more likely to prefer a strategy of high attachment (e.g. in the sentence *"the spy saw the cop with the binoculars"*, high attachment interpretations see the spy as having the binoculars) after reading primes with unambiguous high-attached phrases. However, this effect was eliminated when primes and targets did not share the same verb, leading to the conclusion that syntactic priming is verb-dependent.

Nevertheless, effects of syntactic priming were clearly dissociated from effects of verb overlap in an ERP study by Ledoux et al. (2007). Their experiment involved reduced relative clauses (e.g. *"The manager proposed by the directors was a bitter old man"*) combined with main clause sentences (e.g. *"The speaker proposed the solution to the group"*). Targets were always reduced relatives, while primes varied between main clause and reduced relative structures; lexical overlap was also manipulated such that some Targets contained both lexical and syntactic overlap with Primes. Event-related potentials were recorded at the critical noun following disambiguation (i.e. *directors* in the above example) and a larger positive shift around 600ms post-onset (P600) was found for reduced relative targets primed with main clause primes compared to matching reduced relative primes. This effect occured indepdently from lexical overlap, and therefore directly implicated syntactic structure as a source of priming.

The causes of syntactic priming are still contentious. A dominant explanation takes a similar view of priming as the individual differences in WM theory by Just and Carpenter (1992), as discussed in section 1.2.1, in that lingering activation of cues causes those cues to be more easily retrieved after processing. These *residual activation* models suggest that, much like in semantic priming, the prior acivation of a syntactic structure node lingers until after the processing of one structure has finished, causing facilitated processing of another such structure shortly afterwards (Pickering and Branigan, 1999). However, this finding contradicts the persistent nature of syntactic priming: effects are often found to persist across multiple intervening filler sentences and even across experimental sessions. Chang et al. (2006, 2012) and Tooley et al. (2019) suggest syntactic priming can instead be attributed to an error-based implicit learning mechanism, in which repeated exposure to a structure leads to facilitated processing of that structure as the processor gains experience with the grammar. In this sense, "error" refers to sets of constraints placed on participants' performance, including past experience, experimental conditions, sudden adaptations of behaviour, and expectations (Fine et al., 2013).

However, implicit learning accounts struggle to explain the varying persistence of syntactic priming when lexical overlap is deliberately excluded compared to when verbs do match. The magnitude of priming effects is increased by matching verbs between prime and target, an effect known as the *"lexical boost"*. While syntactic priming effects persist across several experimental items, as mentioned above, the lexical boost is short-lived and rarely persists any further than the target sentence or one intervening filler (Hartsuiker et al., 2008). The lexical boost therefore cannot rely on implicit learning. Instead, it has been suggested that lexical boost effects rely on residual activation, while syntax-only priming is a purely implicit learning-related effect, leading to *hybrid* accounts of priming (Reitter et al., 2011; Traxler et al., 2014).

Conversely, syntactic priming could be a result of *expectation adaptation* rather than memory demands or implicit learning specifically (Jaeger and Snider, 2013). Speakers continually adapt the lexical domain, phonological constraints, and syntactic structures they expect to use and encounter during speech. Findings of anticipatory eye movements (e.g. Thothathiri and Snedeker, 2008) during reading seem to be consistent with this view. Under an expectation adaptation account, syntactic priming effects are a function of *prediction error*, that is, the discrepancy between speakers' expectations and their environment. During syntactic priming tasks, speakers align with their experienced environment (which involves the presentation of the same syntactic structure) and consequently show facilitated processing in the environment with which they are aligned. Jaeger and Snider (2013) present evidence showing that the more significant the dissociation between initial expectations and the level to which speakers must adapt (in other words, prediction error), the more significant the priming effect. Findings of cumulative priming (e.g. Kaschak et al., 2011) as well as the robust discovery that less frequent structures (i.e. those with higher prediction errors) are more susceptible to priming (e.g. Bock, 1986) also align with the adaptation account.

Following expectation adaptation accounts, no hybrid or dual-mechanism model of syntactic priming and the lexical boost is required. Instead, lexical boost effects are also the result of expectation adaptation: prediction error is determined by the amount of lexical overlap between sentences, and processing is facilitated when there error is reduced, that is, when lexical overlap is more expected (Jaeger and Snider, 2013). The faster decay of lexical boost compared to syntactic priming is explained as a rational response to environmental statistics: lexis is topic-specific, and speakers change topics frequently. However, syntax is not specific to any given topic and expectation adaptation would therefore have a longer impact.

Finally, Heyselaar et al.'s (2021) model of priming is mainly rooted in findings from priming in aging (see Section 1.5), demonstrating how studying older groups can inform theoretical accounts of linguistic phenomena. Heyselaar et al. (2021) propose that both aspects of priming are subserved by *different components* of non-declarative (i.e. implicit) memory. Thus, this account differs from both Chang et al.'s (2012) model, which focuses on one single implicit cause, and dual-mechanism models like Reitter et al.'s (2011), where lexical effects are rooted in explicit cognition. The Heyselaar et al. (2021) account theorises that abstract syntactic priming is subserved by *conceptual memory*, which is responsible for statistical learning, while the lexical boost is rooted in *perceptual memory*, which retains activation of recently processed information. Crucially, both processes are implicit, non-declarative, and groups with declining explicit memory skills should, following this account, still show both abstract priming and lexical boost effects.

As Heyselaar et al. (2021) state, findings from older and "atypical" speakers (such as patients with clinical amnesia, aphasia, or dementia) could inform these different accounts of priming. Pickering and Branigan's (1998) residual activation account would be contradicted by intact syntactic priming and lexical boost effects in older adults, as activational strength has been found to decay more rapidly with age (Salthouse, 1996, see also section 1.7 below). Similarly, if older adults or memory-impaired patients show intact syntactic boost effects, this would also contradict Reitter et al. (2011) and Traxler et al. (2014), whose account of the lexical boost relies on explicit causes. Few studies to date have investigated priming in older or atypical speakers, and much remains unclear about priming in these groups.

1.5 Syntactic Priming and Aging

Syntactic priming in groups with impaired memory was first studied in amnesic patients by Heyselaar et al. (2017), whose group showed severe declines on explicit but not implicit memory. Heyselaar et al.'s (2017) priming task involved prompting participants to describe a picture presented to them after being primed with different grammatical structures, and resulted in a robust priming effect in the amnesic group. This suggests that priming does not rely on the explicit recall or residual activation, as hypothesised by Pickering and Branigan (1998). However, the healthy control group in the Heyselaar et al. study did not show priming effects, which is remarkable given that the control group scored far higher on measures of memory than the patients. More research into typical older adults' priming patterns was therefore clearly needed.

More recently, productive priming studies by Hardy et al. (2017, 2020a,b) employed scripted dialogue tasks in which the experimenter read out cards with either active or passive sentences and prompted the participant to respond. Hardy et al. (2017) 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 largely corroborated in later studies studies (Hardy et al., 2020a,b), resulting in a general conclusion that minimal syntactic processing differences were observed between younger and older groups. Taken together, findings from Hardy et al. (2017, 2020a,b) and Heyselaar et al. (2017) suggest syntactic priming is not dependent on active recall or explicit memory. However, all of the above studies focused on priming in *production*, while syntactic priming in *comprehension* may be sensitive to different cognitive functions.

The void in the comprehension priming literature on older speakers was partially filled by a preliminary study by Hosokawa (2018), although no direct comparisons between younger and older speakers were made in this study. Hosokawa (2018) used a written sentence-picture matching task with a group of 20 older adults and found robust effects of syntactic priming, even persisting over two intervening filler sentences, but no significant lexical boost. These results contradict Hardy et al.'s (2017) but are expected by the suggestion of hybrid priming models (Reitter et al., 2011; Traxler et al., 2014), discussed above, that lexical and syntactic priming rely on different memory types. The adults in Hosokawa's (2018) investigation were compared to a younger group from a different study and were found to have reduced WM capacity overall (though they scored higher than the younger group on vocabulary size). This could suggest WM may have an impact on lexical boost effects, and when considered in tandem with the issue of task demands, may begin to elucidate the processes behind priming in older adults.

In sum, while some evidence suggests both priming and the lexical boost are intact in older adults, at least in production, the little available evidence on priming in comprehension suggests otherwise. This unresolved difference warrants further research into older adults' syntactic comprehension priming, and this project aims to offer more evidence in this regard. As discussed in sections 1.2.1 and 1.3, task demands may have a significant impact on older adults' linguistic performance. Fortunately, syntactic priming has also been recorded using neuroimaging and eye-tracking methods, potentially offering a more direct window into older adults' syntactic processing than behavioural tasks. There are, nevertheless, important caveats to take into account when investigating older adults' ERP patterns. As discussed below, age may have a general slowing or attenuating impact on ERP waveforms, which could complicate the analysis of priming effects from a neuroimaging viewpoint.

1.6 Neuroimaging and Aging

Event-Related Potentials (ERPs) are an effective way of investigating underlying neural activation patterns during language comprehension, and are sensitive to semantic, syntactic, and discourse manipulations. ERPs consist of small fluctuations in the electrical activity recorded on participants' scalps, time-locked to the onset of a stimulus or other visual, auditory, or sensory stimulation. Figure 3 displays typical ERP components elicited by linguistic stimuli (from Rispens, 2009). Wlotko et al. (2010) summarise evidence suggesting ERP amplitudes become attenuated with age (e.g. N400 effects become less markedly negative). It is, however, still unclear what the significance of this effect is: Wlotko et al. (2010) suggest a less uniform temporal distribution of components may be at the core of this effect: for instance, N400 effects may occur at slightly earlier or slightly later points in time, and due to the averaging effects of computing ERPs, this may give the impression of a reduced amplitude.

For sentence processing, one of the most frequently studied ERP waveforms is the P600 (for a review, see Leckey and Federmeier, 2020). Specifically, P600 effects have been observed in response to grammatical or syntactic violations (e.g. Canette et al., 2020), but may also be elicited by forcing reanalysis of syntax, such as in garden parth sentences (e.g. *"The horse raced past the barn fell"*, Gouvea et al., 2010). Age-related effects on later components such as the P600 appear to be harder to determine (Wlotko et al., 2010), partially due to the

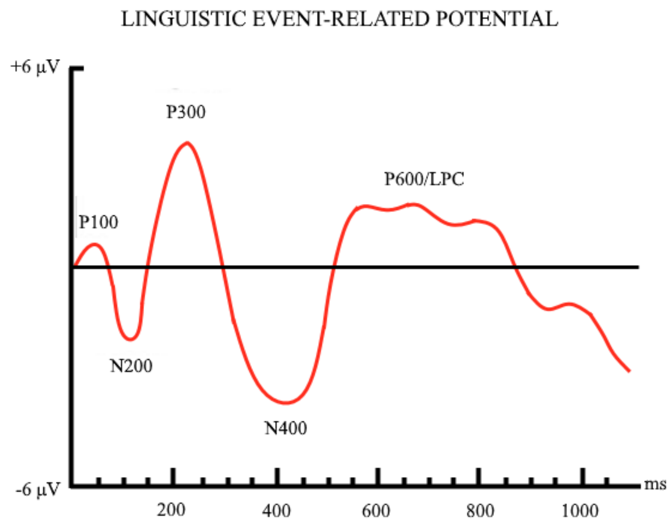


Figure 3 – Generic Plot of A Linguistic Event-Related Potential

paucity of literature on this waveform in older speakers.

Kemmer et al. (2004) conducted a syntax-specific study with older adults focusing on the P600. The waveform was elicited by grammatical number violations (e.g. "Industrial scientists *develops* many new consumer products."). Younger participants were faster and more accurate on behavioural measures than older adults, but there were no significant differences between groups on the size or latency of the P600 component. Instead, the P600 appeared to have a much wider distribution in older compared to younger adults. This finding led Kemmer et al. to conclude that reduced behavioural performance in older adults is more likely the result of motor difficulties. Sentence processing itself, as Kemmer et al. hypothesise, is likely unaffected by aging. As discussed below, Kemmer et al.'s (2004) findings of a wider distribution of the P600 further offer evidence for older adults' recruitment of wider neural resources for sentence processing.

As mentioned above during the discussion of Ledoux et al. (2007), syntactic priming in comprehension also elicits ERP responses. No neuroimaging studies of comprehension priming in older adults exist, but studies from younger groups suggest that neuroimaging effects resulting from syntactic priming may be apparent even if there is no behavioural facilitation. For example, Ledoux et al. (2007) studied the priming of reduced relative sentences (e.g. *"The manager proposed by the directors was a bitter old man"*), manipulating syntactic and lexical overlap in an ERP study. Reduced relatives involve a temporary ambiguity, as the verb "proposed" can be interpreted as a matrix verb with "the manager" as a subject, but also as a past participle. Ledoux et al. therefore hypothesised that P600 effects should be observed at the disambiguating word"by", and set out to investigate whether this effect is modulated by syntactic priming. As predicted, reduced P600 amplitudes were found in reduced relatives that had been primed with earlier reduced relatives. This effect was amplified by, but not dependent on, lexical overlap between prime and target. Importantly, however, no behavioural priming effects were found. This suggests that in some paradigms priming effects may only appear at a sub-behavioural level. Although Ledoux et al.'s (2007) study was conducted with younger adults, given the evidence by Kemmer et al. (2004), which demonstrated that older adults show intact P600 responses, the paradigm used by Ledoux et al. could be applied to older groups to investigate whether syntactic priming remains evident implicitly as aging progresses.

Summing up the discussion so far, age-related changes in syntax processing have traditionally been put down to declines in WM capacity. Although different conceptualisations of the WM system exist, most theories agree that at least some syntax processing functions are subserved by WM, and that age-related memory declines therefore cause impaired performance on syntactic tasks. More recently, this notion has been nuanced by findings of intact performance of older adults on some tasks, which largely be down to the crucial distinction between explicit and implicit processing. Specifically, while tasks relying on the explicit retrieval of memory cues are more difficult for older speakers, implicit tasks generally do not show age-related performance declines.

This distinction led recent research to apply implicit methods in the study of syntax and aging, including syntactic priming. The available research on older adults and priming almost exclusively investigated priming in production, and found generally intact priming effects with age. Whether the same finding holds true for comprehension priming has hithero not been investigated. Syntactic priming may also be combined with neuroimaging methods to uncover sub-behavioural effects of aging. Specifically, available ERP evidence points to a potential slowing or attenuating of waveforms in older adults.

In general, one of the most robust findings of the literature summarised above is an overall slowing of reaction times and ERP latencies in older adults. The importance of this speed of processing is discussed below. Furthermore, aging adults may employ strategies of compensation to aid in the correct interpretation of complex syntactic structures, a hypothesis also discussed in further detail below.

1.7 Processing Speed

The second main discovery from the Obler et al. (1991) study discussed above hypothesised a general slowing of reaction times and cognitive performance in older adults. This slowing has further been emphasised by studies of syntactic priming and by ERP studies of aging. Salthouse (1991; 1992; 1996; 2000; *inter alia*) extensively described the notion that observed cognitive changes in aging may largely be the result of a general slowing of cognitive functions. This Processing Speed theory of cognitive aging has amassed large amounts of evidence in recent decades. Importantly, the theory postulates that slowing is the result of an overarching, broad phenomenon, not a consequence of any specific cognitive impairment or of processing differences. While cognitive slowing itself may not account for all behavioural effects observed in aging, Salthouse (1996) argues that slowing interacts with other limitations such as inhibition or WM to create the effects aging adults exhibit.

Specifically, two separate mechanisms are postulated in the processing speed theory that underpin aging cognition. First, the *limited time mechanism* stipulates that, in a sequence of cognitive operations, if it takes older adults longer to perform early operations, not enough time is left for them to perform later stages of the operational sequence (Salthouse, 1996).

This mechanism may be more evident in tasks with lower levels of complexity rather than more complex paradigms, as tasks with higher processing demands may be more difficult primarily due to the second of Salthouse's (1996) mechanisms rather than due to simple speed effects. However, the limited time mechanism is thought to be one of the main reasons why older adults attain lower scores on even the most simple of processing speed tasks, such as determining whether two strings of letters are the same or different.

The second facet of Salthouse's (1996) theory is the *simultaneity mechanism*, the idea that information processed in the earlier stages of processing may be lost by the time it is needed for later processing. The simultaneity and limited time mechanisms naturally interact, such that the extra time needed for early-stage operations under the limited time mechanism can lead to a loss of information later on under the simultaneity mechanism. This then leads to the situation where (a) information processed early is partially decayed or forgotten, and (b) information processed later is not processed completely. Salthouse (1996) predicts that the implications of this impaired state include longer latencies to processing operations and greatly increased error levels. To give an example of these two mechanisms at work: a linguistic task assessing discourse interpretation usually consists of the reading of several sentences of text, followed by at least one judgement of acceptability or a comprehension question. According to the processing speed theory, 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, and if the task is time-based, much more time will have been spent reading the discourse items and not enough time will have be left for the answering of questions. Conversely, a simpler paradigm such as go/no-go, where the only processing action needed is the decision to press a button in response to a non-linguistic stimuli on a screen, will cause relatively few difficulties for older adults.

While it could be said that the simultaneity mechanism almost directly reflects WM capacity, as per MacDonald and Christiansen's (2002) framework which views WM as a conceptualisation of processing skills, Salthouse (1996) views this conflict differently: the processing speed theory considers the simultaneity mechanism as causal to declines in WM, not as a different conceptualisation of these declines. This view is evidenced by a number of studies on aging which found that statistically controlling for measures of processing speed eliminates much of the behavioural variance caused by measures of WM. Thus, although MacDonald and Christiansen (2002) cite the processing speed theory as supporting their abstract view of WM, the theory itself postulates that processing speed is a *cause* of WM declines rather than being identical to WM.

The simultaneity mechanism relies, like some of the WM theories discussed above and possibly like the syntactic priming account discussed in section 1.5, on activation. The capacity-based theory of WM (Just and Carpenter, 1992) suggests older adults present with a WM deficit because they lack sufficient resources in their activation pools to maintain cues activated over time; this theory therefore appears to be congruent with the processing speed theory on some grounds. More specifically, if older adults indeed suffer from a decline in processing speed in line with the simultaneity mechanism, and if syntactic priming relies on activational resources, then older adults should show syntactic priming declines. This interaction of processing speed, WM theories, and syntactic priming is a crucial component of the current project.

Similar to the discussion around what measure most directly taps WM capacity, different tasks purport to measure Processing Speed most effectively. In particular, the Digit Symbol Substitution Task worked into the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 1955, 2008) is a frequently used speed measure. In this Task, participants are presented with a set of symbols matched to a series of numbers. The symbol $\divideontimes$ may, for instance, be paired to number 5. Participants are then presented with a list of numbers and told to input the correct symbol corresponding to each number on the page within a certain time limit. A participant encountering number 5 in the list must, therefore, copy the symbol $\divideontimes$. Relations between age and performance on this test are high, and the test is a reliable indicator of cognitive decline (e.g. Jaeger, 2018). However, as Salthouse (1992) and Chen and Li (2007) point out, the Digit Symbol test may not be a reliable test of processing speed per se: the test requires participants to effectively memorise what symbols are paired to what numbers, conflating speed with WM. Alternative tests such as the Letter Comparison and Pattern Comparison Test (Salthouse, 1991b; Salthouse and Babcock, 1991), eliminate this problem: in these tasks, participants are presented either with two short sequences of letters (in the Letter Comparison Test) or two symbols or patterns (in the Pattern Comparison Test) and asked to judge whether these two elements are identical or different. A participant's score is defined as the number of correct trials responded to within 30 seconds. Requiring far less memory involvement and processing cost, these tests have been forwarded as a more reliable indicator of speed by itself. As such, the Letter Comparison Test was used as the speed measure in the current project.

In short, processing speed appears to be a highly important factor in explaining older adults' performance on linguistic tasks. The comprehensive processing speed theory by Salthouse (1996) stipulates that reduced speed of processing has two main tenets: first, the longer time it takes older adults to perform early stages of processing consequentially means there is not enough time for late-stage processing to occur; and second, due to the longer time it takes for early-stage processing to complete, cues activated during these early stages may no longer be sufficiently maintained when later processing requires the information they hold. Given that sentence comprehension is an inherently incremental process where information from early in the processing sequences may be required during later processing stages, the Salthouse (1996) theory is a valuable framework in which the current project is conducted.

Processing speed has also been forwarded as a potential compensation mechanism for older speakers (e.g. Brébion, 2003; Hess, 2014). In this view, older adults' generally slower cognitive operations make up for the fact that WM operations or sentence processing is less efficient. Returning to Obler et al.'s (1991) main conclusions, compensation mechanisms have generally been discussed as critical to older adults' linguistic performance. One of these potential mechanisms was further alluded to in the discussion of syntactic priming (see section 1.5). The following section discusses some of these potential mechanisms.

1.8 Compensation Mechanisms in Older Adults

The final conclusion from the Obler et al. (1991) study suggested that several compensation mechanisms may be at play during language comprehension that make up for older speakers' reduced processing ability. Older speakers have, for example, been shown to exhibit greater vocabulary knowledge (Zhu et al., 2019), as well as greater crystallised intelligence (Campbell et al., 2016). As some cognitive functions such as WM decline, language processing may become subserved by alternative mechanisms of cognition, resulting in a process of compensation whereby unimpaired or superior processes make up for less effective sentence processing. Some evidence for this comes from Poulisse et al. (2019), as discussed above, a study which found that an absence of semantic content in pseudowords caused greater declines in older readers' speed. This suggests semantics may act as a 'buffer' which compensates for poorer performance on the syntax element of processing.

A further, more concrete compensation mechanism may involve the increased spreading of neural activation over larger areas during processing. Ledoux et al. (2007) made reference to this hypothesis following their finding that syntactic priming effects on ERPs were more spread out across the scalp in older compared to younger readers. Indeed, one of the most significant neural underpinnings of language differences with age is the notion that brain function becomes less specialised (e.g. Peelle, 2019). Many studies have found that older speakers may compensate for less efficient or slower cognition by a more spread pattern of activation. For example, Antonenko et al. (2013) compared younger and older speakers in an fMRI paradigm, using ambiguous sentences and a sentence-picture matching task. The study found reduced functional connectivity in older adults, meaning various brain regions did not interact as effectively as in younger speakers. However, more brain regions with more varied functions became active during older adult processing than in younger adults, leading to the suggestion that older adults compensate for reduced processing efficacy by activating a wider selection of regions. Additionally, Diaz et al. (2016) summarise literature indicating this increased spread of activation may only successfully compensate for deficits up to a certain point. With increased task demands, the compensation mechanism fails, and reduced performance on behavioural tasks results. This is in line with the evidence reviewed earlier in this chapter, which generally suggests increased task demands have a greater impact on older speakers than on younger groups.

This neural compensation theory is not, however, a universally accepted hypothesis and not all studies find evidence for neural compensation in this way. In particular, increased spreading of activation can only be termed a compensation mechanism if it results in better behavioural performance, which is certainly not always the case. For instance, Campbell et al. (2016) explain the more widespread activation of frontal brain areas as resulting from task demands rather than age, and dismiss the idea that this leads to increased behvaioural performance. In this study, participants were asked to perform acceptability judgements as well as simply listen to sentences without any tasks. Campbell et al. (2016) found clear differences in activation between stimuli with no attached task and stimuli where an acceptability rating was required, with the latter type of stimulus eliciting more widespread frontal activation. However, while older adults showed increased latencies to acceptability judgements, there were no neuroimaging differences by age group, suggesting both younger and older speakers are susceptible to the same increases in activation by task demands.

The Campbell et al. (2016) study does, however, suggest a link between measures of crystallised intelligence and older adults' performance: with age, crystallised intelligence measures were found to become increasingly predictive of task performance. Indeed, further analyses found the intelligence factor to be a highly significant predictor in the oldest of three groups, but not in the other two. This is indicative of a separate compensation mechanism by which older speakers may successfully use higher intelligence levels to compensate for poorer cognitive performance.

Finally, slower processing speed itself may act as a compensation mechanism in older speakers (as discussed in Section 1.7 above). More cautious, slower intake of information may allow older speakers to avoid tip-of-the-tongue experiences and avoid an overload of information (e.g. Hess, 2014). Again, however, this notion is not without contention. Caplan et al. (2011) offer evidence against processing speed being used as a compensation mechanism. While older participants in their study showed marked slowdowns when reading demanding points in sentences (such as the relative clause in *"It was the child that the movie terrified"*), comprehension accuracy was still below that of younger readers. This slowdown did therefore not aid comprehension accuracy. The same patterns are found across the aforementioned aging and comprehension literature.

More recently, Malyutina et al. (2018) manipulated speed of presentation during sentence reading with older and younger groups. External presentation rates were adapted *relative to* participants' own self-paced reading speeds. Malyutina et al. hypothesised that if older adults deliberately slow their reading speed to a level below the upper limit of their performance, they should be less affected by increases in presentation rate than younger adults. This hypothesis was not borne out, and older and younger readers were equally affected by presentation rate increases (Malyutina et al., 2018). Whether processing speed declines are truly strategic, therefore, is still an open question.

In sum, successful behavioural performance by older adults on some linguistic tasks may not indicate unimpaired language abilities, but may rather be evidence of their tendency to compensate for difficulties in cognition with processes that are unimpaired or even at higher levels than in younger groups. Neurally, this may lead to more widespread activation patterns where other brain regions are recruited for successful behavioural performance, although the evidence for this is not uniform. Cognitive skills that are traditionally unimpaired with aging, or continue to expand as people age, include verbal and crystallised intelligence, while capacities such as WM decline.

1.9 Summary

Older adults have traditionally performed worse than their younger counterparts on measures of sentence comprehension (Norman et al., 1992; Obler et al., 1991). This has led to the assumption that sentence processing becomes impaired with age. However, the picture may not be as black and white as previously assumed: some linguistic functions may be preserved, even amplified, with age. Recent syntactic studies of aging have found comparable performance between age groups and similar linguistic parsing strategies (Hardy et al., 2020a,b; Payne et al., 2014). Task demands have frequently been implicated as a central cause for older adults' poorer performance on linguistic measures (Caplan et al., 2011). These effects may also depend on the type of memory demand involved with particular task. While WM has been shown to affect performance on explicit linguistic tests requiring conscious memory recall, its connection to implicit measures is less clear (Waters and Caplan, 1996a, 2001). The impact of WM on task performance could therefore simply be a matter of implicit and explicit task specifics.

It is therefore not clear whether older adults show declines on sentence processing itself, or whether they struggle with specific tasks that require conscious memory recall. Indeed, recent research paints a highly contradictory picture: while older adults were found to exhibit intact syntactic priming in language production (Hardy et al., 2017, 2020a,b), other evidence still points towards impaired comprehension, especially in the absence of meaningful semantic content (Poulisse et al., 2019). Nevertheless, the general tendency for studies finding impaired performance with age using mostly explicit measures, while implicit experimental manipulations find no age differences, persists to this day.

The possibility exists that WM tests might not be the most accurate way of measuring older adults' problems with language comprehension. Instead, viewing WM not as a limited-capacity system (MacDonald and Christiansen, 2002) and focusing on the quality of WM operations (Van Dyke and McElree, 2006) has the potential to elucidate the working of the memory system in relation to language comprehension further. For instance, including similarity-based interference conditions into studies on syntax and aging could show whether older adults' WM systems are more susceptible to interference or cue overload.

Finally, the influence of declining processing speed on linguistic parsing and to what extent older adults can successfully compensate for age-related declines has further received significant attention. While processing speed limitations can cause difficulties such as loss of information or incomplete parsing, there are suggestions that slower speed is in fact a conscious strategy older adults use to make up for cognitive declines. Prioritising semantic information and recruitment of additional regions of the brain while processing sentences are other ways in which older adults may compensate for syntax processing declines.

Ultimately, prioritising implicit measurement in the study of aging and language offers a reliable, empirical basis for conclusions about what cognitive functions are affected by age and, more importantly, which ones are not.

1.10 Research Aims and Hypotheses

This review highlights several key issues that remain unsolved in the field of aging and language. Two overarching aims tie the Studies reported here together. First, it is still unclear whether sentence processing in aging is selectively impaired or whether past studies have reported confounding declarative memory demands as sentence processig impairments. This project therefore aimed to elucidate this potential problem further by focusing on implicit, non-declarative measures in its Studies. Second, whether and to what extent declining Working Memory and Processing Speed have an effect on language in older age, and especially on syntactic priming and relative clause disambiguation, formed the second overarching aim of this project. Specific aims of all four studies are as follows:

- Study 1 aimed to elucidate whether syntactic comprehension priming is observable in older adults;

- Study 2 aimed to explore whether older adults show distinct processing patterns on a task which has been tied to WM capacity more directly than syntactic priming: relative clause disambiguation;

- Following Study 1, Study 3 aimed to expand the study of syntactic priming and aging using an electrophysiological component, to investigate whether older and adults show neural markers of syntactic priming in comprehension;

- Study 4 reports an additional analysis of part of the data collected for Study 3 with the aim of investigating the effects of intervening fillers on syntactic priming in comprehension, and the impact of these findings for popular accounts of syntactic priming.

In Study 1, older adults are hypothesised to show intact abstract syntactic priming (in the absence of lexical overlap), despite the absence of peer-reviewed publications which have reported results on syntactic comprehension priming in older adults. Results from production suggest that while abstract priming may be intact, the lexical boost may not be. Findings of intact priming could imply equally intact sentence processing with age. Moreover, intact priming in older adults *despite* WM or processing speed difficulties could provide evidence for accounts of syntactic priming that do not rely on either of these factors, such as implicit learning accounts (e.g. Chang et al., 2012) or accounts based in non–declarative memory (e.g. Heyselaar et al., 2021).

Due to the declining nature of WM capacity, older adults are hypothesised to show different relative clause attachment patterns in Study 2 compared to younger adults. Furthermore, if the quality of WM operations also declines with age, older adults should be more severely affected by the presence of interfering memory loads. This, then, would lend support to theories of individual differences in WM affecting sentence processing, such as the Just and Carpenter (1992) and Waters and Caplan (1996a) accounts. On the other hand, if older and younger adults show similar attachment preferences despite differences on WM and processing speed, this would have important implications for the general understanding of WM in relation to language, as this finding would contradict accounts that tie WM directly into processing.

Electrophysiological differences between age groups are expected in Study 3, in line with established literature. Nevertheless, given that syntactic priming has only rarely been investigated using ERPs (see Ledoux et al., 2007; Tooley et al., 2014), it is unknown what direction these group differences would take. If, in spite of neural differences, the older and younger groups showed similar syntactic priming effects, this would evidence accounts of older adults' successful behavioural performance and continued sensitivity to syntactic manipulations despite potential neural inefficacies.

Finally, abstract but not lexical priming effects are hypothesised to stay intact across four fillers in Study 4, given previous literature which has shown lexical effects to be short–lived (e.g. Hartsuiker et al., 2008). If, however, lexical and abstract effects persist across fillers, this would indicate different mechanisms underpin priming in production (where all tests of priming persistence have been conducted to date barring the study by Pickering et al. (2013)) than in comprehension.

Thus, this project considers sentence processing from several different angles. First, the focus on an implicit, sensitive measure like syntactic priming aims to shift the study of language processing and aging away from declarative tasks such as paragraph comprehension. To directly address effects related more directly to WM, this project also includes a study of relative clause comprehension and adds memory interference manipulations to this task. Finally, including an electrophysiological component to the syntactic priming paradigm has the potential to be highly informative of older adults' processing, and manipulations of intervening fillers may elucidate the mechanisms underlying priming in comprehension further.

2 Study 1 – Syntactic Comprehension Priming and Lexical Boost Effects in Older Adults

2.1 Abstract

The extent to which syntactic priming in comprehension is affected by aging has not yet been extensively explored. It is further unclear whether syntactic comprehension priming persists across fillers in older adults. This Study used a self-paced reading task and controlled for syntactic and lexical overlap, to (1) discover whether syntactic comprehension priming exists in older adults, across fillers, (2) to uncover potential differences between older and younger adults on priming measures, and (3) identify whether Working Memory or Processing Speed affect priming in older adults. Both older ($n = 30$, $M_{\text{age}} = 68.6$, SD = 3.68) and Younger adults ($n = 30$, $M_{\text{age}} = 21.6$, SD = 2.44) showed effects of syntactic priming and lexical boost. This suggests sentence processing does not decline with age, and that abstract priming and the lexical boost are not dependent on residual activation or explicit retention in memory.

2.2 Introduction

Although increases in word retrieval difficulties (Goral et al., 2007; MacKay et al., 2002; Wulff et al., 2019), and changes in the use of semantic information during processing (Joyal et al., 2020; Vonk et al., 2020; Zhu et al., 2019) are widely observed in older populations, deficits in syntax processing have appeared harder to specify and may depend on sentential context, memory constraints, or task demands. While past research has investigated older populations' performance on *explicit* sentence comprehension tasks, such as tasks requiring conscious recall of information through comprehension questions (DeCaro et al., 2016; Kim et al., 2016; Norman et al., 1992; Poulisse et al., 2019), *implicit* tasks such as syntactic priming have recently been applied to older and memory-impaired populations as a way of uncovering more subtle age-related changes (e.g. Hardy et al., 2020b; Heyselaar et al., 2017). In syntactic priming paradigms, processing of a grammatical structure is facilitated by experiencing the same structure previously (e.g. Bock, 1986; Tooley and Traxler, 2010). Priming is additionally amplified by lexical overlap between Prime and Target, known as the *lexical boost* (for a review, see Tooley, 2020).

There still remain significant questions around older adults' sensitivity to syntactic priming. All previous priming studies with older adults have focused on priming in production, and none have included intervening fillers between Prime and Target. Common accounts of syntactic priming and lexical boost mechanisms contrast the longevity of abstract syntactic priming (without lexical overlap) with the short-lived nature of the lexical boost (e.g. Hartsuiker et al., 2008; Traxler et al., 2014). It is unknown whether this holds for older adults. This Study also sought to investigate whether declining Working Memory (hereafter WM) and Processing Speed functions with older age affect priming patterns, and in what way.

2.2.1 Syntactic Priming

In syntactic (or *structural*) priming, the processing of a grammatical structure is facilitated by participants having read or heard the same grammatical structure earlier in the task (Bock, 1986; Pickering and Branigan, 1998; Tooley et al., 2019). Syntactic priming has been widely demonstrated to affect language production, where speakers prefer to use previously-heard grammatical structures (Jacobs et al., 2019; Raissi et al., 2020), but appears more elusive in comprehension. Syntactic priming in comprehension may depend on lexical overlap between prime and target, such that *abstract* priming, in the absence of lexical effects, is non-existent (e.g. Arai et al., 2007). Past studies have generally struggled to discover abstract comprehension priming, although Tooley and Traxler (2010) summarise that comprehension priming experiments have generally been conducted using online methods, and it may simply be too difficult to detect abstract syntactic priming in these paradigms. In production, syntactic priming is often investigated using picture-naming or scripted dialogue tasks (e.g. Bock, 1986; Hartsuiker et al., 2008), and the few available studies using online methods in production generally find much smaller priming effects (see Tooley and Traxler, 2010).

Nevertheless, more recent evidence from comprehension suggests that abstract priming may be more evident than previously believed (e.g. Giavazzi et al., 2018; Thothathiri and Snedeker, 2008; Ziegler and Snedeker, 2019), even when online methods are used. As Tooley and Traxler (2010) predicted, this discrepancy may be dependent on the sensitivity of the method used: Ziegler and Snedeker (2019) recorded eye movements and found abstract syntactic priming, while both Giavazzi et al. (2018) and Thothathiri and Snedeker (2008), who found abstract priming in comprehension, required active responses from participants, suggesting that abstract priming might require a more sensitive method of measurement than priming in production. More generally, syntactic priming effects can be recorded through behavioural, neuroimaging, and eye-tracking measures. Priming effects on event-related potentials (ERPs) have been demonstrated as reduced P600 amplitudes in primed compared to unprimed sentences (Ledoux et al., 2007; Tooley et al., 2009), while syntactic priming has also been shown to reduce regressions and reading times in eye-tracking paradigms (Tooley et al., 2019). Behaviourally, syntactic priming in production is often measured as the proportion of participants' responses that use the primed syntactic structure (e.g. Bock, 1986), or, in comprehension, as recordings of reading times (Tooley and Traxler, 2010).

Several competing accounts of the mechanisms underlying syntactic priming have been proposed over the years. Pickering and Branigan (1998) suggested that priming is the result of lingering activation of syntactic structures and their associated lemmas, facilitating processing of that structure and biasing speakers towards using it. However, this approach cannot account for the finding that syntactic priming persists across multiple intervening sentences (Bock and Griffin, 2000; Hartsuiker et al., 2008), and even between experimental sessions (Kaschak et al., 2011), as residual activation is short-lived and decays rapidly over time (e.g. Lewis et al., 2006). Chang et al. (2012) (see also Chang et al., 2006) therefore formulated the hypothesis that syntactic priming relies on an implicit learning mechanism, whereby the language processing system learns to process a grammatical structure or lexical item after exposure, thereby facilitating processing of that structure or item. These implicit learning systems are error-based, implying that the more unexpected a given structure, the greater the implicit learning effect. This principle accounts for the observation that infrequent structures are more primable than more frequent types (Fine et al., 2013; Jaeger and Snider, 2013).

Implicit learning mechanisms struggle to account for lexical boost effects, however, which have been found to be far less long-lived (Hartsuiker et al., 2008). Rather than proposing a unitary model meant to explain both abstract syntactic priming and the lexical boost, Hartsuiker et al. (2008) and Tooley and Traxler (2010) suggested a dual mechanism account, whereby syntactic priming relies on implicit learning, while the lexical boost is the result of short-term lingering activation. Several distinct dual mechanism accounts exist (see Tooley, 2020), however, most accounts agree that abstract priming is caused by an implicit learning mechanism. The nature of the lexical boost is more disputed, with some models referring to Pickering and Branigan's (1998) residual activation model (e.g. Traxler et al., 2014), and others suggesting that readers explicitly remember the Prime's content words (including verbs) leading to facilitated processing (cf. Ziegler and Snedeker, 2019).

2.2.2 Priming in Older Adults

Investigating priming effects in older adults may be a way to adjudicate between these competing theories, as cognitive control (Friedman et al., 2009), WM (Bopp and Verhaeghen, 2005), and – potentially – syntactic processing itself decline (Van Boxtel and Lawyer, 2021), but implicit learning is subject to far less severe declines (Jelicic, 1996; Ward et al., 2013; Ward and Shanks, 2018)m and vocabulary size (Verhaeghen, 2003) continues to grow. Past research has shown older adults exhibit syntactic priming effects in production (Hardy et al., 2017, 2020a,b), but syntactic comprehension priming in older groups has not yet been extensively investigated. In production, Hardy et al. (2017) played a dialogue with participants, taking turns to describe pictures that denoted transitive events, and could therefore be described with passives and actives. Both younger and older groups were significantly more likely to use passives after the experimenter primed them with a passive. Furthermore, lexical boost effects occurred regardless of age group, supporting the notion that underlying representations of syntax and lexical items appear intact in older adults, at least when used in language production. Note, however, that neither the Hardy et al. (2017) study nor its follow-up investigations (Hardy et al., 2020a,b) tested priming across several intervening fillers; whether older adults show priming across fillers therefore remains unexplored.

Including fillers in syntactic priming with older adults moreover allows for a more direct test of the accounts of syntactic priming summarised above: one of the most robust findings in the aging literature is older adults' significantly slower reading speed (Hartley et al., 1994; Kemtes and Kemper, 1997; Liu et al., 2017). The Processing Speed theory of adult cognition (Salthouse, 1996; Salthouse and Babcock, 1991, among others) suggests the slower speed at which older adults process information results in much of this information having lost the activation necessary for its retrieval or use in cognitive operations (see further Bezdicek et al., 2016; Bott et al., 2017; Caplan and Waters, 2005; Ebaid et al., 2017; Pichora-Fuller, 2003). In other words, processed information is lost or forgotten more quickly in older readers because they fail to maintain sufficient activation of lexical items, syntactic structures, or semantic information (Salthouse, 1996). An activation-based theory of syntactic priming would, therefore, predict age-related differences in the degree of syntactic priming or boost effects. Conversely, since implicit memory appears relatively unaffected in older adults (cf. Ward et al., 2020), theories that consider priming the result of implicit learning mechanisms (Chang et al., 2012) should predict intact syntactic priming in older adults. Following dual mechanism accounts, which suppose the lexical boost still relies on lingering activation or on explicit memory, it could be expected that older adults exhibit a less robust lexical boost compared to younger adults. If both syntactic priming and the lexical boost are unaffected by age and persist across fillers, this would suggest both effects rely on other mechanisms.

2.2.3 Memory and Linguistic Aging

Crucially, syntactic priming effects occur independently of explicit, conscious memory or linguistic abilities – even amnesic patients (Ferreira et al., 2008; Heyselaar et al., 2017) and people with aphasia (Yan et al., 2018) have exhibited syntactic priming effects, indicating that impaired explicit memory or speech does not prevent these effects from occurring. Conversely, the study of language and aging has generally focused on potential declines in syntactic and grammatical complexity as a result of explicit memory declines (Burke and Shafto, 2011; Kemper and Anagnopoulos, 1989; Kemper et al., 1990; King and Kutas, 1995; Kynette and Kemper, 1986, among many others). Working Memory (hereafter WM), the memory type most often investigated in relation to older adults' language, involves a system for the temporary storage, processing, and retrieval of relevant cues (Baddeley, 2010), which appears to decline as age progresses (Bopp and Verhaeghen, 2005). Connections between syntax comprehension and WM are frequent: for instance, DeDe et al. (2004) discovered that by-age differences on sentence and text comprehension measures were mostly accounted for by including WM in statistical models. Reading comprehension and WM have also been connected more recently: for example, DeCaro et al. (2016) investigated age effects on sentence comprehension accuracy using offline questions and manipulating the syntactic complexity of auditorily-presented sentences. Comparing subject-relative and object-relative structures, DeCaro et al. (2016) also included a length manipulation, expecting older adults to show less efficient processing of longer and more complex sentences. Age-related declines were discovered only on more complex object-relative sentences, and these age differences were fully accounted for by controlling for WM span and hearing acuity in statistical modelling. Similar results were obtained by Grossman et al. (2002), Caplan and Waters (2005), DeDe et al. (2004), Waters and Caplan (1996b), and Sung et al. (2017).

However, increasing evidence supports the idea that WM declines in older adults' do not always impact sentence comprehension. For instance Poulisse et al. (2019) prompted older and younger participants to detect grammatical errors in short two-word phrases (such as "I work" and *"I works"), which kept memory demands to a minimum. While older readers were less accurate and slower at detecting grammatical errors than the younger group, Poulisse et al. (2019) suggest WM could not have significantly affected processing in their study due to the short stimuli used. Similarly, while DeDe et al. (2004) discovered significant impact of WM on conscious recall of sentence information in older adults, no such effect was found on online measures. Additional factors must therefore account for these age-related effects.

Poulisse et al. (2019) offer a suggestion as to what one of these additional factors might be. Older adults in their study were disproportionately slower on detecting errors on pseudoverbs (e.g. "I spuff" and *"I spuffs") compared to real verbs. This, Poulisse et al. argue, offers evidence for older readers' prioritisation of semantic information as a compensatory mechanism for syntactic processing declines. Compensation mechanisms are one of the main factors suggested to explain age-invariant performance on some linguistic tasks (e.g. Stine-Morrow, 2007; Wingfield and Grossman, 2006), and may take a variety of forms. Jackson et al. (2012) and Stine-Morrow et al. (2006, 2008) stress the importance of cognitive training, having an engaged lifestyle, and motivation to allocate resources to language processing as critical compensation mechanisms to alleviate the negative impact of age-related cognitive declines. Peelle (2019) and Wingfield and Grossman (2006) offer evidence suggesting older adults may even recruit additional brain regions not observed in younger readers – although whether this dedifferentiation results in enhanced cognitive performance is still contentious. Additionally, while Poulisse et al. (2019) found evidence for semantic compensation, they also emphasise the importance of processing speed for older adults, suggesting that high processing speed may further compensate for problems processing syntax (cf. Malyutina et al., 2018).

As mentioned above, several authors have emphasised the dissociation between age-related effects on *explicit* (conscious) and *implicit* (unconscious) processing operations (e.g. DeDe et al., 2004; Ward et al., 2020; Wingfield and Tun, 2001). Language use relies heavily on implicit memory and learning: speakers are often unable to explicitly articulate the rules of their grammar, and children learn languages without explicit instruction (Fodor, 1983; Lenneberg, 1967). Nevertheless, studies investigating older adults' sentence comprehension have largely used off-line, explicit tasks (though see for instance Campbell et al., 2016), despite the great potential of implicit measures for uncovering age-related language processing changes in the absence of demands for conscious memory searches. While implicit memory and learning may not remain completely unaffected by the aging process, and while specific sub-domains of implicit memory may deteriorate with age, general age-related declines on implicit memory tasks are far less strong and universal than those recorded for explicit memory types (for further reading, see Hicks et al., 2018; Rieckmann and Bäckman, 2009; Ward et al., 2013, 2020; Waters and Caplan, 2001). An implicit paradigm was therefore chosen to contrast older and younger readers.

To sum up, the mechanisms underlying syntactic priming could benefit from research on wider demographics, including older adults, to clarify what theoretical account of priming and the lexical boost is most in line with the data. Findings of syntactic priming in older groups could further elucidate the nature of cognitive aging, especially when connected to potential declines in Working Memory and Processing Speed. Building on previous research on syntactic priming in language production, this Study is the first to examine syntactic comprehension priming in older adults and use intervening fillers between primes and targets. In short, this Study addressed: (1) whether abstract syntactic priming and lexical boost effects exist in older adults' comprehension across fillers; (2) whether differences between younger and older adults on these measures exist; and (3) whether WM or Processing Speed affect priming patterns. While older adults are expected to show similar abstract priming effects – in the absence of lexical overlap – to younger adults, effects of the lexical boost may show age–related variation. The influence of WM on the implicit measures used in this study is expected to be minor, but the effect of Processing Speed on syntactic priming has not been extensively explored, and as such no explicit predictions are made regarding its impact.

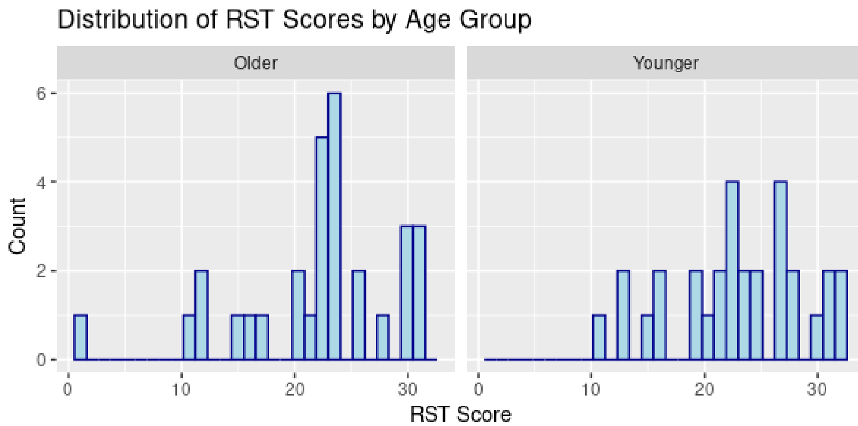
2.3 Methods

2.3.1 Participants

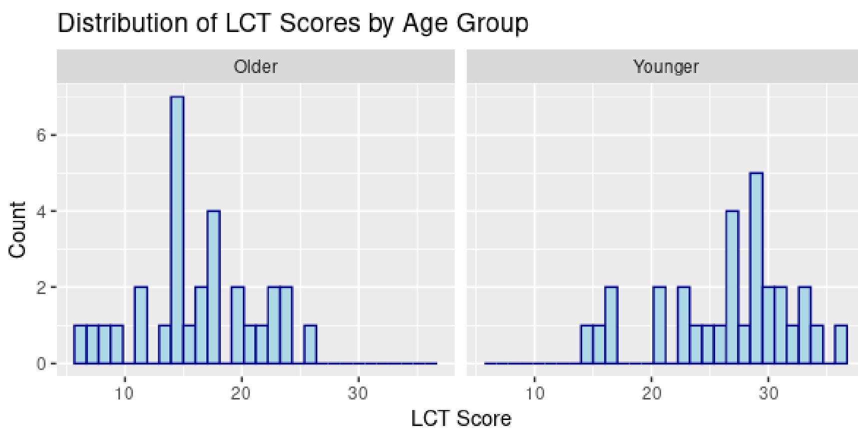
74 participants took part in this study, which was fully approved by the University of Essex Social Sciences Ethics Subcommittee. Participants for this experiment were recruited through the Prolific online recruitment platform (Prolific, 2014), and were paid for their participation. All participants gave informed consent before taking part. Data from 14 participants was rejected either due to incomplete submissions or failing a pre-defined attentional threshold. Attention was monitored in this experiment through the inclusion of comprehension questions at random points throughout the study; if a participant's correctness score on these questions fell below 80%, their data was eliminated from the analysis. The younger participant group ($n = 30$) consisted of 18-25-year olds, while the age of participants in the older group ($n = 30$) ranged from 65 to 77. All participants were native speakers of English. The average number of years spent in education did not differ between groups ($t(52.4)$ = -.444, $p > .05$), and neither did participants' self-reported scores on the International Standard Classification of Education (ISCED; Unesco Institute for Statistics, 2012; $t(58) = .301$, $p > .05$). A summary of other participant demographics is given in Table 1, and distributions of pre–test scores by Age Group are given in Figure 4.

Table 1 – Summary of participant demographics for Study 1. RST: Reading Span Task; LCT: Letter Comparison Task. Education Level was measured along the International Standard Classification of Education (UNESCO Institute for Statistics, 2012).

	Younger Group	Older Group
Age	M = 21.6, SD = 2.44; [18,25]	M = 68.8; SD = 3.68; [65,78]
Gender	18 Female, 12 Male	13 Female, 12 Male
Years in Education	M = 15.37; SD = 2.38	M = 15.03, SD = 3.35
Education Level	*Mode* = 3 (Upper Secondary)*	*Mode* = 2 (Lower Secondary)*
RST	M = 22.95, SD = 5.88	M = 21.98, SD = 6.94
LCT	M = 26.6, SD = 5.57	M = 16.37, SD = 5.27



(a) Histograms of RST Scores by Age Group in Study 1.



(b) Histograms of LCT Scores by Age Group in Study 1.

Figure 4 – Histograms of pre–test scores by Age Group in Study 1, indicating similar but not equal distributions for RST scores, and concrete Age Group differences by LCT score.

2.3.2 Reading Span Task

To assess WM, participants completed an online version of the Reading Span Task (RST; Daneman and Carpenter, 1980; Daneman and Hannon, 2007) before the main experiment. The RST for this study asked participants to make an acceptability judgement about sentences presented in incrementally increasing sets ranging from three to seven items, as well as to recall the final words of each sentence. The RST for this study was hosted online using Qualtrics (Provo, Utah, USA, 2021). Sentences used in the RST had an average length of 6.97 words (SD = 1.44, range = 7), all had simple grammar, no complex or compound clause structures, and included no jargon or technical phrases. Half of all sentences were designed as *appropriate* (e.g. "Yesterday I climbed a mountain.") while the other half were *inappropriate* (e.g. "The rocks in the park waved in the gale force winds.").

The RST was preferred over other span tasks due to the processing requirements embedded into the RST: WM differs from short-term memory in that information stored in WM is processed concurrently (Baddeley, 2010), which is effected in the RST by asking participants to answer questions about the sentences they read, while maintaining information from those sentences in memory. A full list of sentences used in the RST appears in Appendix A.

A participant's RST score was calculated as the total number of correctly recalled words in the correct order. Half points were further awarded for words recalled in the correct trial, but not the correct order. Performance on the RST was high in both groups, as summarised in Table 1. WM span did not differ significantly between groups ($t(56.5) = .582$, $p = .562$), and age was not significantly associated with WM span, either when considering all participants together (see the covariance matrix in Figure 5), or in the younger group ($r = .092$, $p = .503$) or the older group ($r = .064$, $p = .638$) considered separately. This lack of memory capacity difference was unexpected. Previous studies have generally shown marked declines on measures of WM with age (for reviews, see Bopp and Verhaeghen, 2005; Meguro et al., 2000). The possibility exists that the lack of a WM group difference could be a result of both groups' relatively high education levels (with means of over 15 years spent in education), since previous research has shown higher education is generally associated with higher WM spans (Boller et al., 2017; Pliatsikas et al., 2019). Alternatively, the infinite duration of the sentence presentation screens, which may have allowed for participants to rehearse the final words, may have helped older readers especially (Hering et al., 2019; Oberauer, 2019).

2.3.3 Letter Comparison Test

The Letter Comparison Test (LCT; Salthouse, 1991) was used to assess Processing Speed, and was administered after the RST. Unlike frequently used measures of Processing Speed such as the coding sub-test of the Wechsler Adult Intelligence Scale (Drozdick et al., 2018;

Wechsler, 1955), the LCT involves virtually no memory demands and very little processing cost. In the LCT, participants are presented with two sets of character strings and asked to judge whether these strings are identical or different. A participant's LCT score is calculated as the number of correct answers given in a 30-second time limit.

The LCT for this study included 48 string pairs, half of which were identical. String pairs were equally subdivided into pairs of six, nine, or twelve letters. Non-matching string pairs included fully randomised letters. All strings were generated using an online letter generator and were presented in white capital letters in Arial font in the centre of a grey background, using PsychoPy 3 2020.1.3 (Peirce and MacAskill, 2018; PsychoPy/Pavlovia, 2021). Participants were instructed to indicate via a keyboard button press whether the two letter strings they saw on screen were the same or not, and to respond as quickly as possible. Five practice trials were presented before the start of the main LCT.

RST and LCT Scores correlated highly, as seen in the covariance matrix in Figure 5. To ensure models were not adversely contaminated by this correlation, additional models in each ROI were run, only including either RST score (without LCT score) or only LCT score (without RST). These models did not result in changes to the significance of RST or LCT score compared to the main models. Appendix I includes the full code and model output for these additional models.

Neither pre-test correlated heavily with age, and both pre-test scores correlated heavily with measures of Education (which were not included in any models as neither measure was predictive in any model). The two measures of education naturally correlated very significantly.

2.3.4 Materials

The main experiment comprised 90 trials, with each trial consisting of Prime, Filler 1, Filler 2, and Target items, totalling 360 sentences altogether. Trials were divided into three conditions: *Primed*, with syntactic overlap but no lexical overlap; *Boosted*, with syntactic overlap and

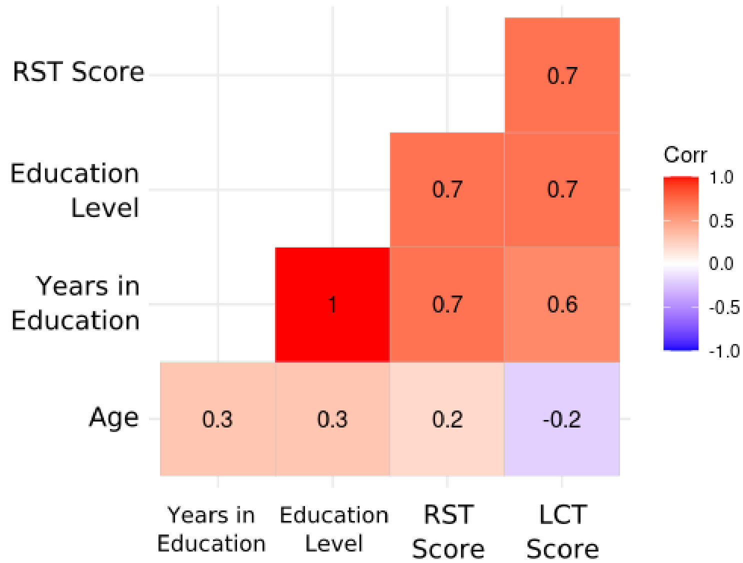


Figure 5 – Covariance Matrix of predictors. Note that Years in Education and Education Level were not included in final models due to insignificant predictive power in every model.

lexical overlap; and *Unprimed*, with no syntactic or lexical overlap. As an additional lexical control condition (or LCC) for the lexical boost effect, lexical overlap between Prime and Filler 2 was manipulated in a subset of *Unprimed* trials. 15 Primes shared the same matrix verb as Filler 2s, and a further 15 Prime – Filler 2 pairs were designated as non-overlapping controls. No syntactic overlap existed between any Primes and Filler 2s. This manipulation was included in Filler 2 rather than Target sentences as the aim to measure completely unprimed Targets was not compromised in this way, and the duration of the experiment would have exceeded 80 minutes if a further 15 full Trials had been added to the study. The LCC did not affect the number of syntactically-unrelated fillers between Prime and Target, and LCC manipulations did not affect lexical boost effects since LCC trials comprised a subset of trials in the Unprimed condition. A schematic overview and a visualisation of the experiment are provided in Figure 6.

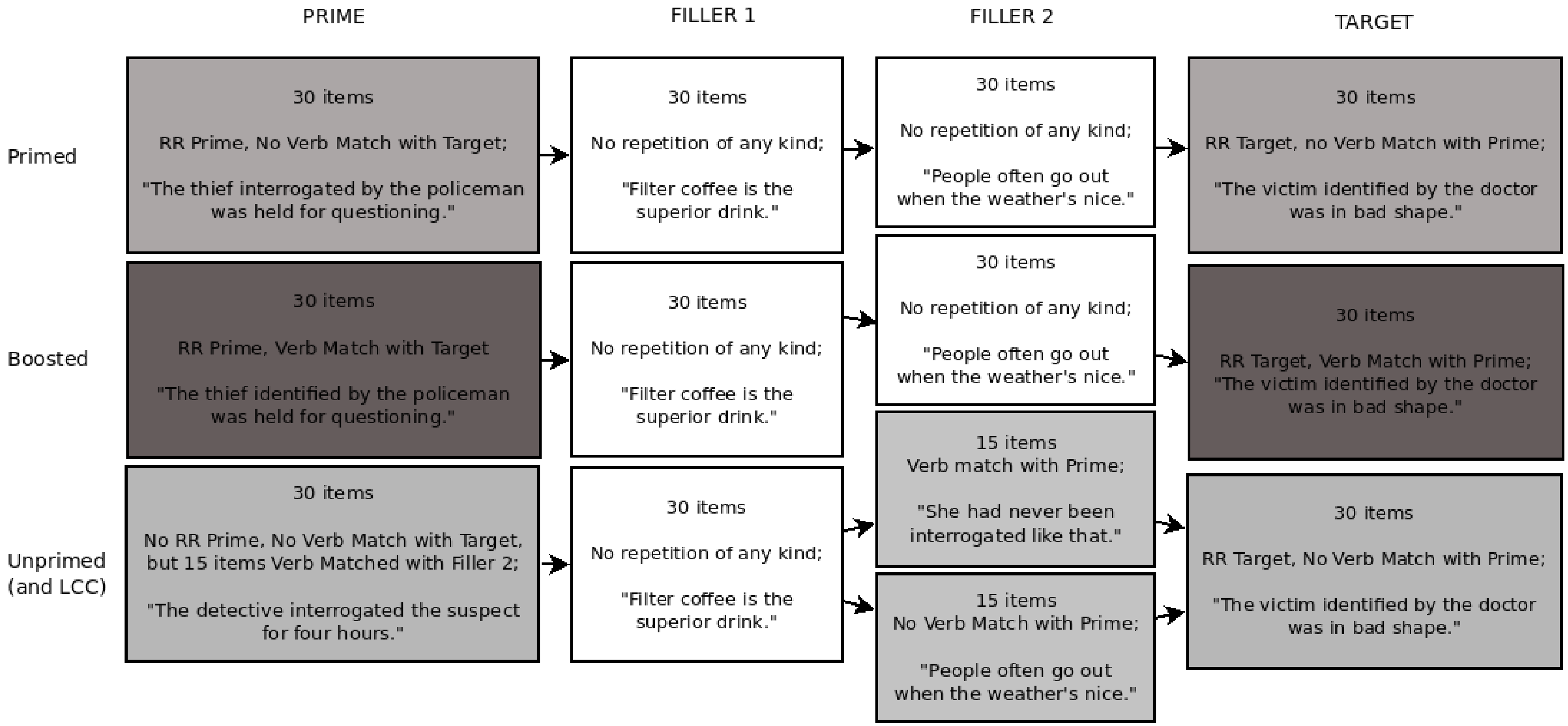


Figure 6 – Schematic overview of experimental conditions. Each column denotes one sentence presented in sequence, such that all Primes and Targets were separated by two grammatically unrelated Fillers. Primed and Boosted Primes and Targets were both reduced relatives, while Prime sentences in Unprimed trials were syntactically unrelated to Targets. Verbs only matched between Primes and Targets in the Boosted condition. The LCC did not affect the verb matching of Prime and Target, but only manipulated lexical overlap between Prime and Filler 2.

Critical Sentences

Targets and Primes were adapted from several different previous studies on syntactic priming (Manouilidou and Almeida, 2009; Tooley et al., 2009; Traxler, 2008). American English spellings and terminology in any sentences from previous studies were adapted to British English variants, as the majority of participants in this study came from a British English background, and the same items used here were also used in Study 3, where participants were recruited from the local area surrounding the University of Essex. Sentences ranged from 7 to 14 words, averaging 9.75. There was no significant difference between the lengths of Prime and Target structures ($t(169) = -.77$, $p > .05$).

All Target items were reduced relative sentences (e.g. "The child cheered by the teacher spelled the word correctly"), with the start of the reduced relative clause always set as the fourth word in the sentence to allow for reading time comparisons. Following from previous investigations of reduced relative priming (e.g. Ledoux et al., 2007; Tooley et al., 2019), the critical reading time regions in Target sentences were defined as (a) "by" and the following noun phrase (By ROI); and (b) two words following the "by" and NP, to account for spillover effects (Spillover). For example, in the Target sentence "The dealer captured by the policeman denied any wrongdoing", the By ROI comprises "by the policeman", and the spillover region consists of "denied any". Prime sentences in the *Primed* and *Boosted* conditions (which involved syntactic overlap) were also reduced relatives, while Prime items in the *Unprimed* condition comprised complex sentence types with no reduced relative clauses (e.g. "The scandalous hooligan destroyed the sculptor's valuable artwork"). A list of all critical trials appears in Appendix B.

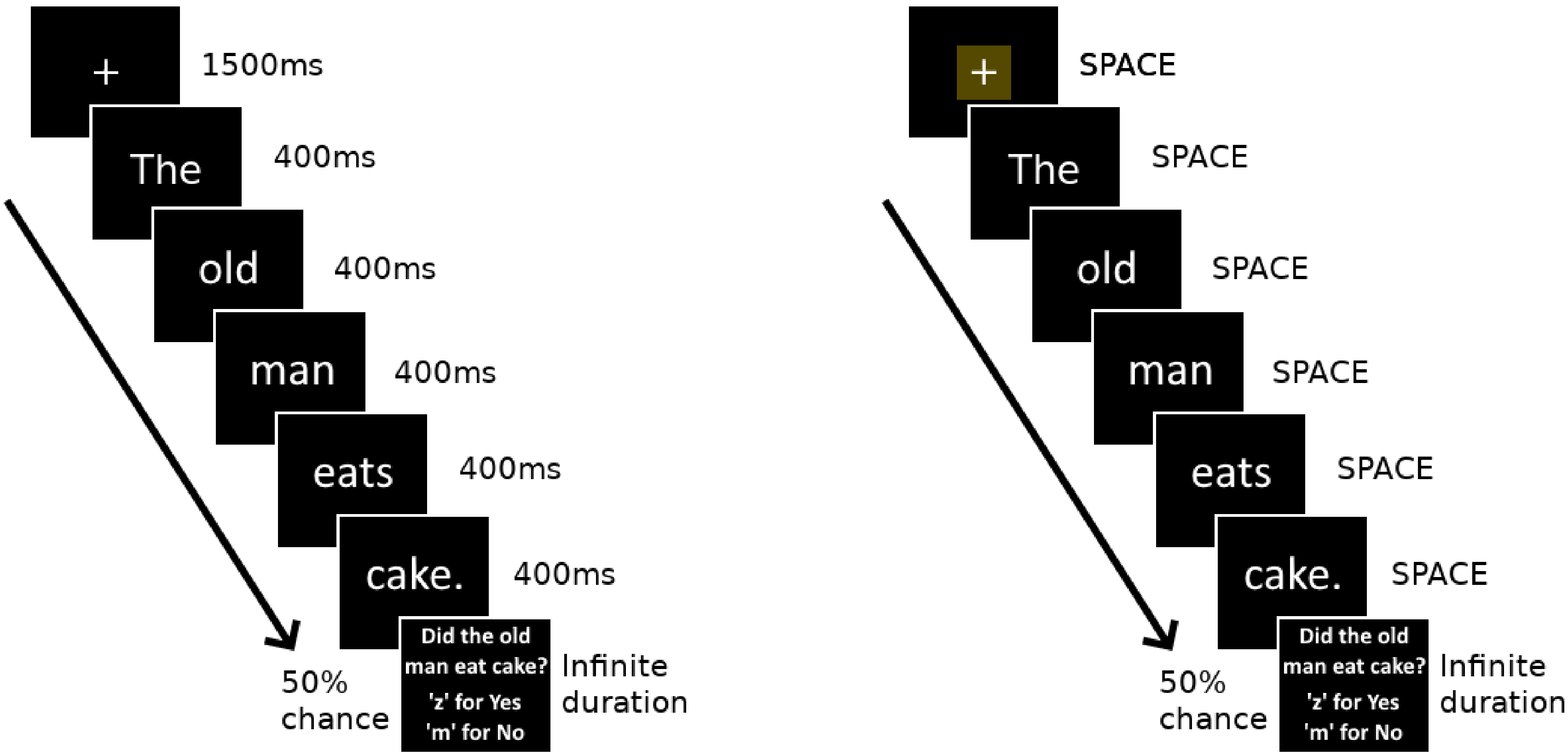
Filler Sentences

The number of Fillers intervening between Prime and Target was set at two. This number kept task difficulty and length to a minimum while accounting for the long-lasting nature of syntactic priming (Hartsuiker et al., 2008). As this is the first investigation of syntactic comprehension priming in older adults involving fillers between Primes and Targets, the number of fillers was maintained at two to create a larger likelihood of capturing syntactic priming effects (Cho-Reyes et al., 2016). Filler sentences were constructed with complex syntactic structures without reduced relative clauses or lexical repetition, except for LCC items (a subset of 15 items in the *Unprimed* condition), which were specifically designed to investigate lexical overlap. A full example of trials in each condition is given in Figure 6, while a full list of all Filler sentences appears in Appendix B. Two ROIs were defined for LCC sentences, similar to Target ROIs: (a) the main Verb (Verb); and (b) a spillover region for the main Verb of two words (Spillover). For example, in the LCC item "The grave economist warned about a recession once again", the Verb ROI consisted of "warned" and the Spillover ROI comprised "about a".

2.3.5 Procedure

The experiment was presented using PsychoPy 3 2020.1.3 and hosted online using Pavlovia (Peirce and MacAskill, 2018; PsychoPy/Pavlovia, 2021). All sentences were presented on a word-by-word basis in white Arial font at the centre of a grey screen. The RST, LCT, and five practice trials preceded the main experiment. The main part of the study was presented in four blocks of 18 trial sets, consisting of 72 sentences each. Each block lasted approximately 10–15 minutes. Participants were encouraged to take a short break between blocks, and the order of blocks and trials was fully randomised across participants.

Second Filler and Target sentences were self-paced, while the presentation of Primes and Filler 1 items was externally paced. This design allowed for the recording of reading times on critical Target and LCC sentences while reducing strain on participants as much as possible. To mark self-paced trials, fixation crosses preceding Filler 2 items and Targets were surrounded by a yellow square. Participants were trained to recognise these squares in the practice trials. In externally paced sentences, the fixation cross duration was set at 1500ms, and each word was presented for 400ms. This is longer than some previous comprehension priming studies (e.g. Ledoux et al., 2007), however, this Study sought to ensure the older group, which was thought to read more slowly, fully comprehended all sentences. Self-paced and externally paced sequences of the main experimental items are visualised in Figure 7.



(a) (b)

Figure 7 – Figure 7a displays externally-paced trials while Figure 7b shows self-paced trials. Presentation of comprehension questions was fully randomised and did not depend on the presentation of a question in the previous sentence. Questions appeared after Primes, both Fillers, and Targets.

2.3.6 Analysis

Data analysis was conducted in R (R Core Team, 2020) using the *lme4* package for linear mixed modelling (Bates et al., 2015), *EMAtools* for generation of Cohen's *d* effect sizes (Kleiman, 2017), *sjPlot* for model plots (Lüdecke et al., 2021), and *performanceAnalytics* (Peterson et al., 2018) and *ggcorrplot* (Kassambara and Kassambara, 2019) for covariance matrix generation. Linear mixed effects models were built for the two ROIs in both Targets (*By* and *Spillover*) and LCC items (*Verb* and *Spillover*). Reading times (RTs) in each ROI were residualised by character count: RTs for each word in an ROI were added together and divided by the sum of characters presented in that ROI. For instance, if a *Verb* ROI comprised the word "claimed" (7 characters) and a participant's RT to this ROI was 350ms, the residualised reading time (RRT) would come to 350 / 7 = 50. RRTs were then log-transformed and trimmed such that all RRTs above or below 2.5 standard deviations from each participant's individual mean were eliminated. Any trials with incorrect comprehension responses on Target sentences were additionally rejected from the data. In total, these eliminations resulted in 7.4% of data points being rejected.

Models in each ROI included random effects for Trial and Participant and fixed effects for Condition (Priming or LCC) by Age Group, Condition by RST score, and Condition by LCT score. An examination of whether random slopes of Participant by Trial were warranted was conducted, however after visual confirmation that Trial slopes were not different by Participant, random slopes were not included. Covariates (LCT and RST scores) were centered before being added to any model. Contrasts on the Priming Condition parameter were coded such that comparisons were made between primed and unprimed trials, to examine syntax-only priming, and between primed and boosted trials, to capture the lexical boost. In LCC models, items with verb repetition were compared against unrepeated verbs.

An additional Bayesian analysis was conducted to complement the main models, in particular those models where the outcome was a null effect of the critical terms. Bayesian analyses, especially those based on Bayes Factors, may be used to more confidently express null effects as the most likely outcome of a model parameter, as opposed to traditional statistical techniques (see Kruschke and Liddell, 2018, for a discussion). Bayesian linear mixed models were fitted using the *brms* package (Bürkner, 2017) to confirm results (see further Wagenmakers, 2007). Sets of models including a Priming Condition * Age Group interaction, and models including only main effects of Priming Condition and Age Group as controls were constructed. All models were built with weakly informative prior ex-Gaussian distributions (Matzke and Wagenmakers, 2009), run for 3000 iterations, and resulting inverse Bayes Factors were calculated using the *bridgesampling* package (Gronau et al., 2017). Appendix I includes the full code used for the analysis.

2.4 Results

2.4.1 Target Sentences

By ROI

All readers were successfully primed in this ROI ($t(4871)$ = -2.191, $p < .001$, d = -.063), such that primed Targets were read faster than unprimed items. However, lexical boost effects were not captured in this ROI ($t(4871)$ = .332, p = .740, d = .010), and neither pre-test score had an effect on reading times (both ps > .05). While older adults read all sentences more slowly across conditions ($t(57.18)$ = -3.274, p = .002, d = -.866), there was no interaction between age group and abstract priming ($t(4872)$ = .301, p = .763, d = .009) or between age group and lexical boost ($t(4872)$ = -.036, p = .721, d = -.010). Additionally, neither pre-test score interacted with abstract priming or lexical boost parameters (all ps > .05). For a full overview of the model in this ROI, please refer to Table 2.

Spillover ROI

Both effects of abstract priming ($t(4890)$ = -8.850, $p < .001$, d = -.253) and of the lexical boost ($t(4892)$ = -11.732, $p < .001$, d = -.336) were evident in this ROI, indicating that primed items were read faster than unprimed items, and boosted sentences faster than primed sentences. As in the *By*-ROI, neither pre-test affected reading times in this ROI, although there was a trend for participants with higher WM spans to read all sentences faster ($t(58.56) = 1.514$, $p = .136$, $d = .396$). However, RST score did not interact with abstract priming or the lexical boost, and neither did scores on the LCT (all ps $> .05$). Crucially, while priming effects were highly significant in this ROI, neither abstract priming ($t(4892) =$ -.081, $p = .936$, $d =$ -.002) nor the lexical boost ($t(4849) =$ -.081, $p = .421$, $d =$ -.023) interacted with age group, despite the finding that older adults read more slowly than younger adults across conditions ($t(57.29) =$ -3.827, $p < .001$, $d =$ -1.011). Table 3 displays full results for this ROI, and Figure 8 visualises condition effects.

Table 2 – Linear Mixed Model Summary for the Target (By) ROI. ($R^2_{Marginal}$ = *.199;* $R^2_{\text{Conditional}}$ = *.644*). Contrasts of priming condition included Unprimed vs. Primed (Abstract Priming) and Primed vs. Boosted (Lexical Boost). "Trial" denotes the numeric value of trial numbers in presentation order. Significant values are represented in bold.

Parameter	Estimate	SE	*DF*	*t*	*p*	*d*
Intercept	-2.2450	.0576	59.50			
Abstr. Priming	-.0183	.0083	4871	-2.191	< **.0001**	-.0627
Lex. Boost	.0027	.0082	4871	.332	.7400	.0095
Age Group	-.2881	.0880	57.18	-3.274	**.0018**	-.8660
RST	.0933	.0500	58.04	1.868	.0669	.4903
LCT	-.0858	.0552	58.04	-1.555	.1254	-.4082
Abstr. Priming * Age Group	.0039	.0130	4872	.301	.7634	.0086
Lex. Boost * Age Group	-.0046	.0128	4872	-.0358	.7206	-.0102
Abstr. Priming * RST	.0069	.0078	4876	.889	.3742	.0254
Lex. Boost * RST	.0018	.0077	4871	.232	.8163	.0066
Abstr. Priming * LCT	-.0007	.0086	4876	-.087	.9310	-.0025
Lex. Boost * LCT	.0082	.0085	4874	.957	.3384	.0274

Bayesian Analysis

Bayesian LMMs were fitted with weakly informative priors along an exponential Gaussian distribution, with one model including a Priming Condition * Age Group interaction, and the other only including main effects of these parameters. 3000 iterations of each model were run using *brms*. For the *By* ROI, model comparison using *bridgesampling* returned a Bayes Factor (BF) of .0010, providing extremely strong support for the null hypothesis (Lee and Wagenmakers, 2014). Similarly, in the Target Spillover ROI, model comparisons returned a BF of .0023, again suggesting extremely strong evidence for the null hypothesis.

Table 3 – Linear Mixed Model Summary for the Target (Spillover) ROI. ($R^2{}_{Marginal}$ = .213; $R^2{}_{Conditional}$ = .546.) Contrasts of priming condition included Unprimed vs. Primed (Abstract Priming) and Primed vs. Boosted (Lexical Boost). "Trial" denotes the numeric value of trial numbers in presentation order. Significant values are represented in bold.

Parameter	Estimate	SE	*DF*	*t*	*p*	*d*
Intercept	-2.276	.0578	58.25			
Abstr. Priming	-.0954	.0108	4890	-8.850	<**.0001**	-.2531
Lex. Boost	-.1225	.0170	4892	-11.732	<**.0001**	-.3355
Age Group	-.3383	.0884	57.29	-3.827	**.0003**	-1.0111
RST	.0761	.0503	58.56	1.514	.1355	.3956
LCT	-.0760	.0553	58.57	-1.343	.1844	-.3510
Abstr. Priming * Age Group	-.0014	.0169	4892	-.081	.9355	-.0023
Lex. Boost * Age Group	-.0135	.0167	4849	-.0805	.4207	-.0230
Abstr. Priming * RST	.0063	.0101	4896	.622	.5339	.0178
Lex. Boost * RST	-.0039	.0100	4889	-.399	.6899	-.0114
Abstr. Priming * LCT	-.0098	.0111	4897	-.886	.3758	-.0253
Lex. Boost * LCT	.0025	.0111	4897	.230	.8181	.0066

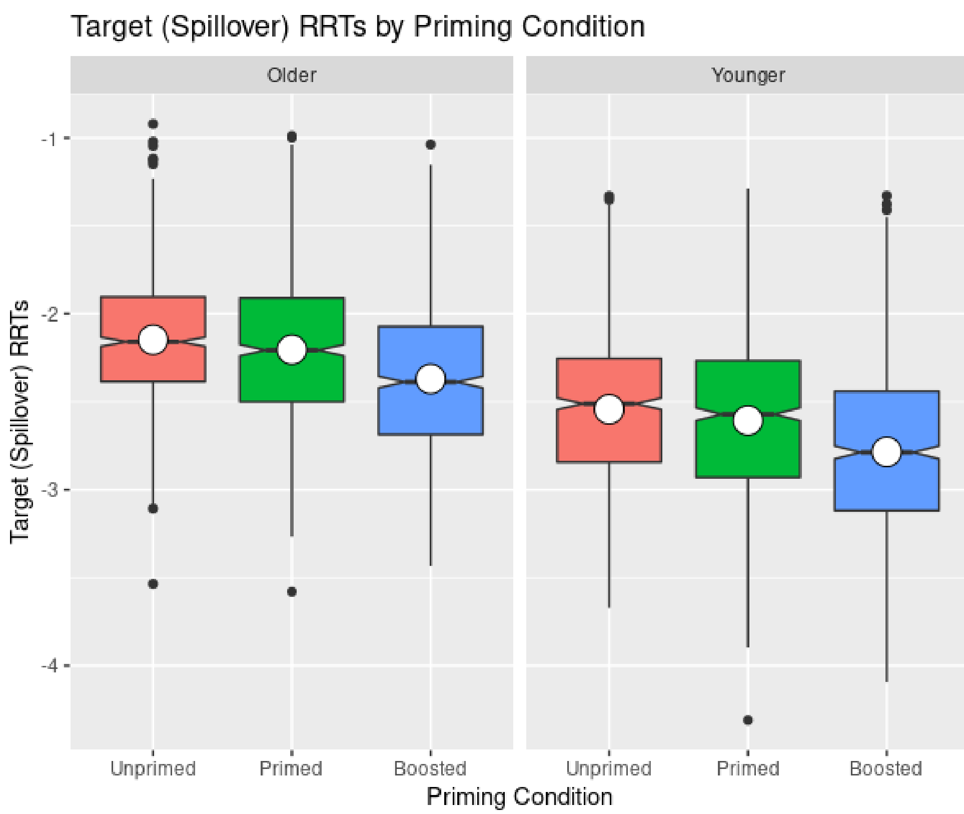


Figure 8 – By-group overview of residualised reading times in the Spillover ROI. Central dots indicate means for that condition. A clear stepwise facilitation effect can be seen, where primed trials were read faster than unprimed trials, and boosted trials faster than primed trials.

2.4.2 LCC Sentences

Verb ROI

The LCC manipulation had significant effects in this ROI ($t(2377)$ = -4.314, $p < .001$, d = -.177), but not in the expected direction: unrepeated verbs were read faster than repeated verbs. This effect was not modulated by age as the interaction between age group and repetition was not significant ($t(2378)$ = .607, p = .544, d = .025). There were trends towards effects of RST score ($t(60.21)$ = 1.761, p = .083, d = .454) and LCT score on Verb reading times ($t(60.12)$ = -1.445, p = .154, d = -.373), but these did not reach significance. Similarly, neither pre-test interacted with repetition condition (all ps > .05). As in Target ROIs, older readers exhibited slower reading speeds across the board ($t(57.71)$ = -2.430, p = .018, d = -.640). Full details for the model in this ROI are given in Table 4.

Spillover ROI

Condition effects in the LCC Spillover ROI were reversed compared to those in the Verb ROI, and followed the expected pattern such that repeated items were read faster than unrepeated items ($t(2370)$ = 4.890, $p < .001$, d = .201). While a main effect of age group existed ($t(57.61)$ = -3.098, p = .003, d = -.816), condition effects did not vary by age group ($t(2371)$ = -1.217, p = .224, d = -.050). As before, LCT score did not interact with repetition condition and did not predict reading times across the board (both ps > .05). However, reading times were faster as RST scores increased ($t(60.13)$ = 2.017, p = .048, d = .520). RST scores nevertheless failed to interact with repetition condition ($t(2381)$ = .071, p = .943, d = .003). Please refer to Table 5 for a full summary of effects in this ROI.

Table 4 – Linear Mixed Model Summary for the LCC (Verb) ROI ($R^2{}_{Marginal}$ = .110; $R^2{}_{Conditional}$ = .450). "Trial" denotes the numeric value of trial numbers in presentation order. Reference level for Repetition was Unrepeated. Significant values are represented in bold.

Parameter	Estimate	SE	*DF*	*t*	*p*	*d*
Intercept	-2.825	.0689	59.79			
Repetition	-.0628	.0146	2377	-4.314	<**.0001**	-.1770
Age Group	-.2559	.1053	57.71	-2.430	**.0182**	-.6397
RST	.1062	.0603	60.21	1.761	.0833	.4539
LCT	-.0962	.0666	60.12	-1.445	.1537	-.3726
Repetition * Age Group	.0138	.0227	2378	.607	.5442	.0248
Repetition * RST	.0085	.0136	2389	.621	.5349	.0254
Repetition * LCT	-.0131	.0149	2388	-.876	.3810	-.0386

Table 5 – Linear Mixed Model Summary for the LCC (Spillover) ROI ($R^2{}_{Marginal}$ = .143; $R^2{}_{Conditional}$ = .472). "Trial" denotes the numeric value of trial numbers in presentation order. Reference level for Repetition was Unrepeated. Significant values are represented in bold.

Parameter	Estimate	SE	*DF*	*t*	*p*	*d*
Intercept	-2.317	.0599	60.41	-38.683	<**.0001**	
Repetition	.0623	.0127	2370	4.890	<**.0001**	.2009
Age Group	-.2828	.0913	57.61	-3.098	**.0030**	-.8164
RST	.1055	.0523	60.13	2.017	**.0481**	.5203
LCT	-.8463	.0577	60.04	-1.466	.1479	-.3784
Repetition * Age Group	-.0242	.0199	2371	-1.217	.2239	-.0500
Repetition * RST	.0008	.0119	2381	.071	.9432	.0029
Repetition * LCT	.0054	.0131	2380	.417	.6769	.0171

2.5 General Discussion

The present study investigated the robustness of older and younger adults' syntactic priming in comprehension. Participants' reading times to Target and Lexical Control Condition sentences (LLC; worked into Filler 2 items) were recorded to investigate the effects of syntactic and lexical overlap. Target sentences were either primed, primed and boosted, or unprimed, while verbs in LCC sentences were either repeated from the Prime or showed no overlap. Measures of Working Memory and Processing Speed were recorded and added to linear mixed models as covariates.

2.5.1 Syntactic Comprehension Priming

Older adults showed intact abstract syntactic comprehension priming in all defined Target ROIs, though most robustly so in the Spillover region. This study therefore does not support the notion that syntactic processing becomes impaired with age. Instead, results suggest the measurements used in past studies of language in older adults, which have mainly relied on conscious, declarative skills, resulted in decreased performance compared to younger groups. This impaired performance may therefore have been the result of slower motor skills, reduced declarative memory, or even of more extensive searches through larger vocabularies (Ramscar et al., 2014), but given the current evidence, not of impaired syntactic processing.

Reading times across conditions were, nevertheless, slower in the older group, even when LCT scores were accounted for, which likely reflects a general slowing of cognitive functions related with age (Salthouse, 1996, inter alia) – importantly, however, this slowdown did not affect Priming Condition. The finding of intact syntactic priming in comprehension corresponds with the findings of Hardy et al. (2017, 2020a,b), who found similar effects in production, and with Ferreira et al. (2008) and Heyselaar et al. (2017), who found intact priming effects in patients with amnesia whose explicit memory was severely impaired.

The finding of intact abstract comprehension priming across two intervening fillers in the older sample contradicts the residual activation account of syntactic priming (Pickering and Branigan, 1998), especially since older adults' processing speed limitations are thought to affect the effectiveness of cue retrieval via residual activation. However, both an implicit learning account (Chang et al., 2012) and dual mechanism accounts (Tooley and Traxler, 2010) could explain these patterns, as implicit learning does not suffer from the same age-related declines as activation decay does. The abstract syntactic priming findings therefore offer insufficient evidence to discern between implicit learning and mixed accounts. However, results from the lexical boost condition are more informative.

2.5.2 Lexical Boost

The relatively long-lived nature of the lexical boost in this Study may be seen to contradict several previous investigations (notably Hartsuiker et al., 2008). Indeed, Hartsuiker and colleagues only reported lexical boost effects in immediately adjacent sentences. However, upon further inspection of Hartsuiker et al.'s data, some lexical boost effects are still observable in their "lag 2" condition, where two intervening fillers were produced between Prime and Target. There is also some indirect evidence from previous studies to suggest that the lexical boost in syntactic comprehension priming might be observable across two sentences. For instance, Ledoux et al. (2007) recorded syntactic priming and lexical repetition effects on ERP responses while "at least two" fillers intervened between Prime and Target. This study confirmed Ledoux et al.'s suggestion with evidence that speaks directly to both abstract priming and lexical boost effects across two fillers. Active manipulation of the number of intervening fillers in future studies, as well as monitoring of participants' brain responses as Ledoux et al. did, could help to elucidate the persistence of the lexical boost further.

Crucially, the lexical boost in this study was completely intact in the older group, casting doubt on most dual mechanism accounts of syntactic priming, which still consider the lexical boost to be the result of residual activation or explicit memory. Given the much lower performance of older adults on the LCT, activation of lexical representations should decline faster in older compared to younger adults, resulting in decreased lexical boost effects following dual mechanism accounts. This prediction was not reflected in the data, as older adults showed equally strong lexical boost effects after two fillers compared to the younger group. There were, additionally, no group differences on LCC trials, suggesting that lexis-only priming is also intact in older readers.

Prediction error-based models of syntactic priming, such as those put forward by Jaeger and Snider (2013) and Malhotra et al. (2008), could also explain the abstract syntactic priming effects in this study. Under these accounts, priming is the result of expectation-based error, that is, of the surprisal readers experience when encountering a structure. The more exposure to a structure a reader experiences, the more facilitated processing becomes. Reduced relatives, as used in this study, are an infrequent structure that elicits high prediction error and therefore large priming effects. However, previous evidence suggests the lexical boost is not affected by prediction error (Tooley et al., 2019), and indeed, this study largely used common verbs in Targets and Primes (such as “checked”, “rescued”, “cleaned”, etc.; for a full list of stimuli, please refer to Appendix B), which would not have been associated with large prediction error. While these findings of abstract syntactic priming may therefore have been the result of prediction error effects, lexical boost effects do not support error-based models.

Tooley (2020) formulated a mechanistic account of the lexical boost which posits that lexical effects result from a connection between syntactic structure representations and lexical lemmas (much like in the account of Pickering and Branigan, 1998). The older adults in this Study, however, also exhibited processing facilitation when *only* the verb was repeated in the Lexical Control Condition. Verb-structure pairing, therefore, also cannot be the only explanation for the lexical boost.

Instead, the evidence presented here suggests that the lexical boost relies on similar mechanisms as abstract priming, and is therefore in line with implicit memory or learning accounts. Specifically, a recent proposal by Heyselaar et al. (2021) is supported by the data. The Heyselaar et al. account stipulates that both abstract priming and lexical boost effects are grounded in non-declarative (i.e. implicit) memory, with *perceptual* non-declarative memory (which supports activation of recently-processed information) underpinning short-term effects such as the lexical boost, while long-term abstract priming is subserved by *conceptual memory* (the learning of relationships between stimuli). Heyselaar et al.’s (2021) account is particularly strong in its explanation of intact priming in aging, when declarative skills decline. Although the data are in line with this account, no specific test of subsystems of non-declarative memory was included, something which would be of interest for future studies. The current investigation should therefore be expanded upon with additional pre-tests of different memory types, as well as deliberate manipulation of the number of fillers intervening between Prime and Target to test the conflicting accounts of syntactic priming and examine whether the Heyselaar et al. account is indeed supported.

2.5.3 Working Memory and Processing Speed

As syntactic priming is an implicit linguistic measure, and the RST used in this study tested explicit, declarative skills, the absence of predictive power of WM on priming condition was to be expected. While span tasks have been correlated to linguistic performance by past authors (e.g. Brébion, 2003), the language measures used in these studies generally tested declarative skills. This is a crucial difference between the present study and past investigations. Alternative methods of measuring performance on the RST, potentially involving reaction times or the processing component of the test, may have the potential for more effective correlation with implicit linguistic tasks. This would be an additional benefit of using the RST compared to other span tasks, and would make effective use of its processing task.

The minimal impact of WM on syntactic priming is not unique to this study: Hardy et al. (2017) hypothesised that WM would be insignificant to their results to such a degree that they did not even collect a measure of WM. Nevertheless, groups did not show significant differences on the RST in this study despite large distinctions in processing speed, and a replication of the present Study with a larger sample and more than one WM measure could be more effective in discovering and controlling for WM-related effects. Similarly, LCT scores were not generally predictive of reading times, potentially because age correlated highly significantly with LCT. Neither RST nor LCT scores interacted with priming condition, and this Study therefore finds no evidence for WM or Processing Speed affecting syntactic priming or the lexical boost. Nevertheless, given the unexpected absence of by-group RST differences, this interpretation should be treated with caution.

2.6 Conclusions

The present study examined syntactic comprehension priming in younger and older adults across two intervening fillers. Previous studies of priming in production suggest little to no age-related differences on priming measures, a prediction that the current results support. Older adults showed significant priming and lexical boost effects in line with the younger group. Moreover, none of the priming effects relied on measurements of Working Memory, and both abstract priming effects as well as the lexical boost persisted across intervening fillers. Taken together, these findings cast doubt on models that consider either abstract syntactic priming or the lexical boost the result of residual activation or Working Memory. Future studies on syntactic priming should therefore incorporate both younger and older adults while actively controlling the number of intervening fillers between Prime and Target. Further, this study emphasises the potential of neuroimaging studies with older and younger groups as a way to uncover more subtle priming patterns.

3 Study 2 – A Matter of Memory? Age–Invariant Relative Clause Disambiguation and Memory Interference in Older Adults

The findings of Study 1 suggest implicit measurements of language processing remain age-invariant and that WM or Processing Speed measures have little to no impact on implicit sentence processing. However, linguistic behaviour can be tied more directly into WM ability under certain cicumstances: an example of such circumstances is found in relative clause disambiguation. Past research is strongly suggestive of WM effects on sentence disambiguation. If this is the case, older adults may show different disambiguation patterns compared to younger adults, even when disambiguation is measured using implicit paradigms. Study 2 explored this possibility.

3.1 Abstract

Past research suggests Working Memory plays a role in determining relative clause attachment bias. Disambiguation preferences may further depend on Processing Speed and explicit memory demands in linguistic tasks. Given that Working Memory and Processing Speed decline with age, older adults offer a way of investigating the factors underlying disambiguation preferences. Additionally, older adults might be subject to more severe similarity-based memory interference given their larger vocabularies and slower lexical access. Nevertheless, memory interference and sentence disambiguation have not been combined in studies on older adults before. A self-paced reading paradigm under memory load interference conditions was used, and measures of Working Memory and Processing Speed were collected. Older ($n = 30$) and Younger ($n = 35$) readers took part in the study online and were presented with biased relative clause sentences as well as interference load nouns. Reading times were recorded and measures of comprehension accuracy and load recall were monitored for attention. This

setup allowed for the implicit measurement of attachment biases and memory interference effects.

Results show similarity-based interference affected both age groups equally, but was more pronounced in dispreferred NP2-biased structures. Robust preferences for high (NP1) attachment were found in both age groups: attachment preferences did not differ by group and were unaffected by Working Memory span. Memory interference effects were further not dependent on either span score or processing speed. However, accuracy on recall prompts, requiring conscious memory access, was affected by Working Memory span in both groups. Findings of greater interference in syntactically dispreferred structures support unified processing models where parsing constraints naturally interact. The current results contradict sentence processing accounts based on individual differences in Working Memory as well as the Processing Speed theory of adult cognition. This lack of age differences on further aligns with research finding age-invariant implicit language processing, and calls for further research into older adults' disambiguation strategies under memory interference conditions.

3.2 Introduction

The way syntactic units are bound together and turned into meaning is fundamental to human linguistic behaviour. Relative clause disambiguation tasks have been at the forefront of psycholinguistic research for decades and continue to be a relevant paradigm to the field as reliable indicators of linguistic parsing strategies (e.g. Carreiras and Clifton Jr, 1993; Checa-Garcia, 2016; Frazier and Rayner, 1982; Mak et al., 2002). Disambiguation patterns have been used to discern monolingual and bilingual sentence processing (e.g. Jegerski et al., 2016), children and adult speakers (e.g. Felser et al., 2003), and older and younger adults (Payne et al., 2014). In sentences such as (1), it is ambiguous whether the referent of the relative clause is "the owner" (NP1) or "the house" (NP2). Sentences may also be semantically disambiguated, as in (2) and (3), to an NP1 or NP2 interpretation. Preferences to either interpretation may depend on age (Evans et al., 2015), Working Memory (hereafter WM;

Baddeley, 2010; Peng et al., 2018; Swets et al., 2007), or L1 background (Fernández, 2003). Native speakers of English have generally been found to favour a strategy of *Recency*, that is, binding the relative clause to the most recently processed referent – in this case, NP2 (Altmann et al., 1998; Gibson et al., 1996).

1. The owner of the house that looked old appealed for help.

2. The owner of the house that had the moustache appealed for help.

3. The owner of the house that needed renovation appealed for help.

There is debate around whether advancing age causes disambiguation preferences to shift, and what factors may contribute to this shift. An early study by Kemtes and Kemper (1997) investigated demands on older and younger adults' reading of temporary ambiguity in reduced relative sentences (such as "Several angry workers warned about low wages decided to file complaints"). Kemtes and Kemper (1997) found older adults' reading times on all sentences increased as WM scores declined. However, reading times did not vary by disambiguation bias (as in (2) and (3)). Conversely, older adults were less accurate on comprehension questions about ambiguous sentences (as in (1)) than younger adults, regardless of WM span – there were no by-age differences on questions about unambiguous sentences. Conscious recall of information – such as in comprehension questions – is generally thought to be more dependent on WM and more susceptible to age-related decline than implicit memory (e.g. Bopp and Verhaeghen, 2005; Yang et al., 2020).

The distinction between explicit and implicit memory, and varying levels of age-related changes to these different memory types, has been under discussion for several decades. Waters and Caplan (1996b) hypothesised that conscious (or explicit) memory recall, which is more susceptible to retrieval interference (see below) and involves an active search through memory, is more challenging for readers than unconscious (or implicit) memory. Over the following years, large amounts of evidence has supported this implicit/explicit distinction. Kemper and Herman (2006), for example, conducted a study of older adults' comprehension of subject and object clefts (e.g. *"It was the boy that bothered the girl"* and *"It was the boy that the girl bothered"*). Kemper and Herman (2006) found clear age-related declines on comprehension probes, an offline, explicit memory measure. However, reading time analyses showed that both older and younger adults responded similarly to syntactically complex object clefts – indeed, older adults exhibit less defined slowdowns in difficult regions, suggesting that if anything, their reading of complex syntax was smoother than that of younger adults.

3.2.1 Memory Interference

Memory operations are further complicated by *interference* at the stage of memory retrieval – the point at which the correct stored cue must be selected and used for linguistic processing. Extensive work on memory interference by Van Dyke, Lewis, and colleagues (Lewis et al., 2006; Van Dyke and Lewis, 2003; Van Dyke and McElree, 2006), as well as Gordon and colleagues (Gordon et al., 2006, 2002) discovered that slowdowns in reading speed can occur when memory retrieval operations are complicated by the presence of cues with semantic similarity to the retrieved information. Specifically, Van Dyke and McElree (2006) presented participants with three memory load words before pacing through sentences at their own speed. Memory loads were either semantically similar (interfering) or different (non-interfering) relative to the semantic content in the trial sentence. Interfering loads were found to result in significant slowdowns in regions where semantic similarity was located, and accuracy on comprehension questions dropped.

Gordon et al. (2006) further concluded from an eye-tracking study that these effects are indeed related to memory interference as no slowdowns occured in sentences where memory cues were fully integrated into the sentence *before* any interference could occur. These findings were integrated into a cue-based parsing model of sentence processing (Lewis et al., 2006), which supposes that each processed word elicits memory retrieval attempts to integrate that word into the wider discourse. Retrieval is generally achieved in a 'content-based' manner, where grammatical and semantic features of the cue to be retrieved form the basis of successful binding of agents, patients, and objects in sentences. Thus, interference is created if cues with similar grammatical and semantic features to the cue to be retrieved are stored in WM at the same time as the retrieval operation takes place. The cue-based parsing account has recently been tied into suggestions of a shared semantic competition mechanism, where a general store of available cognitive resources underlies both production and comprehension (Humphreys et al., 2016).

Whether interference effects are related more to explicit memory recall or implicit demands has not been extensively investigated. Further, it is unknown whether older adults are more susceptible to similarity-based interference than younger adults. As mentioned above, not all linguistic tasks requiring memory engagement show age-related declines. For example, in tests of syntactic priming (Hardy et al., 2017, 2020a), an implicit task requiring no conscious recall, older adults have been found to perform at par with younger adults. Indeed, even amnesic patients, whose explicit memory is severely impaired, have been discovered to exhibit intact syntactic priming abilities (Heyselaar et al., 2017). Age-related effects on syntactic disambiguation tasks may therefore also depend on the measure used.

A study of WM-related attachment preferences in bilingual children and adults by Felser et al. (2003) used an implicit, self-paced listening task. Felser et al.'s results partially contradict those of Kemtes and Kemper discussed above, and suggest children's relative clause attachment bias varies along WM-based lines. Specifically, high-span children were found to prefer NP1 interpretations, while low-span participants preferentially attached to NP2, adhering to the Recency principle. Therefore, while Kemtes and Kemper (1997) concluded WM span has little to no effect on implicit syntactic ambiguity processing, Felser et al.'s (2003) results suggest the opposite.

Felser et al.'s (2003) explanation for these WM-related effects on ambiguity processing is based on *syntactic chunking* of sentences. When reading, humans automatically insert prosodic breaks in sentences that aid the storage of information in WM and give the syntactic parser time to process all relevant cues (e.g. Beese et al., 2017). Syntactic chunking is an important aspect of multiple dominant theories of linguistic parsing, including the "Sausage Machine" (Frazier and Fodor, 1978) and Abney's (1991) "Chunking Parser". Specifically, Felser et al. suggest that readers store NP1 in WM, then insert a prosodic break, and only then move on to storing NP2. The first NP may therefore be retained in WM more prominently as this NP has benefitted from the effect of syntactic chunking, allowing for a more stable integration into the WM system. Low-span individuals, Felser et al. suggest, may not have the required memory capacity to maintain both NPs, and would therefore attach to NP2.

3.2.2 Disambiguation and Older Adults

Swets et al. (2007) investigated the effect of chunking on disambiguation by encouraging participants to insert a reading break before and after the relative clause. For instance, the sentence in (1) would be segmented on-screen as *'The owner of the house // that looked old // appealed for help'*. Swets et al.'s (2007) results contradict those of Felser et al. (2003): while low span readers were found to be prefer NP1 when sentences were unsegmented, high span readers preferred NP1 attachment only when sentences were presented in chunks. According to Swets et al. (2007), inserting chunks resulted in all participants reading as low-span individuals do. Even high-span groups ended up attaching to NP1. Conversely, low-span participants in the Felser et al. (2003) study preferentially attached to NP2. This chunking account was further tested by Traxler (2009), who found further evidence for low-span readers attaching to NP1 with an eye-tracking study. As in Swets et al. (2007), Traxler's (2009) ambiguous and unambiguous sentences were segmented to encourage participants to insert a syntactic break. A general bias towards NP1 attachment resulted from this manipulation. Although higher WM was associated with faster reading in this study, these differences were unaffected by ambiguity condition. Traxler (2009) concluded, therefore, that WM constraints must play only a minor role in ambiguity resolution, at least during implicit reading.

Following the findings of Swets et al. (2007) and Traxler (2009), older adults, whose memory capacity declines, should show a preference for NP1 attachment, or a less defined bias towards attaching to NP2 compared to younger adults. This theory was tested by Payne et al. (2014), who, conversely, found their participants experienced more processing difficulty on NP1 as age progressed. Although Payne et al. (2014) did not intentionally segment sentences, reading times on NP1 and NP2 structures became more distinct with higher age – such that older adults showed greater differences between attachment bias conditions than younger adults (Payne et al., 2014). Importantly, participants with lower WM were more predisposed to an NP1 bias than higher-span readers. This effect was especially true for older adults: low-span older readers were most likely to prefer NP1 attachment, and the youngest low-span readers in the Payne et al. study did not show a relative NP1 preference. Higher-span readers of both age groups tended to prefer NP2-attachment. Payne et al.'s (2014) offline comprehension questions further showed that older adults had a smaller advantage for NP2 structures than younger adults, although accuracy on all sentence types was high at 75% or more. This effect, however, was largely moderated by measures of WM and print exposure, such that low span readers of all ages showed a preference for NP1 attachment, while higher span readers preferred NP2. This effect was found to be stronger in older readers (Payne et al., 2014).

The Payne et al. (2014) study, in summary, suggests the following: generally, readers preferred to attach to NP2, but the smaller a participant's WM span, the less likely they were to show a pronounced preference to NP2. Older adults showed a significantly stronger effect of this modulation than younger adults. Notably, Payne et al. (2014) report varying attachment preferences based on the measure recorded: while on-line reading times suggested a general NP2 bias, results from off-line, post-hoc comprehension questions were less clear cut. This again suggests differences between off-line and on-line, explicit and implicit measures when used with older and younger adults (see further James et al., 2018, for a discussion).

Research on syntactic disambiguation and memory capacity therefore paints a confusing picture, with various studies pointing in different directions. While Felser et al. (2003) found lower-span participants to preferentially attach to NP2, more so than high-span readers, evidence from Swets et al. (2007), Traxler (2009), and Payne et al. (2014) suggests the opposite. Although memory demands may therefore have an impact on disambiguation preferences, it is unclear what direction these effects take, and whether older readers are differentially affected.

Additionally, the hypothesis that lower-span readers are more biased towards NP1 compared to higher-span individuals also appears to contrast with abundant evidence around decay of information stored in WM (for instance, see Lemaire and Portrat, 2018; Werner, 2019). Upon storage of a cue in memory, that cue retains a set amount of activation until retrieval operations recall the cue at the right moment. For example, in the sentence *"The boy who played the piano fought the dog"* the cue *"the boy"* is retained until it is tied to the verb *"fought"*. However, if too much material intervenes between the points of storage and retrieval, activation of the cue decays to the point where retrieval becomes more difficult (Lemaire et al., 2018; Lewis et al., 2006). Following this notion, in ambiguous relative clause sentences (such as *"The owner of the house that looked old appealed for help"*) the activation of NP1 (*"the owner"*) would have decayed further than the activation of NP2 (*"the house"*) when the relative clause needs resolving. Nevertheless, Swets et al. (2007), Payne et al. (2014), and Traxler (2009) all suggest NP1 is the more likely referent for readers with lower WM capacity.

3.2.3 Processing Speed and Memory Representations

This objection is especially relevant to older adults, as age-related changes in Processing Speed are likely to affect chunking strategies: the Processing Speed Theory of adult cognition (for a review, see Salthouse, 1996) posits that older adults struggle to maintain representations processed early in a sequence for resolution later on. Therefore, the Processing Speed Theory would predict older adults prefer NP2 because the activation necessary to maintain NP1 is subject to faster decay than in younger adults. The Processing Speed account further predicts longer latencies on processing operations and higher error levels in older adults generally (Salthouse, 1996) – both findings are ubiquitous in the cognitive aging literature.

More generally, prior studies of Processing Speed and syntax comprehension suggest speed deficits may intensify comprehension problems. Grossman et al. (2002) studied a sample of Parkinson's Disease patients on offline comprehension questions, focusing on object- and subject-relative sentences. Only patients who showed disproportionately delayed Processing Speed metrics exhibited difficulties understanding object-relatives, suggesting Processing Speed declines exacerbate syntax comprehension difficulties. Implicit evidence for the same suggestion was provided by Huettig and Janse (2016), using a Dutch task in which participants were presented with four objects and grammatically biased towards looking at a target picture through gender marking of the picture nouns. Huettig and Janse (2016) found Processing Speed scores to be marginally more predictive of anticipatory eye gaze proportions than WM, and both were far more predictive than age alone. This suggests higher Processing Speed may facilitate syntactic processes, or at the very least, anticipatory processing. Whether the same holds true for relative clause processing is a question the current study attempts to address.

It is, in sum, still unclear whether Processing Speed limitations and memory decay would bias older adults towards an NP1 interpretation, or whether the faster decay of cues stored in WM would cause them to prefer NP2-attachment. The current study aims to address this question using a self-paced reading paradigm, an implicit measure of processing. However, as mentioned above, addressing memory capacity and decay is not the only angle from which to consider WM. Memory effects on syntax processing have also been investigated based on the *quality* of WM operations rather than the *quantity* of WM capacity. In particular, the finding that memory representations may be subject to various kinds of *interference* which can aggravate retrieval difficulties has received considerable research attention (e.g. Gordon et al., 2001; Lemaire and Portrat, 2018; Oberauer and Lin, 2017) – combinations of this framework with research on language and aging are nevertheless virtually non-existent.

One exception is the study by Kemper and Herman (2006), which showed that younger adults are affected by memory interference while reading sentences even though older adults were not. Kemper and Herman presented participants with subject and object clefts (see above) as well as interfering and non-interfering memory loads. Again, older adults generally scored lower on comprehension questions than younger adults regardless of memory load, but analyses of reading times showed an opposite pattern: older adults exhibited *fewer* slowdowns in difficult syntactic regions than younger adults. On average, younger adults required an additional 76ms to process object compared to subject clefts compared to around 65ms for older adults (Kemper and Herman, 2006). Kemper and Herman, peculiarly, conclude this is evidence of older adults refusing to allocate sufficient resources for proper interpretation of object clefts. However, although Kemper and Herman gathered a large psychometric database from participants, these measures were not included in any models for the results of the memory load task.

3.2.4 Semantic Compensation Mechanisms

There remains, in other words, a significant gap in the literature around older adults' processing of syntactic ambiguity and memory interference. Making the connection between these two factors nevertheless offers an important window into discovering whether memory operations and syntactic processing remain age-invariant. These questions are complicated by evidence suggesting older adults place greater reliance on semantic and contextual information during reading. For example, Milburn et al. (2021) measured younger and older adults' prediction of potential syntactic referents by using a verb-argument prediction paradigm. Milburn et al. presented older and younger adults with four images of objects (e.g. a glass of water, cup of coffee, cat, and rock), and auditorily presented sentence fragments biasing participants to any one of these four (e.g. *"The dog will drink the ..."*). Participants' eye movements were monitored during the study, which found that older adults were as successful as younger participants in predicting the likely upcoming referent. However, when comparisons were no longer semantically informed, younger adults outperformed the older group. For example, when presented with images of a cake, a branch, a bucket, and a car, and the sentence fragment *"Someone will move the..."*, older adults struggled more than younger participants in defining a possible referent. This suggests that the absence of semantic content causes greater problems for older adults' syntactic processing (Milburn et al., 2021)

Similar evidence was found by Poulisse et al. (2019), who tested older and younger participants on subject-verb agreement, while keeping memory demands to a minimum by only including two-word sentences (such as *"I smoke"* or **"I smokes"*). Poulisse et al. (2019) also manipulated semantic content by including pseudowords in their study (e.g. *"I spuff"* or **"I spuffs*). By measuring participants' grammaticality judgements, Poulisse et al. found that older adults were slower and less accurate than younger adults across conditions (in line with evidence presented above that explicit tasks elicit greater by-age differences). However, older adults were further disproportionately affected by an absence of semantic content, scoring significantly lower on pseudowords compared to real words. This effect was absent in the younger group, providing more evidence for an increased reliance on semantic content with age.

If this is the case, and older adults rely on semantic content more so than younger adults for successful interpretation of sentences, older groups could be more susceptible to similarity-based interference than younger adults. Nevertheless, this has not been tested directly. Examining the effects of similarity-based memory interference on older adults' relative clause disambiguation integrates two separate research angles: the first seeks to elucidate whether older adults' relative clause attachment preferences differ from younger adults', and if so, whether memory limitations play a role in this decline. The second angle investigates whether memory interference affects older adults more severely than younger readers. However, memory limitations are not the only, and perhaps not even the most salient, factor to focus on when investigating older adults' sentence comprehension. Processing Speed has increasingly been emphasised in the context of syntax processing since extensive work by Salthouse and colleagues (e.g. Salthouse, 1996, 2000; Salthouse and Babcock, 1991; Salthouse and Coon, 1993). The current study, therefore, further includes an investigation of Processing Speed and relative clause disambiguation in older adults.

3.2.5 The Present Study

To sum up, despite the extensive past work on relative clause disambiguation, large uncertainties remain around whether attachment preferences change with older age. The current field of disambiguation and aging paints a confusing picture, possibly due to the large amounts of extrinsic and intrinsic variables that may affect a reader's attachment strategies: from animacy and semantic richness of the NPs involved (Wang et al., 2012), to the linguistic experience and L1 background of participants (Felser et al., 2003), or the morphosyntax of elements in the relative clause (Delle Luche et al., 2006), to name but a few. Perhaps more relevant to this study, the role of WM retrieval and interference on preferences is further contentious, as is the impact of Processing Speed limitations. The multitude of potentially confounding variables has important implications for the study of attachment in general, a point which will be discussed further in the Discussion (Section 3.5). The current study integrates past findings on relative clause disambiguation in older adults with accounts focusing on the quality of WM operations rather than the quantity of WM capacity. Specifically, this study considers similarity-based retrieval interference. To this end, implicit measures in the form of a self-paced reading paradigm were used, and memory interference was manipulated using load words presented before each sentence (in the manner of Van Dyke and McElree, 2006).

Following results obtained by Swets et al. (2007) and Traxler (2009), older adults may show a greater NP1 bias or a less defined NP2 bias due to the prominance of NP1 in their memory systems. Conversely, Processing Speed limitations (as reviewed in Salthouse, 1996) and faster decay of cues held in WM might bias older adults towards NP2-attachment. If, as suggested in the aging literature (e.g. Gonzalez-Burgos et al., 2019; Poulisse et al., 2019), older adults place greater reliance on semantic information during comprehension, interference effects may disrupt sentence comprehension more heavily in older compared to younger adults. Not only does this angle of inquiry have the potential to impact knowledge of older adults' sentence processing, but findings should also prove informative of cue-based parsing models and accounts of memory interference, as well as models on the processing of ambiguities.

3.3 Methods

3.3.1 Participants

Participants from two age groups took part in this study online through Prolific (Prolific, 2014). Younger particiants (n = 35) ranged between 18 and 25 years of age, while older participants (n = 30) were all aged over 65 (see Table 6 for group means). Five younger participants were eliminated from the data sample due to failing attentional checks or incomplete responses on one of the pre-tests for this study, resulting in a final sample size of 30. All participants confirmed they were native speakers of English before taking part, and were paid for their participation. All participants gave full informed consent before taking part, and the study received ethical approval from the University of Essex Social Sciences Ethics Sub-committee.

Table 6 displays participant biodata in both groups. Education levels were measured along the International Standard Classification of Education (Unesco Institute for Statistics, 2012). Groups did not differ on any of the measures below, with one exception: younger participants spent more years in education than older participants ($t(44.5)$ = -4.26, $p < .001$), although differences in overall level of education were only marginally significant ($t(47.7) = 1.91$, p = .06). Distributions of pre–test scores are visualised in Figure 9.

3.3.2 Materials

Pre-tests

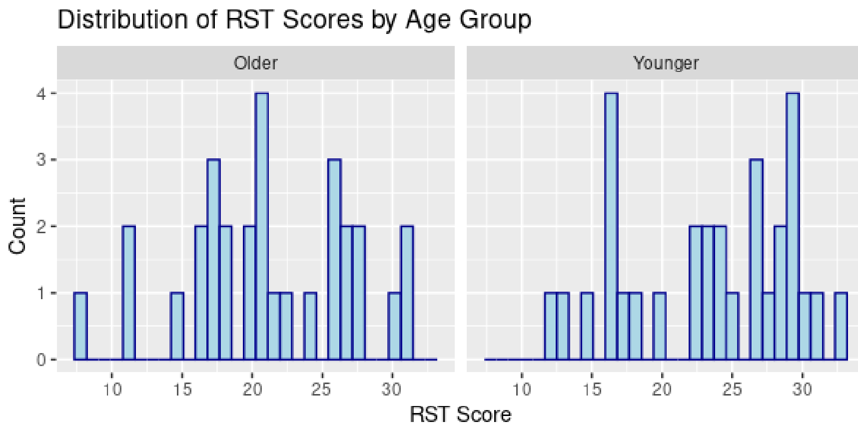
Table 6 – Summary of Participant Biodata for Study 2. RST: Reading Span Task; LCT: Letter Comparison Test. Education Level was measured along the International Standard Classification for Education 2012 (Unesco Institute for Statistics, 2012).

	Younger Group	*Older Group*
Age	M = 21.77; SD = 2.11	M = 68.53; SD = 3.44
Gender	21 Female, 9 Male	17 Female, 13 Male
Years in Education	M = 16.57; SD = 1.66	M = 15.43; SD = 2.78
Education Level	*Mode* = 6 (Bachelor-level)	*Mode* = 5 (Short-cycle Tertiary)
RST Score	M = 23.33; SD = 5.96	M = 21.20; SD = 5.95
LCT Score	M = 28.03; SD = 5.90	M = 17.30; SD = 5.90

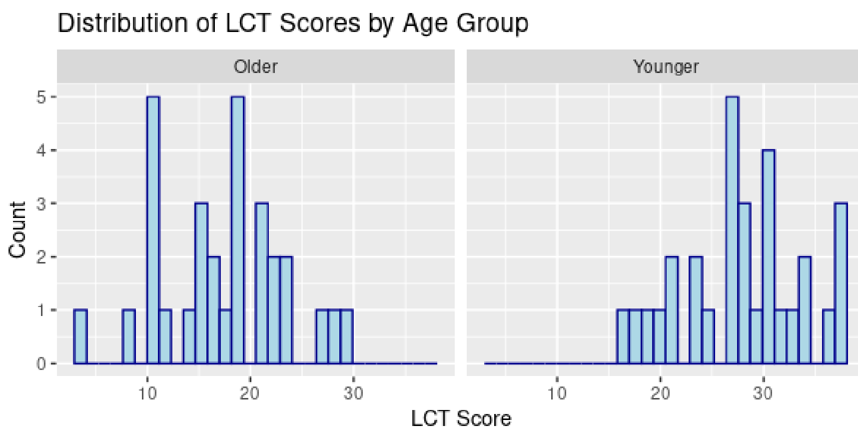
Reading Span Task

Participants completed an online version of the Reading Span Task (RST; Daneman and Carpenter, 1980) hosted using Qualtrics (Provo, Utah, US). Participants were shown sets of sentences incrementally increasing in number, ranging from three to eight sentences per set, and instructed to remember the final word of each sentence. Participants were further asked to rate sentences for appropriateness, with items constructed such that half were appropriate and half were inappropriate. Participants saw each sentence individually before being asked to type the recall words into text boxes on a separate screen. For instance, for the sentence *'The rocks waved in the gale force winds'* participants should select 'Inappropriate' and remember 'winds'. Similarly, for *'Filter coffee is the superior drink'* the correct response was 'Appropriate' and the word to be remembered was 'drink'.

Sentences used in the RST had an average length of 6.97 words (SD = 1.44, range = [5,11]). All sentences were constructed to have simple grammar and no technical jargon or phrases (see Appendix A for a list of all RST items). In total, participants saw 33 sentences, including two practice trials. Points were awarded to participants for recalling a correct word in the correct order, with half points given for correct words recalled in an incorrect text box in the same trial (following Conway et al., 2005). There were no significant by-group differences on the RST ($t(58) = 1.39$, $p = .171$; $M_{\text{Y}} = 23.3$, $M_{\text{O}} = 21.2$). However, age was significantly though weakly correlated with RST score across groups (r = -.07, $p < .001$), as well as when considering the Younger (r = .10, $p < .001$) and Older groups separately (r =



(a) Histograms of RST Scores by Age Group in Study 2.



(b) Histograms of LCT Scores by Age Group in Study 2.

Figure 9 – Histograms of pre–test scores by Age Group in Study 2. Age Group differences by LCT score can be deduced from these distributions, while results on the RST are not as clear–cut.

.04, $p = < .001$).

Letter Comparison Test

Processing Speed was assessed using the Letter Comparison Test (LCT; Salthouse, 1991a; Salthouse and Babcock, 1991). Participants were presented with two letter strings of either three, six, or nine letters, and asked to judge whether these strings were identical or different. Scores were calculated as the amount of correctly identified strings within 30 seconds, after which the test timed out. The LCT used in this study comprised a maximum of 48 character pairs, equally subdivided into identical and different conditions. All non-matching letter strings were generated using an online letter generator, and were fully randomised. Strings were checked for words or wordlike items before being added to the pre-test.

The LCT was presented in white capital letters (Arial font) on a grey background using PsychoPy 3 2020.1.3 and Pavlovia (Peirce and MacAskill, 2018; PsychoPy/Pavlovia, 2021). Strings appeared towards the left and right of the centre of the screen, and participants were instructed to identify whether the two letter strings were identical or different using keyboard presses. Participants completed five untimed practice trials before the main test.

Group differences on the LCT were more pronounced than on the RST (see above; $t(58) = 6.97$, $p < .001$; $M_{\mathrm{Y}} = 28.0$, $M_{\mathrm{O}} = 17.3$); higher age was associated with lower Processing Speed across groups ($r = -.65$, $p < .001$). Further, RST and LCT scores were positively correlated in both the Younger ($r = .16$, $p < .001$) and Older groups ($r = .12$, $p < .001$), although this was not significant when participant groups were pooled ($r = .157$, $p = .09$).

Ambiguity Condition

Materials for the main experiment were adapted from Traxler (2009), and included 120 fillers and 120 experimental items. A full overview of items can be found in Appendix D. Experimental sentences all included a disambiguated relative clause with two possible antecedents, while filler items were constructed to match experimental items for length, and included complex grammar with some unambiguous and unbiased relative clauses. Experimental items were subdivided into two bias conditions, NP1 (as in (1) below) and NP2 (2), which semantically biased participants to preferring one NP as the antecedent. Experimental items were constructed such that the relative clause always began at the sixth word in the sentence, allowing for the direct comparison of reading times by condition. The mean length of experimental items and fillers was 12.9 words, and NP1-biased and NP2-biased sentences were of equal length ($t(118) = .00$, $p > .05$; $M_{\mathrm{NP1}} = 12.3$, $M_{\mathrm{NP2}} = 13.2$).

(1) The owner of the house that had the moustache appealed for help.

(2) The owner of the house that needed renovation appealed for help.

Similarity-Based Interference

Memory interference was created by presenting three nouns to participants before they read each trial sentence. Participants were prompted to remember these words while reading, and faced recall prompts after reading the sentence in 50% of trials. Interference nouns were either semantically related or unrelated to actor(s) in the experimental sentences, since the actor NP must be retained in WM while processing is on-going. For instance, in the examples above, interfering load items could include 'mortgage', 'property', and 'residence', while non-interfering items could be 'experiment', 'takeaway', and 'grill'. In filler sentences, interfering load NPs related to randomly-selected elements in the sentence. Non-interfering load NPs were generated from an online word database, and carefully controlled such that any accidental semantic resemblance to sentence elements was eliminated. Interfering and Non-interfering sentences were of equal length ($t(237.6)$ = -1.87, $p > .05$; $M_{\text{Interf.}} = 12.7$, $M_{\text{Non-interf.}} = 12.8$).

Previous studies (e.g Van Dyke and McElree, 2006) have shown interference is unaffected by differences in number or definiteness between load words, and this was as such left uncontrolled. Conversely, Gordon et al. (2006) found varying interference effects depdending on whether load words consisted of common or proper nouns. No proper nouns were therefore included in the current experiment. Load sets appear alongside corresponding sentences at in Appendix D.

3.3.3 Procedure

Participants completed the RST and LCT before moving on to the main experiment. Each trial began with a 2000ms fixation cross, followed by the interference word set for 4000ms. The duration of the load set was increased from the customary presentation of 3 seconds (e.g. Van Dyke and McElree, 2006) to allow for older participants, who may have required more time to fully memorise items (Jaroslawska and Rhodes, 2019; Salthouse and Babcock, 1991). Participants were promped to "Remember these words", with the three load words presented in capital letters underneath the instructions. All text was presented in the centre of the screen in white Arial font on a grey background, using PsychoPy 2020.1.3 and Pavlovia (Peirce and MacAskill, 2018; PsychoPy/Pavlovia, 2021).

Sentences were presented on a word-by-word basis, and participants pressed the space bar to advance to the next word. Reading times were recorded on all words. Attention was measured by evaluating accuracy scores on comprehension questions and recall prompts. Accuracy was high across groups on questions (M = 89.5%) and prompts (M = 85.7%), and groups did not differ on comprehension accuracy ($t(60.7)$ = -1.46, $p > .05$; M_{Y} = 84.5, M_{O} = 87.5) or recall ($t(51.3)$ = 1.04, $p > .05$; M_{Y} = 87.1, M_{O} = 84.0). Figure 10 displays the full sequence of a single trial item.

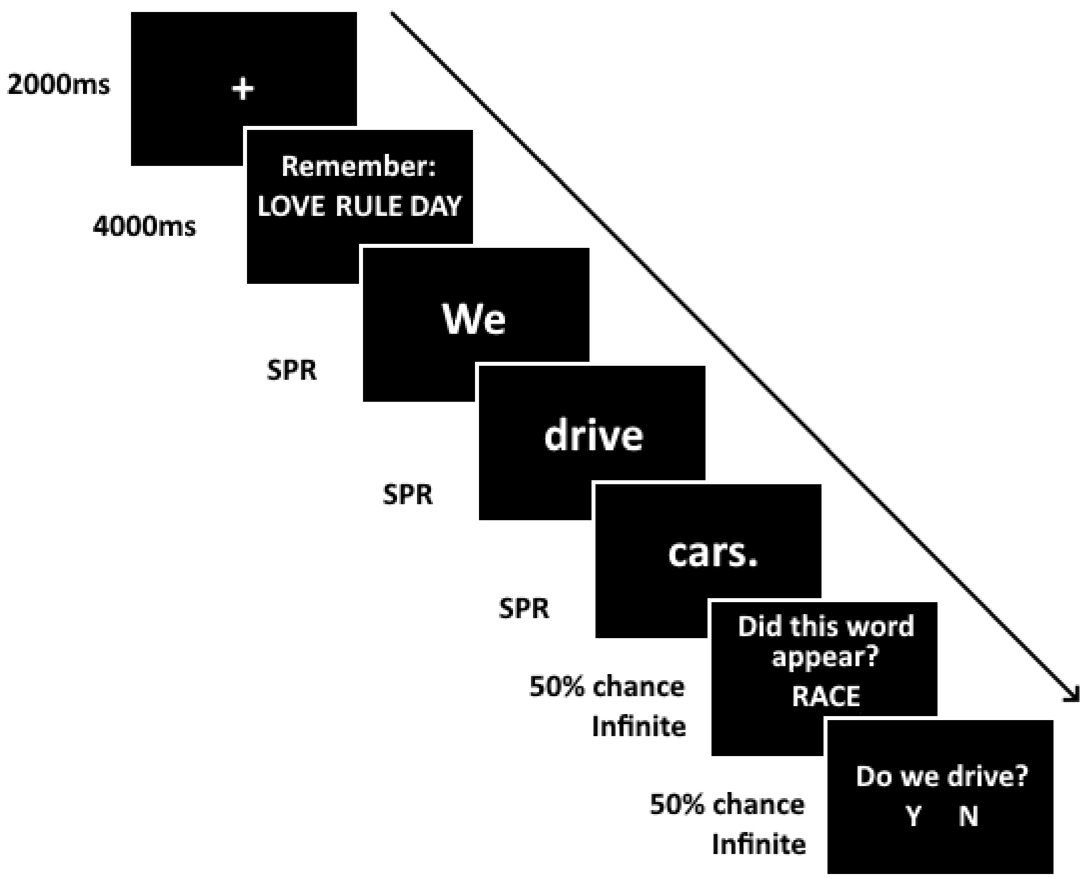


Figure 10 – Example Trial sequence of a main experimental trial. Load word presentation time was extended to 4000ms to allow for older readers' potentially slower storage. Recall prompts and comprehension questions were not mutually exclusive.

3.3.4 Analysis

Analyses centered around two defined Regions of Interest (ROIs): (1) a relative clause NP region of four words; and (2) a Spillover region of two words. For instance, in the sentence *'The owner of the house that had the moustache appealed for help'* the NP ROI consists of *'that had the moustache'* while the Spillover ROI comprises *'appealed for'*. Analysis was conducted in R (R Core Team, 2020) using *lme4* for linear mixed modelling (Bates et al., 2015), *EMAtools* for the generation of effect sizes (Kleiman, 2017), *sjPlot* for plotting models (Lüdecke et al., 2021), and *emmeans* for post-hoc analysis (Lenth et al., 2021). Reading times were residualised by character count in each word to control for different word lengths in the defined regions of interest: for instance, if a participant's reading time to the word *'ambiguity'* (9 characters) was 200ms, this was residualised as 200 / 9 $\approx$ 22.2. Residualised Reading Times (RRTs) were then log-transformed and outliers over 2.5 SDs above or below each participant's mean were trimmed. Pre-tests scores (RST and LCT) were centered before being added to any model.

Linear mixed models for RRT data included fixed effects for Ambiguity and Interference condition (and interactions of Ambiguity and Interference conditions, or either condition with pre-tests), Age Group, centered RST Score, and centered LCT Score, as well as random effects for Participant and Trial. None of the LMMs reported in this article included effects of education, as neither of the two collected measures of education improved model fit anywhere. Apart from an analysis of RRTs, a further exploration of accuracy on the recall prompts included in the experimental sequence was conducted. These models included the same fixed and random effects as RRT models.

Further Bayesian analyses were conducted to confirm the presence or absence of group-related effects. Bayesian regression models were fitted using the *brms* package (Bürkner, 2017) and inverse Bayes Factors generated with *bridgesampling* (Gronau et al., 2017). Bayesian models were run with expotential Gaussian distributions as weakly informative priors (as is typical of reaction times, see Matzke and Wagenmakers, 2009), included 3000 iterations per model, and contrasted models including an Age Group by Condition interaction term with models including only main effects of these terms (Wagenmakers, 2007). Full scripts used for analysis can be found in Appendix I.

3.4 Results

3.4.1 Ambiguity Condition

Reading times in the NP ROI were affected by Age Group, such that older readers read all trials more slowly than participants in the Younger group ($t(56.99)$ = -3.340, p = .001, d = -0.885). However, both NP1-biased and NP2-biased sentences were read at equal speed ($t(6030)$ = -1.246, $p > .05$, d = -.032), and older and younger readers did not read either ambiguity faster than the other group ($t(6029)$ = -.165, $p > .05$, d -.004). Reading times did not vary by RST or LCT score, and these pre-tests did not interact with ambiguity condition (all ps > .05).

However, in the Spillover ROI NP1-biased items were read faster than NP2-biased items ($t(6057)$ = 2.396, p = .01, d = .062). While older participants were slower readers than the younger group across conditions in Spillover regions ($t(57.83)$ = -3.616, p = .001, d = -.951), there were no indications that ambiguity preference varied by age group ($t(6053)$ = -.457, $p > .05$). As in the NP ROI, no pre-tests predicted reading times in the Spillover ROI and ambiguity preferences did not vary by pre-test scores (all ps > .05). For full details of Ambiguity Condition models, please refer to Table 7.

Bayesian Ambiguity Models

The linear mixed modelling analysis was supplemented with Bayesian modelling. Two Bayesian mixed models were compared: a null model including simple effects for Ambiguity Condition, Age Group, and interactions of pre-test scores with Ambiguity Condition; and a model including an interaction of Ambiguity Condition with Age Group. Both models also included random effects for Subject and Trial. Model comparison resulted in an inverted Bayes Factor of .0961 for the NP ROI, providing strong evidence for the null hypothesis (Lee and Wagenmakers, 2014). $BF_{Spillover}$ equalled .0423, again providing strong evidence for the absence of an Age Group by Ambiguity Condition interaction.

3.4.2 Interference Condition

In the NP ROI, Interfering trials were read slower than Non-Interfering trials ($t(6031) = 3.799$, $p < .001$, $d = .098$). Once again, older readers were slower across conditions ($t(57.07) = -3.384$, $d = -.896$), but groups were equally affected by Interference manipulations ($t(6029) = -.570$, $p > .05$, $d = .008$). No pre-test scores predicted reading times in the NP ROI, and neither RST score nor LCT score interacted with Interference Condition (ps > .05).

In the Spillover ROI, Interference effects were not significant ($t(6058) = -1.499$, $p > .05$, $d = -.039$), and while the Younger group read faster than the Older group overall ($t(57.99) = -3.747$, $p > .001$, $d = -.984$), there was no evidence to suggest Interference effects varied by group ($t(6055) = .564$, $p > .05$, $d = .015$). As before, no pre-tests had significant effects on reading times and neither score affected Interference manipulations (ps > .05). Table 8 details the linear mixed model output for Interference models.

To examine whether Ambiguity and Interference condition interacted, models were fitted including an interaction between these two parameters. In the NP ROI, this interaction showed reversed ambiguity preferences depending on Interference condition $t(6029) = -9.229$, $p < .001$, $d = -.238$): under non-interfering memory loads, NP1 was preferred, while NP2-biased trials were read faster under Interfering loads. A three-way interaction between Ambiguity, Interference, and Age Group was not significant ($t(6023) = -.150$, $p > .05$, $d = -.004$), indicating that this effect did not vary by Age Group. The interaction between Ambiguity and Interference Condition was not replicated in the Spillover ROI ($t(6055) = -1.508$, $p > .05$, $d = -.012$). Interaction models are further detailed in Table 9.

Bayesian Interference Models

As with Ambiguity models, the null effect of Age Group was re-examined with Bayesian models. Comparison of models including an Interference * Age Group interaction and a null

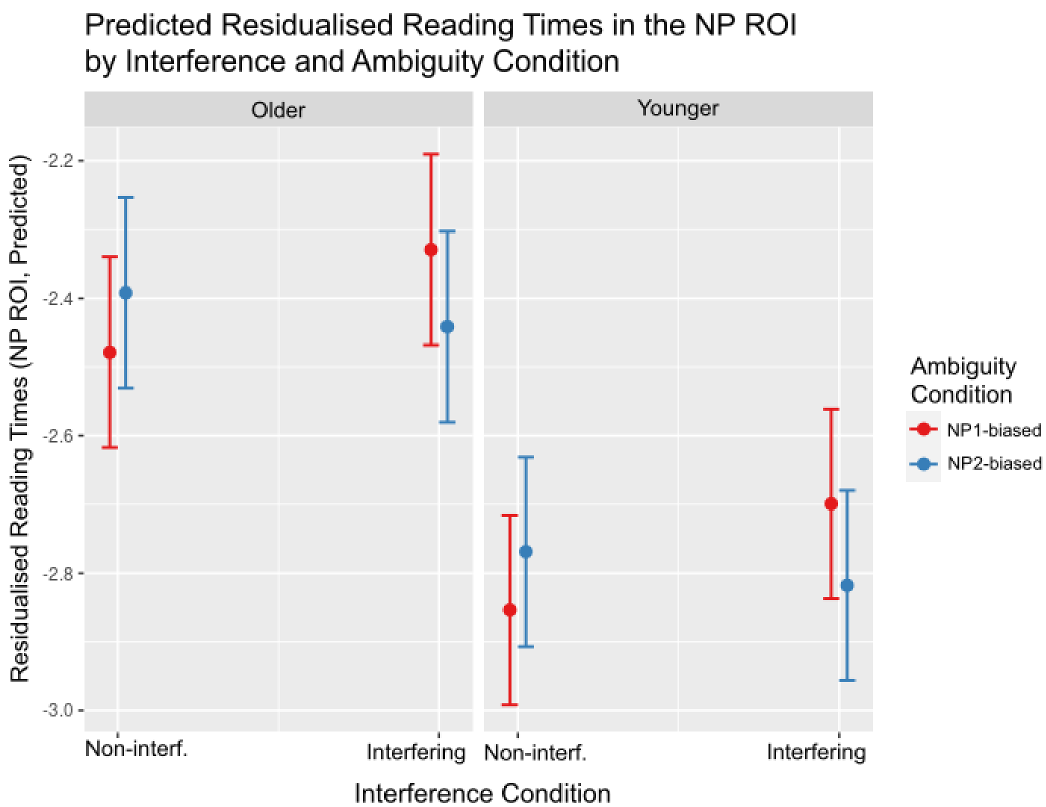


Figure 11 – Model plot of residualised reading times in the NP ROI by Ambiguity and Interference Condition, displaying the reversal of Ambiguity preferences depending on interfering or non-interfering memory load.

model including only main effects of these terms resulted in $BF_{NP} = .0871$ and $BF_{Spillover} = .1791$, providing strong and moderate evidence for the null hypothesis, respectively.

3.4.3 Recall Prompts

Accuracy

Accuracy and response times on memory recall prompts, which were presented on 50% of trials and queried recall of one of three memory load nouns, was examined further. While recall accuracy was not affected by Ambiguity Condition as a main effect ($t(103) = 1.172$, $p > .05$, $d = .006$), there was a marginally significant interaction of RST score by Ambiguity Condition, such that high-span readers showed higher accuracy on dispreferred NP2 structures ($t(7146) = 1.917$, $p = .05$, $d = .045$). This interaction is further visualised in Figure

Table 7 – Summary of Ambiguity Condition model in both ROIs. *Note*: these models further included significant random effects for Trial and Subject. Reference level for Ambiguity Condition was NP1-biased.

ROI	*Predictor*	*Estimate*	*SE*	*T-value*	*p*	*d*
NP	Intercept	-2.400	.0070			
	Age Group	-.3740	.1120	-3.340	**0.002**	-.8849
	LCT	-.0095	.057	-.167	0.8678	-.0443
	RST	.0017	.0428	.040	.9685	.0105
	Ambiguity Condition	-.0162	.0130	-1.246	.2126	-.0321
	Ambiguity * Age Group	-.0035	.0211	-.165	.8686	-.0043
	Ambiguity * LCT	.0016	.0108	.146	.8842	.0038
	Ambiguity * RST	-.0041	.0080	-.513	.6077	-.0132
Spillover	Intercept	-2.421	.0699			
	Age Group	-.4032	.1115	-3.616	**.0006**	-.9509
	LCT	-.0127	.0568	-.224	.8238	-.0588
	RST	.0136	.4258	.319	.7512	.0839
	Ambiguity Condition	.0420	.0175	2.396	**.0166**	.0616
	Ambiguity * Age Group	-.0129	.0283	-.457	.6477	-.0117
	Ambiguity * LCT	.0138	.0145	.950	.3419	.0244
	Ambiguity * RST	-.0061	.0108	-.560	.5756	-.0144

Table 8 – Summary of Interference Condition model in both ROIs. *Note*: these models further included significant random effects for Trial and Subject. Reference level for Interference Condition was Non-Interfering.

ROI	*Predictor*	*Estimate*	*SE*	*T-value*	*p*	*d*
NP	Intercept	-2.434	.0704			
	Age Group	-.3790	.1120	-3.384	**.0013**	-.8958
	LCT	-.0055	.0571	-.097	.9235	-.0255
	RST	-.0072	.0429	-.170	.8658	-.0449
	Interference Condition	.0493	.0130	3.799	**.0001**	.0978
	Interference * Age Group	.0065	.0209	.309	.7570	.0080
	Interference * LCT	-.0061	.0107	-.570	.5685	-.0147
	Interference * RST	.0135	.0080	1.684	.0923	.0434
Spillover	Intercept	-2.387	.0700			
	Age Group	-.4184	.0117	-3.747	**.0004**	-.9841
	LCT	.0050	.0569	.088	.9305	.0230
	RST	.0070	.0426	.180	.8574	.0474
	Interference Condition	-.0263	.0175	-1.499	.1339	-.0385
	Interference * Age Group	.0160	.0283	.564	.5725	.0145
	Interference * LCT	-.0211	.0144	-1.461	.1442	-.0376
	Interference * RST	.0062	.0108	.575	.5651	.0148

Table 9 – Summary of Condition Interaction model in both ROIs. *Note*: these models further included significant random effects for Trial and Subject. Reference levels were NP1-biased for Ambiguity Condition and Non-Interfering for Interference Condition.

ROI	*Predictor*	*Estimate*	*SE*	*T-value*	*p*	*d*
NP	Intercept	-2.478	.0707			
	Age Group	-.3753	.1122	-3.344	**.0015**	-.8810
	LCT	-.0091	.0568	-.160	.8735	-.0427
	RST	-.0008	.0043	-.0197	.9846	-.0052
	Interference Condition	.1493	.0152	9.849	**<.001**	.2536
	Ambiguity Condition	.0865	.0155	5.595	**<.001**	.1441
	Interference * Ambiguity	-.1988	.0215	-9.229	**<.001**	-.2377
	Interference * Age Group	.0052	.0214	.246	.8055	.0062
	Ambiguity * Age Group	-.0017	.0218	-.000	.9366	-.0020
	Interference * Ambiguity * Age Group	-.0046	.0030	-.150	.8811	-.0039
Spillover	Intercept	-2.414	.0707			
	Age Group	-.3889	.1121	-3.469	**.0010**	-.9020
	LCT	-.0056	.0563	-.099	.9214	-.2649
	RST	.0106	.0423	.252	.8023	.0672
	Interference Condition	-.0058	.0209	-0.279	.7806	-.0072
	Ambiguity Condition	.0404	.0213	1.897	.0579	.0489
	Interference * Ambiguity	-.0133	.0296	-.452	.6516	-.0116
	Interference * Age Group	-.0443	.0294	-1.508	.1317	-.0388
	Ambiguity * Age Group	-.3130	.0299	-1.046	.2958	-.0269
	Interference * Ambiguity * Age Group	.0681	.0417	1.635	.1021	.0420

11. Main effects of age and pre-test scores were non-significant (all ps > .05).

Similarly, correctness scores on recall prompts were unaffected by Interference Condition ($t(7136) = .008$, $p > .05$, $d \approx .000$); in Interference models, RST score was a significant predictor, such that high-span participants showed greater accuracy on recall prompts ($t(10.30) = 2.702$, $p = .008$, $d = .523$). LCT score was not a significant predictor and accuracy scores did not differ significantly by age (all ps > .05). Recall accuracy models are fully detailed in Table 10.

Response Times

On Recall prompt RTs, a marginal interaction of Ambiguity Condition by Age Group emerged, such that greater Age Group differences were discovered on dispreferred NP2 struc-

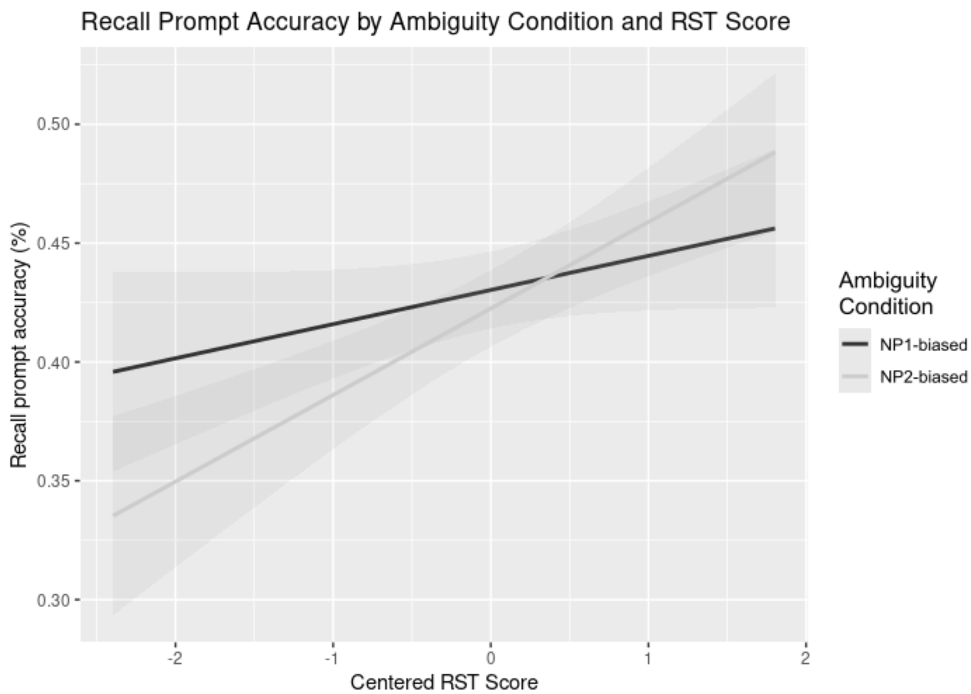


Figure 12 – Plot showing the significant impact of RST score on recall prompt accuracy, the explicit measure recorded in this study. Higher-span readers were additionally facilitated on NP2-biased trials, which were dispreferred in both age groups.

Table 10 – Summary of Recall Prompt Accuracy models. Models further included random effects for Trial and Subject.

Condition	*Predictor*	*Estimate*	*SE*	*T-value*	*p*	*d*
Ambiguity	Intercept	.4124	.0190			
	Age Group	.0358	.0306	1.172	.2438	.2310
	LCT	-.0180	.0156	-1.159	.2490	-.2285
	RST	.1581	.1167	1.354	.1786	.2669
	Ambiguity Condition	.0053	.0195	.270	.7868	.0064
	Ambiguity * Age Group	-.0261	.0313	-.832	.4056	-.0197
	Ambiguity * LCT	.0059	.1596	.371	.7107	.0088
	Ambiguity * RST	.0230	.0120	1.917	.0533	.0454
Interference	Intercept	.4149	.0190			
	Age Group	.1806	.3056	.591	.5558	.1165
	LCT	-.0192	.0156	-1.233	.2203	-.2401
	RST	.0315	.0117	2.702	**.0081**	.5326
	Interference Condition	.0002	.019	.008	.9933	.0002
	Interference * Age Group	.0094	.0313	.302	.7630	.0071
	Interference * LCT	.0082	.0160	.516	.6060	.0122
	Interference * RST	-.0085	.0120	-.713	.4760	-.0169

tures ($t(3491) = -1.858$, $p = .06$, $d = -.063$). High LCT scores also positively affected RT duration ($t(62.24) = 3.341$, $p > .001$, $d = -.936$), and Older readers responded more slowly than the Younger group overall ($t(61.91) = -2.163$, $p = .03$, $d = -.550$). Response times on NP2 sentences were longer than on NP1-biased items ($t(3485) = 3.341$, $p = .001$, $d = .113$).

Interference condition also marginally affected Recall prompt RTs, such that Interfering trials elicited longer RTs than Non-Interfering items ($t(3491) = -1.908$, $p = .06$, $d = -.065$). While older readers responded more slowly across the board ($t(62.50) = -2.634$, $p = .01$, $d = -.666$), the two age groups did not show RT differences by Interference Condition ($t(3491) = .274$, $p > .05$, $d = .009$). There was a trend for high-span participants to respond faster to Interfering prompts than low-span participants ($t(3485) = 1.942$, $p = .05$, $d = .066$), and high LCT scores again facilitated fast responses ($t(62.64) = -3.246$, $d = -.820$). Full details for Recall response time models are given in Table 11.

Table 11 – Summary of recall prompt RT models, which further included random effects for Trial and Subject.

Condition	*Predictor*	*Estimate*	*SE*	*T-value*	*p*	*d*
Ambiguity	Intercept	2.712	.1704			
	Age Group	-.5865	.2711	-2.163	**.0344**	-.5498
	LCT	-.5106	.1383	-3.693	**.0005**	-.9361
	RST	-.0514	.1037	-.496	.6218	-.1257
	Ambiguity Condition	.2595	.0777	3.341	**.0008**	.1132
	Ambiguity * Age Group	-.2314	.1245	-1.858	.0633	-.0629
	Ambiguity * LCT	.0862	.0364	1.355	.1756	.0458
	Ambiguity * RST	.0096	.4791	.200	.8416	-.0067
Interference	Intercept	2.9133	.1710			
	Age Group	-.7171	.2722	-2.634	**.0106**	-.6664
	LCT	-.4503	.1387	-3.246	**.0019**	-.8202
	RST	-.0934	.1040	-.899	.3723	-.2274
	Interference Condition	-.1485	.0778	-1.908	.0565	-.0646
	Interference * Age Group	.0342	.1246	.274	.7838	.0093
	Interference * LCT	-.0367	.0635	-.578	.5635	-.0196
	Interference * RST	.0927	.0477	1.942	.0522	.0658

3.5 Discussion

The present study combined measurements of relative clause attachment preferences with similarity-based memory interference conditions in older and younger adults. A self-paced reading experiment with groups of younger (18-25) and older (65+) adults was conducted, involving NP1 and NP2-biased relative clause sentences and interfering or non-interfering three-word memory load conditions. Participants were also tested for Working Memory on the Reading Span Task and for Processing Speed using the Letter Comparison Test. This study was the first to combine memory load interference conditions with disambiguation metrics in groups of older and younger adults.

Disambiguation Bias and Memory Interference

This study shows robust evidence for an NP1 bias in both older and younger readers, contradicting the *Recency* strategy (Li and Sheng, 2017; Sturt et al., 2002). This preference manifested as facilitated reading times on NP1-biased compared to NP2-biased sentences (the main measurement in the current study), and additionally as higher correctness scores on memory word recall prompts on NP1 compared to NP2 items. Recency preferences have been widely reported in both older (e.g. Cuetos and Mitchell, 1988) and more recent (e.g. Akal, 2021) investigations, yet this study did not find a preference for NP2. This is not the only reading study to report an NP1-preference, however: both Swets et al. (2007) and Traxler (2009) reported participants generally preferred attachment to NP1. Although these studies intentionally segmented sentences to elicit NP1-biases, which this study did not, participants in this study were allowed to set their own reading speed, which would have allowed for segmentation at any point. Nevertheless, an expansion of the current study that would directly test the results of Swets et al. and Traxler could include sentence segmentation in experiments with older adults.

Evidence was also found suggesting that similarity-based interference conditions differentially affected ambiguity conditions. Specifically, it was discovered that under non-interfering loads, participants preferred NP1 attachment, while interfering loads resulted in a preference for NP2. NP1-biased sentences were therefore subject to greater memory interference, and reading times on NP2-biased items were similar in either interference condition. The lack of recent implicit behavioural results in similar experiments make an informed interpretation of these results difficult. Indeed, the studies by Gordon et al. (2002) and Van Dyke and McElree (2006) are among the very few investigations that used a sentence comprehension task while manipulating three memory load nouns, and which measured interactions of comprehension difficulty and interference. The current findings align with those of Gordon et al., who found stronger memory interference effects on complex (object cleft) versus less complex (subject cleft) items. While Van Dyke and McElree did not manipulate sentence complexity or parsing preferences, their results did suggest that interactions between memory interference load and syntactic complexity may exist. The current study confirms these findings.

Regardless of the direction of the observed effects, the interaction of interference and ambiguity condition in this study supports unified sentence processing models which take and integrate information from many different sources (e.g. McRae and Matsuki, 2013; Van Gompel, 2013). This Study specifically emphasises Futrell et al.'s (2020) *Lossy-Context Surprisal* model, designed to integrate expectation- and memory-based sentence processing models, as a potentially useful resource for explaining the current findings. *Lossy-Context Surprisal* explains processing difficulty through surprisal effects *based on* current memory representations. Futrell et al. suggest that while memory representations are continually affected by predictions of upcoming cues during parsing, these predictions are *also* affected by memory representations. Applying *Lossy-Context Surprisal* to the current study, therefore, the concurrent memory load participants retained would have led to extra processing cost while reading, and dispreferred structures (in the current case, NP2-biased items), would have resulted in even greater cost.

Specifically, Futrell et al. suggest the interaction of memory and prediction leads to significant amounts of 'noise' surrounding memory representations. This noise may consist of contextual memory cues which have been recalled through prediction updating, and which may either improve or decrease the quality of the representation. Noise may add to incomplete memory representations, or it may lead to the loss of information contained in memory representations, or both. In this experiment, while participants' representations of load words were relatively noise-free when processing of the sentence began, continual updating of processing predictions, introducing more concurrent memory representations, could have led to larger amounts of noise surrounding the representation of load words. Given that NP1, on which readers experienced more interference, is stored in WM earlier than NP2, NP1 cues could therefore have been subject to more memory updating and therefore more noise. This, in turn, would have led to longer response times.

Notably, the interaction between interference and ambiguity condition occured in both age groups; none of the model interaction terms including Age Group reached significance, and Bayesian modelling further confirmed the absence of Age Group interaction effects. Older and Younger adults were therefore not only equally susceptible to interference in general, but the effects of memory interference on disambiguation patterns were also found to be age-invariant. The *quality* of WM operations, (as emphasised by Gordon et al., 2002; Pearson et al., 2014, and many others), therefore did not selectively affect older readers' linguistic parsing. It is further unlikely that hypothesised compensation strategies in older adults' language processing resulted in this lack of age differences: one of the most well-documented compensatory mechanisms, in which older adults have been found to rely more heavily on semantic compared to syntactic information (e.g. Poulisse et al., 2019), is hard to reconcile with this study's similarity-based memory interference findings.

Poulisse et al. (2019) found older adults placed greater reliance on semantic information during syntax processing, and off-line performance declined more severely in older adults when semantic context was absent than in younger adults. Further, results from semantic priming studies suggest adults' sensitivity to semantic information becomes more refined with age – indeed, Laver and Burke (1993) suggests semantic priming effects *increase* as age progresses, in line with the increased reliance on semantic information proposed by Poulisse et al.

(2019). Nevertheless, if older adults rely more on semantic information during processing, and struggle to process semantically impoverished stimuli (as Poulisse et al. claim), memory interference based on semantic information should impact older adults more severely. This was not the case in the present study. This Study therefore suggests the quality of memory operations did not decline with age in this sample.

The fairly confusing and multi-sided framework surrounding relative clause disambiguation (for instance, the findings that both NP1 and NP2 preferences can be predictable depending on semantic and participant circumstances) makes the case for larger-sample studies with accurately controlled demographics. Suggestions from some studies (e.g. Payne et al., 2014) that WM capacity modulates attachment preferences are complicated by the varying direction of the observed effects, the categorical treatment of span groups in some but not all studies (e.g. Felser et al., 2003), and the findings of other studies that do not consider WM predictive of attachment preferences (Traxler, 2009). A valuable angle for future research would be the recruitment of a large, age–continuous sample (in the style of Payne et al., 2014), using a selection of eye-tracking and neuroimaging methods, and stimuli carefully controlled for NP animacy and the amount of information presented between NPs.

Impact of Working Memory & Processing Speed

Disambiguation preferences were also found to be unaffected by scores on pre-tests, the Reading Span Task (RST) and Letter Comparison Test (LCT). This study therefore contradicts the results of Payne et al. (2014), one of the few examinations of disambiguation preferences in older adults, as this study did not find that disambiguation preferences were modulated by WM or age, as Payne et al. did. Kemtes and Kemper (1997) also found age and WM effects on sensitivity to ambiguity, although they make no claim about what preference readers exhibited. The current results could differ from the findings of Payne et al. due to the absence of by-group differences on the RST in this study: both groups showed roughly equal WM scores ($M_{\mathrm{Y}} = 23.3$, $M_{\mathrm{O}} = 21.2$). Nevertheless, greater age was associated with lower RST scores across groups and within both groups in this study, and the effects of RST score in recall prompt models suggests the RST design was effective.

It could also be the case that the measure of Processing Speed, the LCT, accounted for much of the variance Payne et al. accredit to WM span. LCT Score correlated heavily with age in this study and group differences were far more pronounced than on the RST. Furthermore, past studies have emphasised the interplay between Processing Speed and Working Memory: for instance, Salthouse (1992) found that controlling for Processing Speed took away much memory-related variance in an age-continuous sample of participants. Additionally, both Processing Speed and Working Memory are subserved by similar cognitive resources or even neural structures, both in development (Fry and Hale, 2000; Newbury et al., 2016) and decline (Kim and Park, 2018; Unibaso-Markaida et al., 2019).

This study further emphasises the dissociation between conscious and unconscious, implicit and explicit memory, especially in older adults. This distinction is well-attested in the literature (e.g. Waters and Caplan, 2001; Bopp and Verhaeghen, 2005; Hicks et al., 2018; though cf. Ward and Shanks, 2018), and this study suggests distinguishing explicit and implicit memory is key to uncovering language processing differences between age groups. This suggestion is supported by findings from recall prompts, which do require conscious memory recall. Notably, recall accuracy marginally interacted with RST score, the measure of WM, which showed that high-span participants across groups exhibited less difficulty answering prompts on NP1-biased items than their lower-span peers. However, this interaction was not found in the analysis of reading times, where RST score was a universally non-significant predictor. The absence of WM effects on implicit measures of this study contradicts previous research (e.g. Felser et al., 2003; Yoo et al., 2017) which has reported WM-related variance on measures of syntax processing. More broadly, the notion that individual differences in WM capacity affect sentence processing is a central tenet of the *shared resource* account of Just and Carpenter (1992), which directly connects reading ability to WM span and has fed psycholinguistic discussion for decades. The current study offers no evidence for this account, and rather supports processing accounts which do not consider WM to be predictive of implicit processing (e.g. MacDonald and Christiansen, 2002).

This study is not alone in suggesting minimal impact of WM on disambiguation measures, however. Evans et al. (2015) found little to no predictive power of WM in their study, and Traxler (2009) further suggested the impact of WM on eye movements during disambiguation is minimal. The conflict between the present data and Payne et al.'s (2014) is, therefore, not unique. Methodological differences may at least be partially responsible for this dissociation: similar to age-only effects, WM limitations may affect explicit tasks more than implicit measures – as the additional analysis of recall prompts showed – and this distinction often causes contradictory conclusions about older adults' memory and language functions. Indeed, this notion is supported by recent studies on syntax processing in aging by Hardy et al. (2017, 2020a), as well as results from Study 1, which have found intact implicit processing patterns in older adults unaffected by WM scores.

The possibility further exists that the older group's high levels of *language experience* caused their performance to be more like that of the younger participants. Language experience has been tied directly into processing efficiency by various past authors (e.g. Dussias et al., 2019; McCauley and Christiansen, 2015), and as stressed by Ramscar and colleagues (Ramscar and Baayen, 2014; Ramscar et al., 2014), language experience may be critical to aging and linguistic performance specifically. This point was further emphasised in disambiguation studies by Wells et al. (2009) and Payne et al. (2014), which included investigations of linguistic experience. It is possible that the current Study's participants may have had higher-than-average linguistic and reading experience – being part of a group which voluntarily registered with an online participant pool. Although no measures of linguistic experience were included in this study, high levels of experience in the sample could potentially have resulted in more efficient processing relative to samples in other studies. Including measures of language experience, such as the Author Recognition Test (Moore and Gordon, 2015; Stanovich and West, 1989) or an Author Naming Test (McCarron and Kuperman, 2021) into future projects could be worthwhile.

The patterns of Processing Speed-related variance found in this study were perhaps surprising. Following Salthouse (1996), age-related speed declines should cause more difficult retrieval of information processed early in a processing sequence. Therefore, older adults were predicted to show a more defined NP2 bias than younger readers by this account. However, both groups showed highly similar reading time patterns by Ambiguity condition, despite significant differences on the LCT. Not only does this finding contradict central tenets of the Processing Speed Theory, but also recent research on the impact of Processing Speed on use of contextual information (e.g. Grindrod and Raizen, 2019). Despite this, the current data do not discount the role of Processing Speed on reading generally. Indeed, older adults read sentences more slowly than younger adults across conditions. The present study does, however, indicate that syntactic ambiguity resolution is unaffected by Processing Speed differences.

3.6 Conclusions

The current study used a self-paced reading paradigm to investigate relative clause disambiguation and memory interference in younger and older adults. Age-invariant disambiguation patterns and semantic memory interference effects were discovered. Participants across age groups showed clear preferences towards attaching relative clauses to NP1. All participants were affected by an interaction of similarity-based interference and ambiguity preference, such that interference effects were found to be stronger in dispreferred NP2-biased sentences in both groups, suggesting that the processing constraints on the parser interact to increase processing latency.

The similar disambiguation strategies used by older and younger adults in this study cast doubt on theories of individual differences in WM affecting language processing, as well as the Processing Speed Theory of adult cognition, as reading times were unaffected by span scores and older adults' showed similar disambiguation patterns despite lower Processing Speed scores. This study further makes the case for a theoretical distinction between conscious memory recall and implicit memory processes in older adults, as RST scores affected recall prompts included in the study, but not reading times.

This study was the first to combine similarity-based interference with disambiguation in older adults, and the current results make the case for further research into this topic. Future studies should furthermore include neuroimaging and eye-tracking methodology, since previous research has shown disambiguation effects on event-related potential waveforms and eye movements (Pynte et al., 2003; Traxler, 2009). Combining ERP and eye-tracking data with implicit behavioural measures could provide greater insight into the processing cost associated with reading dispreferred structures under memory interference, and consequently, what models of sentence processing are favoured by evidence from disambiguation tasks. Taking into account other factors that may mitigate age-related changes to syntax processing, such as linguistic experience and print exposure, could further elucidate older adults' WM operations and linguistic parsing.

4 Study 3 – In the Prime of Life: ERP Evidence for Syntactic Comprehension Priming in Older Adults

Taken together, Study 1 and 2 are suggestive of an absence of age-related sentence processing deficits. Given the novelty of these findings, however, and especially since both studies are based on data collected in an online rather than lab format, Study 3 was designed to replicate and expand upon the syntactic priming paradigm used in Study 1. Additionally, this project sought to delve beyond the restrictions to which behavioural measures are prone and include an electrophysiological component. If older adults' neural patterns are similar to those found in younger adults' syntactic priming, this would add compelling evidence to the hypothesis that sentence processing remains age–invariant.

4.1 Abstract

Syntactic priming is an effective tool to examine implicit sensitivity to syntax. However, most priming studies with older adults have focused on production, and none have included an electrophysiological component. This study explored the neural correlates of syntactic priming in older adults' comprehension. A self–paced reading and event-related potential paradigm was used with groups of older and younger adults. Reduced relative Targets were Primed, Unprimed, or lexically Boosted, while reading times and EEG recordings were obtained. Older adults showed intact syntactic priming and lexical boost on reading times, while lexical facilitation was dependent on syntactic overlap in the older but not the younger group. P600 attenuations were more significant in the younger than the older group, and took a frontal distribution in both groups. The current findings support compensatory accounts of older adults' sentence processing and emphasise the potential role of recognition memory in syntacic comprehension priming.

4.2 Introduction

With great age comes great wisdom. However, most studies of sentence comprehension in healthy older adults have emphasised the declining nature of comprehension. These deficits are seen either as a consequence of impaired Working Memory capacity (hereafter WM; e.g. Norman et al., 1992; DeDe et al., 2004; Waters and Caplan, 2001), of Processing Speed limitations (e.g. Salthouse, 1996; Salthouse and Babcock, 1991), or of some age-specific decline unrelated to memory or speed demands (e.g. Poulisse et al., 2019). Following the majority of sentence comprehension literature, therefore, great age brings impairments and declines.

Nevertheless, numerous recent investigations have few or no age-related differences on various sentence comprehension measures (Hardy et al., 2017; 2020a; 2020b; Malyutina et al., 2018; see also Studies 1 and 2). This recent increase in reports of age-invariant sentence comprehension seems to be associated with a general shift from declarative measures, such as paragraph comprehension and sentence recall scores, to implicit paradigms, including priming, eye-tracking tasks, and Event-Related Potential (ERP) recordings (e.g. DeDe, 2014; though cf. Huang et al., 2012).

This dissociation is an extremely important one. Understanding the cognitive and linguistic effects of aging is now more relevant than ever: in a world where the average life expectancy has been climbing rapidly in recent decades (Keyfitz et al., 1991; Kinsella and Velkoff, 2001) and workforces gradually become older (Silverstein, 2008), answering the question of whether great age is indeed associated with great wisdom, or whether organisations and institutions should adapt the language they use to suit older adults' linguistic processing strategies and, possibly, limitations, is of paramount importance.

It is, in short, still unclear whether sentence comprehension abilities actually decline with age. The extent to which WM and Processing Speed contribute to age-related language comprehension difficulties is also not fully understood. This study aimed to investigate these issues using syntactic comprehension priming, an implicit measure that taps sensitivity to syntactic manipulations, and using an ERP paradigm. In a previous investigation (See Study 1), intact priming despite Processing Speed differences was reported. However, to what extent older adults' ERP patterns differ from those of younger adults in syntactic priming tasks has not yet been explored, and further replication of syntactic comprehension priming in older adults is needed.

4.2.1 Cognitive Aging and Sentence Comprehension

Language comprehension is intricately tied to cognitive skills, such as WM (Just and Carpenter, 1992) and Processing Speed (Salthouse, 1996), and past authors have cited these skills as reasons for apparent age-related declines in sentence comprehension. In a seminal paper, Just and Carpenter (1992) directly connected the size of a speaker's WM span to their ability to comprehend longer, more complex sentences. This *capacity-based theory* of comprehension is one of several processing models emphasizing the importance of WM to comprehension (MacDonald and Christiansen, 2002; Waters and Caplan, 1996b).

Older adults generally show declines on declarative, explicit memory measures such as span tasks (Bopp and Verhaeghen, 2005; Hoyer and Verhaeghen, 2006); older groups should therefore show reduced language comprehension performance as well. Indeed, Norman et al. (1992) showed lower scores on comprehension questions for paragraph reading in older compared to younger adults, as well as lower WM spans. An exacerbated decline of both WM capacity and reading comprehension was moreover found in "old-old" participants, those aged over 75 (Norman et al., 1992). A large-sample meta-analysis by Daneman and Merikle (1996) reinforced the view that declining WM can be directly tied to declining comprehension. Taking data from over 6,000 participants together, Daneman and Merikle (1996) suggest sentence comprehension correlates most strongly with WM tasks requiring concurrent processing of storage and information, such as the Daneman and Carpenter (1980) Reading Span Task.

Apart from WM, declining speed of processing has been cited as an important reason for older adults' lower performance on linguistic tasks. Salthouse (1996) claimed the declining speed at which older adults process information results in much of this information being lost when it needs to be retrieved. Activation of these cues, Salthouse (1996) proposes, declines faster in older compared to younger adults. Additionally, older adults spend disproportionate amounts of time on early stages of processing, such as encoding in WM, leaving too little time for later stages such as retrieval. This results in inefficient and qualitatively impaired processing. Linguistic evidence for the Salthouse (1996) account is given by Grossman et al. (2002), who studied a group of Parkinson's Disease patients and found that longer processing speeds were associated with reduced accuracy on sentence comprehension queries. Additionally, vast amounts of studies have found slower overall reading speeds in older compared to younger adults (Hartley et al., 1994; Stine-Morrow et al., 1996; Brysbaert, 2019, among many others; see also Studies 1 and 2).

Finally, a recent investigation by Poulisse et al. (2019) dismissed WM grounds as the basis for syntactic comprehension issues in older adults, claiming sentence processing declines with aging independently of individual difference measures. In their experiment, Poulisse et al. (2019) presented participants with short, two-word phrases to minimise the effect of WM demands. Nevertheless, older adults were less accurate and slower than the younger group in detecting agreement errors in these phrases. When phrases were substituted with pseudo-words, older adults' accuracy declined even further, also suggesting that an absence of semantic content in sentences has a stronger effect in older groups.

Despite this large body of research, there has been a small undercurrent of literature critiquing the dominant view that cognitive skills decline with age for decades. Schaie (1974) already lamented the dominant trend that "intelligence" declines with age (cf. Horn and Donaldson, 1976). More recently, Ramscar et al.'s (2014) opposition to what they term the "myth" of cognitive decline centers around the frequently observed patterns of reduced performance of older adults on psychometric tests, which Ramscar et al. suggest is a result of the larger semantic memory and linguistic experience associated with age, rather than cognitive deficience.

Indeed, a growing body of research suggests older adults maintain intact sentence comprehension abilities compared to younger groups, and even outperform them. For instance, Hardy et al. (2017) tested older and younger adults' ability for syntactic priming, where syntactic structures are remembered or learned during processing, resulting in an increased tendency to use the same structure in a following experimental trial. Hardy et al. found both age groups were comparably sensitive to syntactic priming, supporting the notion that older adults' sensitivity to syntax does not decline. Additionally, older groups generally score significantly higher than younger adults on measures of vocabulary size (Harada et al., 2013; Verhaeghen, 2003), which in turn may positively affect their linguistic skills (cf. Ramscar et al., 2014).

This dissociation between impaired and intact sentence processing in older adults may be the result of declarative task demands. Declarative memory, which refers to the conscious, explicit extraction of encoded material from mental storage (see Ergo et al., 2020, for a discussion), declines significantly with age (e.g. Al Abed et al., 2020; Hoyer and Verhaeghen, 2006; Reifegerste et al., 2021). Nevertheless, the majority of linguistic tasks examining sentence comprehension have relied on declarative demands. Paragraph comprehension (used by Norman et al., 1992; and comprising most studies analysed by Daneman and Merikle, 1996) relies on participants searching through memory to find encoded information. Grossman et al.'s (2002) study on Processing Speed in Parkinson's again used sentence comprehension queries. And even Poulisse et al. (2019) explicitly queried agreement error detection.

It is unsurprising these tasks resulted in declining performance with greater age. These impairments may be the result of declining declarative memory abilities rather than deficient sentence processing or sensitivity to grammatical structures. The exploratory syntactic priming studies in language production mentioned above support this notion. Furthermore, in a previous experiment, intact syntactic *comprehension* priming effects in older adults were demonstrated in spite of Processing Speed differences between groups (see Study 1). Below, a discussion of priming in aging sets out how syntactic priming can act as an implicit measure of sentence comprehension abilities and how implicit, non-declarative measures are an essential tool for investigating older adults' language.

4.2.2 Syntactic Priming in Older Adults

As mentioned above, syntactic priming studies have thus far shown age-invariant performance in older and younger adults. However, virtually all priming studies with older adults or other populations with memory difficulties have focused on language *production* (Hardy et al., 2017, 2020a,b; Heyselaar et al., 2017), while priming in *comprehension* would address older adults' language processing from a novel, different perspective. Syntactic comprehension priming occurs when the reading of a syntactic structure facilitates consequent reading of that structure (Bock, 1986; Tooley and Traxler, 2010). Unlike syntactic priming in production (where primed structures are used more frequently than unprimed structures), comprehension priming has proven to be elusive, and is frequently absent without lexical overlap between primes and targets (Tooley et al., 2019). Nevertheless, recent studies have demonstrated that syntactic priming in comprehension can be recorded through eye-tracking (e.g. Thothathiri and Snedeker, 2008), ERPs (e.g. Ledoux et al., 2007), or self-paced reading (see Study 1).

Ledoux et al. (2007) elicited syntactic comprehension priming in an ERP paradigm using temporary ambiguities in reduced relative sentences, such as "The parents worried by the teenager decided to talk to him". These structures involve a temporary ambiguity before the word "by", as the first verb may be interpreted as a matrix verb (where, in the above example, the parents caused someone to worry) or as a past participle. Disambiguation effects, observable as an increase in P600 amplitude at the disambiguating word "by", show readers are forced to re-interpret the sentence in favour of a relative clause interpretation (Mecklinger et al., 1995), and syntactic priming may cause attentuations of this disambiguation effect (Tooley et al., 2009; see also Study 1). Ledoux et al. (2007) found reduced P600 amplitudes in primed compared to unprimed reduced relatives, and suggested facilitated processing of primed structures reduces unexpected ambiguity effects. Ledoux et al. thus created an innovative paradigm to test implicit sensitivity to linguistic adaptation.

Studies of syntactic priming in older adults have nevertheless focused almost exclusively on priming in production. Hardy et al. (2017) conducted a scripted dialogue task with participants, aiming to elicit passsive–active priming. Older adults were significantly more likely to use passives when primed with a passive compared to an active sentence, and even more likely to show priming when lexical overlap existed between prime and target. This lexical effect is known as the *lexical boost*, and syntactic priming in comprehension seems more dependent on the boost than in production (Traxler, 2008). Priming in the absence of lexical overlap is also known as *abstract* syntactic priming. Hardy and colleagues replicated significant abstract priming and lexical boost effects in several further studies with older adults (Hardy et al., 2020a,b; Heyselaar et al., 2021).

Older adults' priming data have an important role in determining the causes of syntactic priming. While early priming accounts focused exclusively on activational spread as the underlying mechanism for syntactic priming (Pickering and Branigan, 1998), non-declarative causes such as implicit learning mechanisms are now more widely supported by the available evidence (Chang, 2008; Chang et al., 2012). Nevertheless, the long-lasting nature of abstract syntactic priming compared to the short-livedness of the lexical boost (Hartsuiker et al., 2008) led to dual–mechanism accounts of priming, where lexical effects rely on declarative mechanisms, and abstract priming is rooted in implicit, non-declarative abilities (e.g. Tooley and Traxler, 2010; Traxler et al., 2014). The available evidence from older adults has further suggested non-declarative, implicit skills are the more likely underlying mechanisms for syntactic priming and possibly for the lexical boost (Heyselaar et al., 2021). While older adults' explicit memory deteriorates, the intactness of abstract priming and the lexical boost despite these cognitive changes makes the case for implicit, non-declarative bases for priming and boost.

However, the virtual non-existence of age-focused syntactic priming studies *in comprehension* leaves significant questions to be answered. Study 1 reports the only comprehension priming study with older adults to date. This study found intact abstract priming and lexical boost effects in older adults' comprehension, despite clear differences on processing speed measures and indications of WM declines. This further challenged the notion that the lexical boost is rooted in explicit memory, as lexical effects were recorded even across two intervening fillers in the older group.

4.2.3 The Present Study

In this study, syntactic comprehension priming in groups of older and younger adults was investigated. Specifically, this study aimed to elicit facilitated reading of reduced relative clause sentences and attentuations of associated ERP amplitudes (after Ledoux et al., 2007). As summarised above, effects of disambiguation in reduced relatives can be modulated by syntactic priming, and so faster reading of disambiguating regions in primed compared to unprimed trials was expected, and faster reading still in boosted compared to primed trials. P600 amplitudes were hypothesised to be attenuated in Primed trials, and N400 waveforms should be modulated by the lexical boost. Following previous research with older adults, no abstract syntactic priming differences between age groups was anticipated, however the possibility of lexical boost differences remained open.

4.3 Methods

4.3.1 Participants

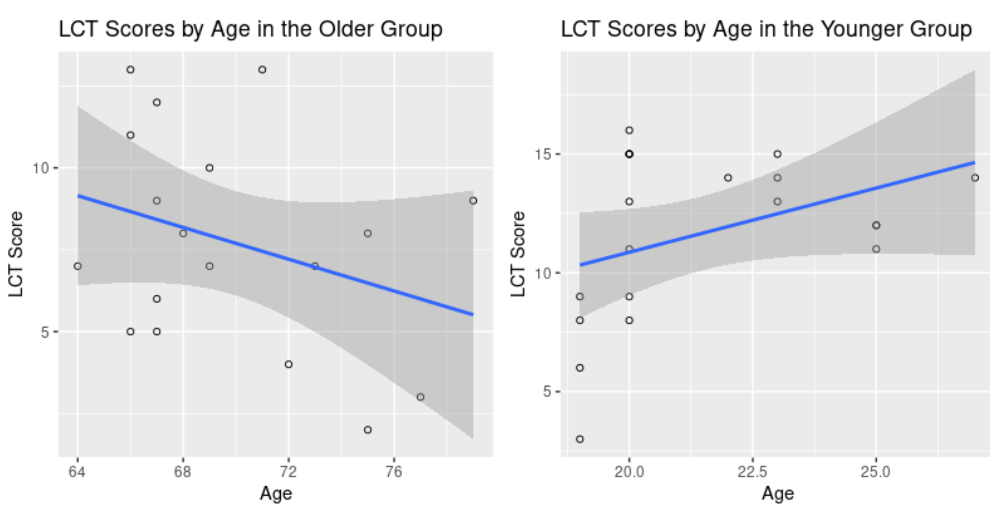
Older (n = 18; M_{Age} = 69.6; [64,79]) and Younger (n = 20; M_{Age} = 21.4; [19,27]) participants took part in a two-hour session, and were paid for their participation. Participants provided informed consent before taking part, a process fully approved by the University of Essex Social Sciences Ethics Sub–Committee. Table 12 displays a full summary of participant demographics. Biodata measures were compared between groups using independent samples t-tests and Bayesian regression models using the *brms* packages in R version 1.4.1717 (Bürkner, 2017; R Core Team, 2020). Bayes' Factors smaller than 1 indicate evidence for the

Table 12 – Overview of participant demographics. Education levels were measured along the International Standard Classification of Education (ISCED; UNESCO Institute for Statistics, 2012), ranging from 0 (less than primary education) to 8 (doctoral or equivalent). Both education levels and years in education were self-reported.

	Younger Group	*Older Group*
Age	M = 21.4; SD = 2.28; [19;27]	M = 69.6; SD = 4.01; [64,79]
Gender	18 F, 2 M	13 F, 5 M
Years in Education	M = 15.49; SD = 2.45; [8,20]	M = 15.68; SD = 4.12; [9,25]
Education Level	*Mode* = 3	*Mode* = 5
LCT Score	M = 8.37; SD = 4.30; [2,20]	M = 8.37; SD = 4.30; [3,16]
RST Score	M = 17.57; SD = 6.12; [7,28]	M = 13.5; SD = 6.02; [2.5,26.5]

null hypothesis – in this case, that no by–group differences existed in biodata measures (Lee and Wagenmakers, 2014).

Older and younger participants had spent a similar number of years in formal education ($t(26.7)$ = -.146, p = .885; BF = 2.84 (ambivalent)), and both groups showed roughly equal levels of education ($t(32.6)$ = -1.146, p = .26, BF = 2.80 (ambivalent)). Older participants scored lower on the measure of Processing Speed (the Letter Comparison Test, see section 4.3.2 below) than Younger adults ($t(35.9)$ = -3.577, p = .001; BF > 100). Older adults further



(a) Older Group **(b)** Younger Group

Figure 13 – Plots of scores on the Letter Comparison Task by numerical age, faceted by Age Group. LCT scores were negatively related to age in the Older group, where those with lower LCT scores were older than those with higher scores, but not in the Younger group, where the opposite pattern was observed.

exhibited smaller WM spans than the Younger group ($t(36)$ = -2.300, p = .03; BF > 100). However, while RST scores showed an expected distribution where age was associated with lower scores in both groups, LCT scores showed a different pattern. As visualised in Figure 13, LCT scores declined with age in the Older group, but were positively related to age in the Younger group. This skewed distribution will be discussed further during the interpretation of results in Section 4.5. Histograms of RST scores by Age Group are presented in Figure 14, and a cross-correlation table of all predictors is presented in Figure 15, showing strong expected correlations between the two measures of education, expected negative correlations between age and pre-test scores, and weak correlations between other predictors.

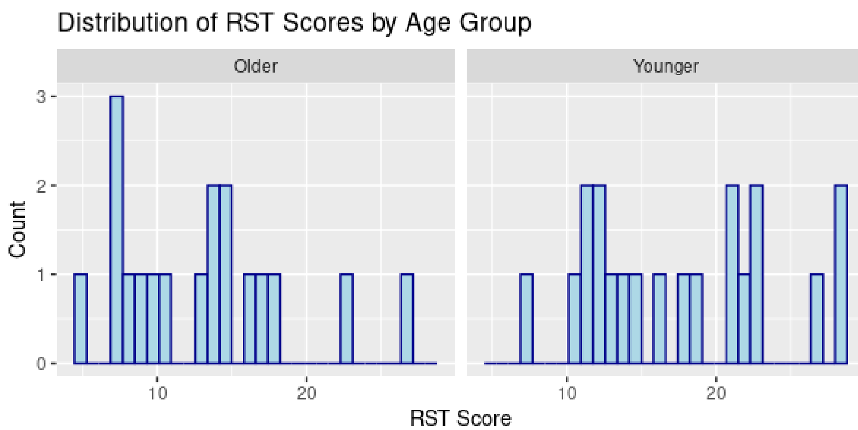


Figure 14 – Histogram of RST score by Age Group in Study 3.

4.3.2 Materials

Letter Comparison Test

The Letter Comparison Test (hereafter LCT, Salthouse, 1991a; Salthouse and Babcock, 1991) was used to assess Processing Speed. In the LCT, participants are asked to judge whether two character strings presented on screen are identical or different. The test times out after thirty seconds, and participants' score is calculated as the number of correct trials within this period. The LCT rather than the popular Digit Symbol test of the Wechsler Adult Intelligence Scale (Drozdick et al., 2018; Wechsler, 1955) was used as the LCT involves little to no memory or processing demand and can therefore be considered a more direct

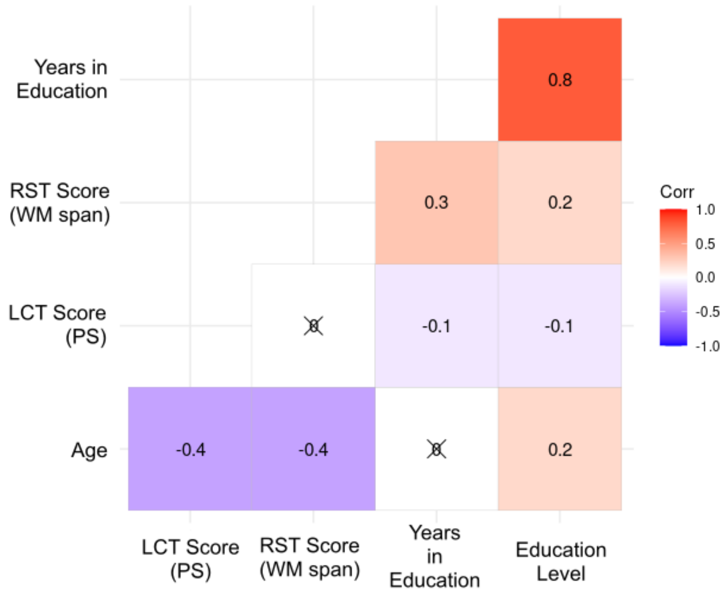


Figure 15 – Cross-Correlation Matrix of predictor variables. This matrix shows expected high correlations between Years in Education and Education level, and no strong correlations between other predictors.

measure of Processing Speed itself. The LCT for this study comprised 48 string pairs of 3, 6, or 12 letters each (equally subdivided), half of which were identical and half were different. Letter strings were checked for similarities to English words. Participants pressed the "m" key for identical trials and the "z" key for different pairs. Five practice trials preceded the experimental phase.

Reading Span Task

To measure WM, Daneman and Carpenter's (1980) Reading Span Task (hereafter RST) was conducted: participants were asked to rate sentences for appropriateness, as well as to remember the final word of each sentence. For instance, for the item "Filter coffee is the superior drink", participants should respond "appropriate" and remember "drink". Similarly, for "Dusty library books were the man's house", the correct response was "inappropriate" and "house". Sentences were presented in sets incrementally increasing in length, ranging from three to eight sentences. Sentences had an average length of 6.97 words (SD = 1.44) and comprised simple grammar without complex or compound structures. One practice set of two sentences preceded the experimental phase. Participants were asked to recall all sentence-final words in the correct order after each set was presented, and one point was assigned for each word recalled in its correct place – half points were given to words recalled in the correct set, but the incorrect order (following Conway et al., 2005). The sum of all points across sets was used as a participant's WM span.

Main Study

Items for the main experiment were sourced from Tooley et al. (2009), Manouilidou and Almeida (2009), and Traxler (2008). 90 trial sequences were constructed in total, equally subdivided into Unprimed, Primed, and Boosted conditions (30 sentences per condition). There was no syntactic and no lexical overlap between Prime and Target in the Unprimed condition; the Primed condition involved reduced relative structures as both Primes and Targets, but in the absence of lexical overlap; and in the Boosted condition, Primes and Targets shared a reduced relative structure as well as a matrix verb.

Additionally, lexis-only overlap was investigated using a Lexical Control Condition (hereafter LCC) in second filler items – a subset of 30 second fillers included either the same verb as the Prime, or a different verb matched in position to repeated verbs. The LCC manipulation left Prime-Target sequences unaffected, and allowed for the investigation of lexical effects in the same trials as syntactic priming without compromising the elicitation of the priming effect.

Filler items comprised sentences with complex syntactic structures, but excluded reduced relative clauses and lexical repetition (except in the LCC). At least two Fillers intervened between Prime and Target; lists of all critical and filler Trials appear in Appendices B and F. Trials were randomly assigned to one of five blocks of 18 trials each. One block showed 90 sentences on average, depending on the amount of intervening fillers, which was randomised to vary from 2 to 5. This meant each participant read an average of 450 sentences. Items ranged from 7 to 14 words, with an average length of 9.66 words, and there were no significant differences between the lengths of Prime and Target items ($t(169) = -.77$, $p > .05$).

4.3.3 Procedure

Participants completed the study in a dimly lit room on a 21.5-inch Iiyama ProLite B2283HS monitor, and responded using a Microsoft 600 wired keyboard. Both pre-tests as well as the main study were presented using OpenSesame 3.3 (Mathôt et al., 2012) running on Ubuntu 20.04. The LCT and RST were completed before the main study. The main experiment took most participants between 50 and 70 minutes, and the total experimental session lasted between 90 and 120 minutes. Participants were offered the opportunity for a break between all five blocks of the main experiment. Block order was fully randomised across participants, as was the order of trials within blocks.

Primes and all filler sentences except second fillers (which were used for lexical repetition control) were externally paced at a random duration between 200 and 500ms to avoid anticipatory stimulus-preceding negativity (Brunia et al., 2012). Presentation rates therefore mirrored those of Ledoux et al. (2007). Participants paced through Targets and second fillers by pressing the space bar to advance word-by-word through the sentence. While motor potentials related to button presses may show on ERP signals depending on circumstance (e.g. Falkenstein et al., 1999; Touzalin-Chretien et al., 2010), self-paced reading methods have been successfully combined with ERPs in past studies to great effect (e.g. Payne and Federmeier, 2017; Van Berkum et al., 2005). Indeed, Ditman et al. (2007) summarise that no study (up until that point) had verified what motor interference on ERPs might look like. Ditman et al. (2007) present findings replicating both well–known behavioural linguistic effects (in the form of slow–downs due to morphosyntactic violations) and well-known ERP findings (robust N400 effects in response to semantic anomalies and P600 effects upon reading morphosyntactic mismatches). The Ditman et al. study therefore demonstrated the viability of conducting studies with concurrent ERP recording and self–paced reading. In this study, self-paced items were marked by the presentation of a yellow block surrounding the fixation cross, which participants were trained to recognise in the practice phase: seven practice trials, two of which were self-paced, preceded the experimental phase.

At least two and a maximum of four fillers intervened between Prime and Target. There was a 50% chance of comprehension questions appearing after any item, including filler and Prime sentences, which queried an action statement from the sentence. For example, for the Target item "The parents worried by the teenager decided to talk to him", the related comprehension question was "Were the parents worried by the teenager?". Answers to these yes/no questions were not analysed except as a way to judge whether participants attended to the task. Half of all questions required a positive response (using the 'z' key) while the other half required a "no" response (using the 'm' key).

4.3.4 Analysis

Data analysis was conducted in R (R Core Team, 2020) using the *lme4* package for linear mixed modelling (Bates et al., 2015), *SjPlot* for mixed model plotting (Lüdecke et al., 2021), *EMAtools* for generation of effect sizes (Kleiman, 2017), *brms* for Bayesian mixed modelling (Bürkner, 2017), and *bridgesampling* for calculation of Bayes Factors (Gronau et al., 2017).

Four behavioral Regions of Interest (ROIs) were defined. In Targets, the disambiguating ROI (hereafter *By ROI*) ranged from "by" up to and including the following noun ("by the teenager" in (1) below). Further, a two-word *Spillover ROI* following the By-ROI ("decided to" in the below example (1)) was specified. For the LCC in Second Fillers, reading times on the main verb were analysed (hereafter the *Verb ROI*; "presented" in (2)), and a two-word *Spillover* ROI similar to that in Target sentences ("the quarterly" in (2)) was additionally included.

(1) (*Target*) The parents worried by the teenager decided to talk to him.

(2) (*Second Filler*) The CEO proudly presented the quarterly figures with glee.

Behavioural Linear Mixed Models (LMMs) were constructed for reading times in each ROI, including random effects for Subject and Trial, and fixed effects for Condition (Priming or Repetition)*Age Group, Condition*RST Score, and Condition*LCT Score. Condition parameters were contrast coded such that models contrasted Unprimed vs. Primed trials (to measure abstract priming) and Primed vs. Boosted trials (targeting the lexical boost). The contrast in LCC models was Unrepeated vs. Repeated verbs. Neither self-reported education measure approached significance in any model or ROI, and these are therefore not further reported. Prior to modelling, reading times were residualised by character count: Residualised reading times (RRTs) were calculated as the division of a word's reading time by the word's length in characters. RRTs were then log-transformed to improve normality prior to analysis.

Main models were supplemented with Bayesian Linear Mixed Models, which express the likelihood of null hypotheses with greater confidence than traditional statistical techniques. Bayesian reading time models were constructed using weakly informative ex-Gaussian prior distributions, which are appropriate for RT data (Matzke and Wagenmakers, 2009), while EEG models were fitted using Gaussian (normal) prior distributions. See further Wagenmakers (2007) for procedures on confirming null results with Bayesian models.

4.3.5 EEG Recording

EEG signals were obtained using a BioSemi system with 64 Ag-AgCl scalp electrodes (BioSemi Instrumentation, Amsterdam, NL), which were placed in accordance with the extended 10-20 positioning system (as visualised in Figure 16), and referenced to the average voltage of two mastoid electrodes. Ocular movements were recorded using three electrodes placed above, below, and to the side of the right eye. EEG data was transmitted to a BioSemi ActiveTwo AD amplifier box which digitised signals at 512 Hz. ERP triggers were coded in the *pyserial* toolbox (Liechti, 2016) in OpenSesame 3.0. Triggers were sent upon presentation of the word "by" as well as the subsequent verb in Primes (where applicable) and Targets, and on the verb in second fillers.

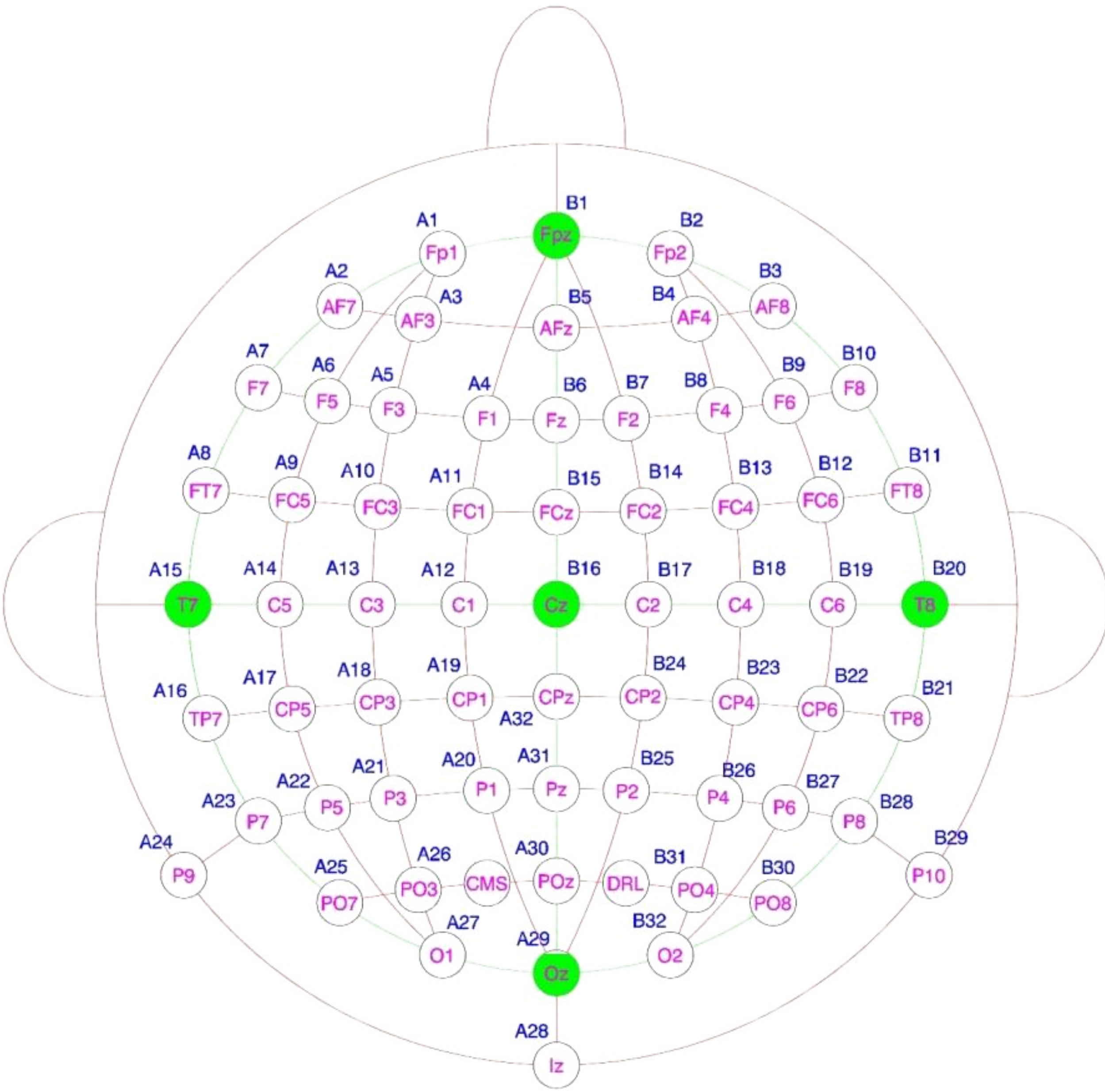
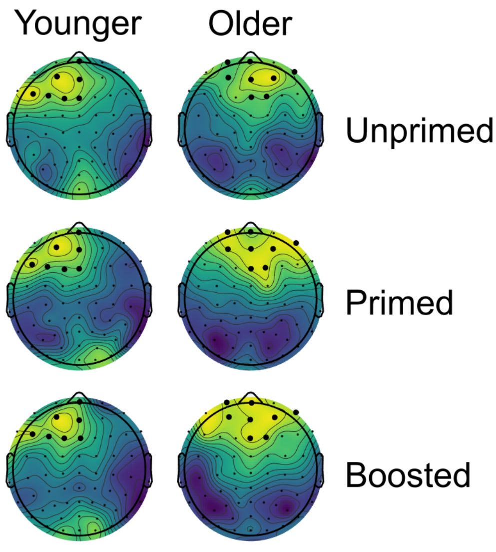


Figure 16 – Positioning system used for EEG recording (from Biosemi, Amsterdam, NL)

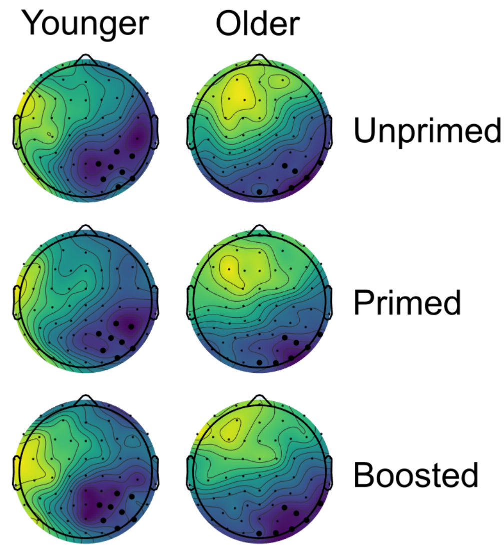
4.3.6 EEG Analysis

EEG recordings, referenced to the average of all electrodes due to issues with mastoid signals in some participants' recordings (across both age groups), were analysed using EEGlab v2021.1 (Delorme and Makeig, 2004) and ERPlab 8.30 (Lopez-Calderon and Luck, 2014), running in Matlab R2021b (MATLAB, Natick, MA: MathWorks Inc). All data were analysed at a sampling rate of 256Hz, and breaks were removed from the data before analysis. Datasets were filtered with a high-pass IIR Butterworth filter of 0.1 and a low pass of 30Hz. This high-pass frequency was selected in an effort to balance data quality on the one hand (which can suffer when applying filters of < 0.1Hz) and non–interference with component onset and attenuation on the other (which may occur when cut–off values of $> .1$Hz are used; see Maess et al., 2016; de Cheveigné and Nelken, 2019). Blink components were automatically flagged after Independent Component Analysis using the *iclabel* plugin (Pion-Tonachini et al., 2019), but manually confirmed in each dataset. Electrodes with significant channel noise were interpolated spherically. Event-related potentials were computed in epochs ranging from -200 to 1000ms around the stimulus, and two rounds of artefact rejection were conducted. The first round detected ocular artefacts in external eye channels using a 60 μV moving window peak-to-peak threshold, with a window step of 50ms, and a second round employed the same method on all scalp channels with a threshold of 120 μV. The average proportion of trials rejected in this manner, across participants and groups, was 4.8%, although there was great variability between participants' data quality. The highest proportion of rejections for any participant was 22.6% of trials.

To determine electrophysiological ROIs, a repeated measures, two-tailed cluster mass permutation test (Bullmore et al., 1999) was run with 2500 random permutations of each participant's data in the *Mass Univariate ERP Toolbox* (Groppe et al., 2011). These tests resulted in the selection of frontal ROIs for the P600 effect (see Figure 17a) and right–parietal ROIs for the N400 (see Figure 17b). While syntactic P600 effects are traditionally found in centro-parietal sites (see Gouvea et al., 2010, for a discussion), frontal P600 distributions



(a) 650ms post–"by"



(b) 450ms post–Verb

Figure 17 – Scalp distributions of Target EEG signals in both groups at critical time windows. Target disambiguation effects resulted in frontally distributed positive waveforms in both groups, though with a wider, less left–lateralised distribution in Older compared to Younger participants. For verbal effects, younger participants showed a clear right–lateralised centro–parietal N400 while older adult's negativity appeared in wider, posterior channels. A positive reversal of the N400 appeared in front–left channels in older adults. Electrodes selected for linear mixed models after

are not without precedent and could be indicative of specific memory–focused processes underlying the effect (Guillem et al., 1995; Leckey and Federmeier, 2020). Univariate tests further raised the possibility of a *verbal* P600 effect occuring on Target verbs, as well the expected N400. A P600 analysis of verbs as well as of the disambiguating "by" was therefore included in the models. The P600 on verbs is hereafter referred to as the *Verbal P600*. Thus, the analysis focused on four waveforms: (1) a syntactic P600, recorded at "by" in Targets; (2) a verbal P600, recorded at Target verbs; (3) an N400, also recorded at Target verbs; and (4) an LCC N400, recorded at second filler lexical control verbs.

Of note is the varying scalp distribution of effects in older and younger adults. The older group exhibited a "smearing out" of neural activity from clusters to broader areas, in line with established literature (e.g. Peelle, 2019). Univariate analyses further showed a more parietal–occipital distribution for the N400 at Target verbs for the older group, compared to a centro-parietal cluster in younger participants. Similar effects were found in analyses of the P600 effect, which was front-left centered in younger adults but showed a broader distribution across frontal channels in the older group. These apparent age differences are contextualised further in the discussion.

This varying topography by age group led to the inclusion of different electrode sites in the analysed ROIs for each group. These selections were motivated by Univariate analyses run by group and are displayed in Table 13. For the purposes of data analysis, the mean amplitude between the latencies described in Table 13 was computed, as well as difference waves by abstract priming, lexical boost, and LCC: abstract difference waves comprised Unprimed - Primed trials, boosted difference waves were composed of Primed - Boosted ERPs, and LCC difference waves were repeated - unrepeated trials. Given that the experimental conditions comprised three levels as well as the LCC manipulation, conditional effects were analysed with "raw" ERP data, and age effects using difference wave calculations. Electrophysiological LMMs comprised a random effect for Subject only (effects for Trial and Electrode Site resulted in issues with model convergence), as well as fixed effects for Condition*Age Group (for raw ERP models) or Age Group only (for difference wave models). While an analysis of latency may have been of interest when working with older adults' ERP data, the univariate analysis resulted in the selection of time windows which sufficiently captured effects in both age groups. Given the relatively small size of the older adult sample presented here and the exploratory nature of studying ERP effects of syntactic priming in older adults, the current study does not report any further latency analyses. However, explorations of differing component onsets in each age group during syntactic priming experiments are a promising area of inquiry for future research.

4.4 Results

The following section details results in each ROI, listing behavioural results first before moving on to ERP findings.

Table 13 – Overview of electrode sites included in analysis for each reported effect (and examples of where these effects were recorded) by age group, reflecting a wider distribution of effects in older compared to younger adults, but consistent general topography.

	Place of recording	*Older Group ROI*	*Younger Group ROI*	*Window post–onset (ms)*
P600	Targets: disambiguating "by" (*The parents worried* ***by*** *the teenager decided to talk to him.*)	FP1 FPz AF3 AFz AF4 AF8 Fz F2	FP1 AF3 AFz F5 F3 F1 Fz	600–700
Verbal P600	Targets: first verb (*The parents* ***worried*** *by the teenager decided to talk to him.*)	FP1 FP2 AF7 AF3 AFz AF4 AF8 F5 F3 F1 Fz F2 F4 F6	AF3 AFz F5 F3 F1 Fz FC5 FC3 FC1 FCz	500–650
N400	Targets: first verb (identical to Verbal P600)	TP8 P6 P8 P10 O2 PO8 Iz	CP4 CP6 P2 P4 P6 P8 PO4 PO8	450–600
LCC N400	Second Fillers: matrix verb (*The CEO proudly* ***presented*** *the quarterly figures with glee*)	TP8 P6 P8 P10 O2 PO8 Iz	CP4 CP6 P2 P4 P6 P8 PO4 PO8	450–600

4.4.1 Reading Times

By-ROI

Table 14 details model parameters in Target regions. Effects of Priming Condition were not evident in this ROI, neither for abstract priming ($t(99.2)$ = -.830, $p > .05$, d = -.167) or for the lexical boost ($t(98.3)$ = -.231, $p > .05$, d = -.047). This contradicts the hypothesis that syntactic priming effects should be observable at the disambiguating "by" in reduced relative Targets. While older adults read more slowly across conditions ($t(3012)$ = -22.93, $p < .001$, d = -.836), there were no group differences by abstract priming condition ($t(3004)$ = .981, $p > .05$, d = .036) or by lexical boost condition ($t(3004)$ = .492, $p > .05$, d = .018). Both age groups, therefore, showed no effects of syntactic priming conditions in this ROI, contrary to expectations.

Pre-tests significantly affected reading times in this ROI, such that higher RST scores were associated with faster reading across conditions ($t(2981)$ = -4.902, $p < .001$, d = -.180), while high scores on the LCT unexpectedly led to slower reading times ($t(2988)$ = 11.983, p

Table 14 – Linear Mixed Model summary of residualised reading times in Target ROIs. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p = .05 are represented in **bold**. Effect sizes are given as Cohen's d (Diener, 2010).

ROI	*Predictor*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
By	Intercept	4.7430	.0497	25.76			
	Priming	-.0223	.02678	99.19	-.830	.4084	-.167
	Boost	-.0062	.0276	98.34	-.231	.8100	-.047
	Age Group	-.2854	.0125	3012	-22.932	<**.001**	-.836
	RST	-.0365	.0074	2981	-4.902	<**.001**	-.180
	LCT	.0897	.0075	2988	11.983	<**.001**	.438
	Priming*Group	.0128	.0130	3004	.981	.3265	.036
	Boost*Group	.0063	.0128	3004	.492	.6266	.018
	Priming*RST	-.0130	.0059	3004	-2.193	**.028**	-.080
	Boost*RST	-.0052	.0058	3003	-.883	.3775	-.032
	Priming*LCT	-.0009	.0060	3003	-.015	.9883	-.000
	Boost*LCT	-.0012	.0059	3003	-.211	.8325	-.008
Spillover	Intercept	4.713	.0582	33.04			
	Priming	-.1107	.0396	93.49	-2.797	**.006**	-.579
	Boost	-.1503	.0395	93.15	-3.803	**.0003**	-.788
	Age Group	-.3254	.0138	3019	-23.621	<**.001**	-.860
	RST	-.0402	.0082	2977	-4.884	<**.001**	-.179
	LCT	.0687	.0083	2986	8.312	<**.001**	.304
	Priming*Group	.0096	.0144	3017	.666	.506	.024
	Boost*Group	-.0140	.0142	3017	-.986	.324	-.036
	Priming*RST	-.0069	.0065	3017	-1.052	.293	-.038
	Boost*RST	.0024	.0065	3017	.374	.708	.014
	Priming*LCT	-.0131	.0066	3017	-1.982	**.048**	-.072
	Boost*LCT	-.0048	.0065	3017	-.737	.461	-.027

$< .001$, $d = .438$). While LCT scores did not interact with either priming contrast (Abstract $t(3003)$ -.015, $p > .05$, d = -.000; Boost $t(3003)$ = -.211, $p > .05$, d = -.008), there was a weak yet consistent interaction between RST score and abstract priming ($t(3004)$ = -2.193, p = .028, d -.080), such that greater facilitating effects of RST score were apparent in Primed and Boosted conditions compared to the Unprimed condition.

Spillover ROI

The Target Spillover ROI was more sensitive at capturing effects of priming than the preceding region. Clear abstract priming ($t(93.5)$ = -2.797, $p < .01$, d = -.579) and lexical boost effects ($t(93.2)$ = -3.803, $p < .001$, d = -.788) were found. Figure 18 illustrates this

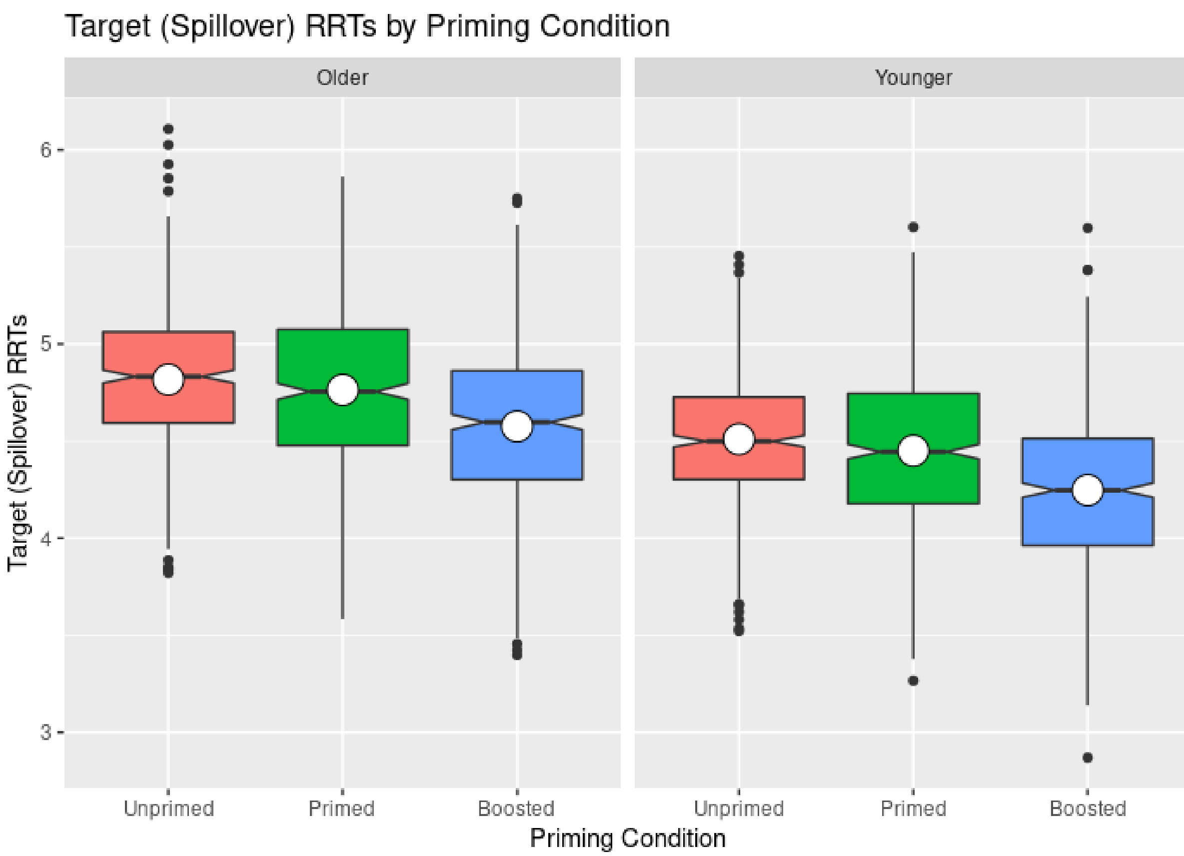


Figure 18 – Residualised reading times in the Target Spillover ROI by Priming Condition and Age Group. Differences between conditions were all significant, though lexical boost effects were larger than abstract priming patterns in both groups.

effect, which comprised a step-wise facilitation where Boosted trials were read faster than Primed trials, which in turn were read faster than Unprimed trials. These patterns were in line with expectations of syntactic priming in comprehension. Crucially, there was no interaction beteen age group and abstract priming ($t(3017)$ = .666, p > .05, d = .024) or lexical boost ($t(3017)$ = -.986, p > .05, d = -.036), indicating that both age groups experienced similar priming effects.

As in the By-ROI, reading times across conditions were slower in the Older compared to the Younger group ($t(3012)$ = -22.932, p < .001, d = -.836) and were similarly facilitated by high RST scores ($t(2981)$ = -4.902, p < .001, d = -.180). Contrary to expectations, reading times increased as LCT scores became higher ($t(2988)$ = 11.983, p < .001, d = .438), an effect visualised by group and priming condition in Figure 19. This effect may have been at

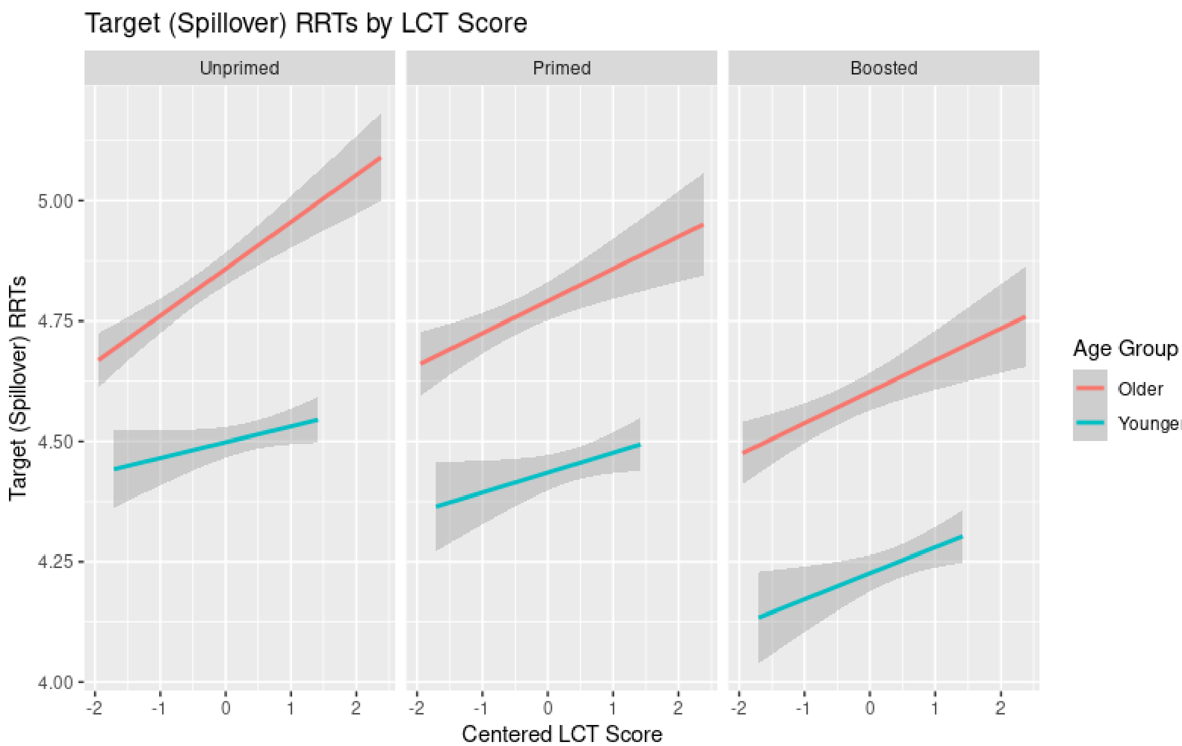


Figure 19 – Residualised reading times in the Target Spillover ROI by centered LCT Score, Priming Condition, and Age Group.

least partially due to the unexpected distribution of LCT scores discussed in Section 4.3.1. There were no interactions of pre-test by either priming condition (*p*s $>$ .05), except a small yet significant one of LCT score by abstract priming ($t(3004)$ = -2.193, $p < .05$, d = -.080), such that somewhat greater LCT-related facilitation was observed in Primed and Boosted compared to Unprimed Targets.

LCC ROIs

Table 15 – Linear Mixed Model summary of residualised reading times in LCC ROIs. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p = .05 are represented in **bold**. Effect sizes are given as Cohen's d (Diener, 2010).

ROI	*Predictor*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
Verb	Intercept	4.166	.0690	52.11			
	Repetition	-.0643	.0480	46.35	-1.339	.187	-.393
	Age Group	-.2758	.0242	1462	-11.409	**<.001**	-.597
	RST	-.0490	.0142	1375	-3.435	**.0006**	-.185
	LCT	.0706	.0143	1392	4.934	**<.001**	.265
	Repetition*Group	.0222	.0182	1489	1.223	.223	.063
	Repetition*RST	-.0093	.0083	1489	-1.116	.265	-.058
	Repetition*LCT	-.0025	.0084	1489	-.300	.764	-.016
Spillover	Intercept	4.688	.0654	55.60			
	Repetition	.0264	.0483	45.53	.546	.588	.162
	Age Group	-.0276	.0209	1479	-13.202	**<.001**	-.687
	RST	-.0343	.0123	1413	-2.777	**.006**	-.148
	LCT	.0633	.0128	1427	5.111	**<.001**	-.271
	Repetition*Group	.0371	.0157	1490	2.365	**.018**	.122
	Repetition*RST	-.0007	.0072	1490	-.094	.925	-.005
	Repetition*LCT	-.0133	.0072	1490	-1.848	.065	-.096

Similar to Target ROIs, effects of the LCC were more evident in the Spillover region. In the Verb ROI, all parameters involving repetition condition turned out non-significant (all ps > .05), suggesting the Verb ROI was not sensitive to repetition–related facilitation. Older readers were once again slower across the board in the Verb ROI ($t(1462)$ = -11.409, p < .001, d = -.597) and reading times were affected by RST and LCT similarly to Target ROIs, such that high RST scores led to faster reading times ($t(1375)$ = -3.435, p < .05, d = -.185) while high scores on the LCT were associated with slower reading ($t(1392)$ = 4.934, p < .05, d = .265). Again, this unexpected non-facilitatory effect of LCT score may be related to the abnormal distribution of LCT scores in either group. Additionally, the Verb ROI showed no condition interactions with either pre–test. All in all, therefore, the Verb ROI was not sensitive to conditional parameters and showed unexpected pre-test patterns.

However, the Spillover region proved more sensitive to capturing effects of the LCC (see

Table 15). While no main effect of repetition was evident in this ROI either ($p > .05$), interaction terms of Age Group by LCC condition revealed this lack of main effect was due to older and younger adults' differing sensitivity to repeated verbs ($t(1490) = 2.365$, $p <.05$, $d = .122$). Specifically, while younger adults were facilitated by lexical repetition, the older group showed no such facilitation, an effect visualised in Figure 20. Older adults therefore showed facilitated reading times, in line with the Younger group, when syntactic *and* lexical overlap were present (see Section 4.4.1 above), they did not show facilitation when *only* verbal overlap was manipulated. Older readers were again slower across conditions in the LCC Spillover ROI ($t(1479) = -13.302$, $p < .001$, $d = -.687$) and both pre-tests affected reading times as in previous ROIs (facilitatory effect of RST: $t(1413) = -2.777$, $p < .05$, $d = -.148$; non-facilitatory effect of LCT: $t(1427) = 5.111$, $p < .05$, $d = -.271$).

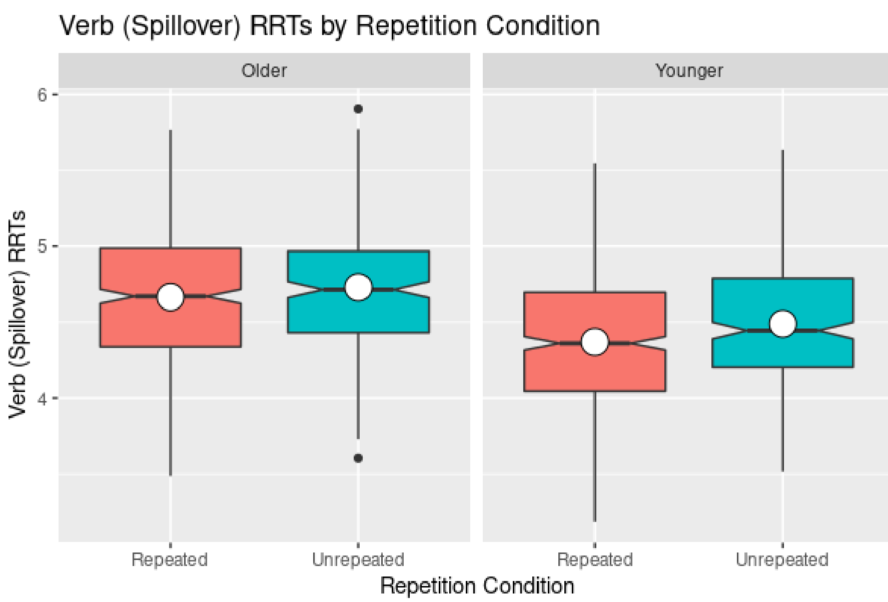


Figure 20 – Plot showing residualised reading times in the LCC Spillover ROI by Repetition Condition and age group. Larger facilitation effects of verb repetition are visible in the Younger group.

4.4.2 Bayesian Behavioural Models

To confirm the absence or presence of group effects, additional Bayesian linear mixed models were constructed for each ROI. One set of models included main parameters of age group and condition (null models) while the other set included age group by condition interactions (full models). Comparing these models yielded Bayes' Factors (BFs), which offer the likelihood of the null or full hypotheses being correct (Lee and Wagenmakers, 2014). BFs of < 1 offer evidence for the null hypothesis (with smaller values offering stronger evidence), while large BFs of at least 1 speak in favour of the full hypothesis. For the full code used for the Bayesian analysis, please refer to Appendix I.

The absence of age group effects was confirmed in the By ROI (BF = .0013) and the Target Spillover ROI (BF = .0027), with both models offering extremely strong support for the null hypothesis. However, in the LCC Verb ROI, only anecdotal evidence for an absence of group interaction was found (BF = .1440), and this was even less strong in the LCC Spillover ROI (BF = .2164). This concurs with the findings of the weak yet significant group*repetition interaction described above.

4.4.3 ERPs

Event-related potential (ERP) plots are provided in Figure 23 for the Older group and Figure 24 for the Younger group. The analysis focused on several different waveforms which are discussed in turn.

P600 — Abstract Syntactic Priming

The disambiguation–related P600 recorded at the word "by" in Target reduced relatives was expected to show priming–dependent changes. Table 16 first reports effects of priming condition on raw ERP waveforms before listing age group effects on P600 difference waves, where conditions were subtracted from one another. Abstract priming effects were evident on the P600 ($t(790) = 2.503$, $p < .05$, $d = .178$), and further differed depending on age group ($t(790) =$ -2.054, $p < .05$, $d =$ -.146; BF = 3.778). These effects are visualised in Figure 21, and suggest Younger adults were primed in line with expectations (P600 amplitudes being facilitated in Primed compared to Unprimed trials) but Older adults were not.

This by–age interaction did not appear on difference wave measures ($p > .05$), suggesting

Table 16 – Linear mixed model summary of P600 responses between 600-700ms following "by" in Targets. Raw ERP and Difference Wave models included a random effect for Participant. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of $p = .05$ are represented in **bold**. Effect sizes are given as Cohen's d (Diener, 2010).

Model	*Predictor*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
Raw ERPs	Intercept	.9918	.2912	34.68			
	Priming	.2281	.0912	789.93	2.503	**.013**	.178
	Boost	-.1087	.0912	789.93	-1.192	.233	-.085
	Age Group	.0058	.4070	34.92	.014	.989	.005
	Priming*Age Group	-.2702	.1315	789.93	-2.054	**.040**	-.146
	Boost*Age Group	.0432	.1315	789.93	.328	.743	.023
Abstract Difference Waves	Intercept	-.5648	.2381	33.02			
	Age Group	.5836	.3354	34.31	1.740	.0909	.594
Boost Difference Waves	Intercept	.4454	.3072	34.40			
	Age Group	-.3565	.4306	35.03	-.828	.413	-.280

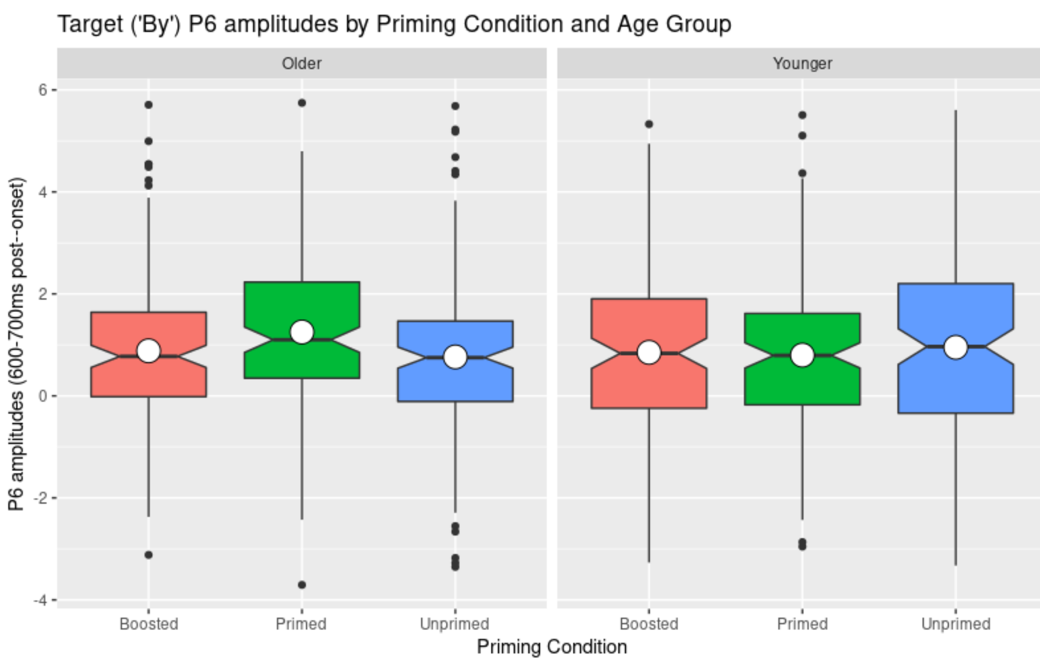


Figure 21 – Plot of average ERP amplitudes between 600 and 700ms post–onset of "by" in Targets, showing a small yet significant effect in Younger but not Older adults.

Table 17 – Model summary of N400 responses 450–600ms following Target Verbs (Boost, Boost Difference Waves) and Second Filler LCC Verbs (LCC: Raw ERPs, LCC Difference Waves). All models included a random effect for Participant. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p = .05 are represented in **bold**. Effect sizes are given as Cohen's d (Diener, 2010).

Model	*Predictor*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
LCC: Raw ERPs	Intercept	-.4492	.2779	43.07			
	Repetition	-.4248	.1687	517.07	-2.518	**.0121**	-.222
	Age Group	.1837	.3856	42.12	.476	.636	.147
	Repetition*Age Group	.2097	.2281	517.07	.919	.359	.081
LCC Difference Waves	Intercept	-.4248	.3679	35.44			
	Age Group	.2097	.5112	34.81	.410	.684	.139
Boost: Raw ERPs	Intercept	-1.584	.2528	35.39			
	Priming	.0299	.0919	793.08	.326	.745	.023
	Boost	.0646	.0919	793.08	.703	.482	.0499
	Age Group	.3483	.3521	35.11	.989	.329	.334
	Priming*Age Group	.0361	.1243	793.08	.290	.772	.021
	Boost*Age Group	.0495	.1243	793.08	.398	.691	.028
Boost Difference Waves	Intercept	-.0994	.3264	35.76	-.305	.762	
	Age Group	-.0629	.4537	35.23	-.139	.891	-.047

that any group differences were minor. Bayesian models were similarly not highly indicative of group differences on abstract priming difference waves ($BF_{\text{Abstract Difference}} = .263$). There were no effects of the lexical boost on P600 amplitudes ($p > .05$) and no by–age differences on boost patterns either in raw ERP or difference wave data (ps > .05; BF = 1.583). In short, there seem to be indications of disambiguating P600 group differences between Older and Younger adults on abstract priming manipulations, although these effects did not reach significance in difference wave models. Moreover, group effects were not significant on lexical boost models, where the greatest age-related changes were expected.

Table 18 – Model summary of Verbal P600 responses 500–650ms post–onset of Target Verbs. All models included a random effect of participant. Est denotes parameter estimate, SE equals standard error, DF denotes degrees of freedom. Values meeting the significance threshold of p = .05 are represented in **bold**. Effect sizes are given as Cohen's d (Diener, 2010).

Model	*Predictor*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
Raw ERPs	Intercept	1.6087	.2565	39.01			
	Priming	-.1646	.0656	1320.76	-2.511	**.012**	-.138
	Boost	-.1720	.0656	1320.76	-2.624	**.009**	-.144
	Age Group	-.2448	.349	36.11	-.701	.487	-.233
	Priming*Age Group	.0454	.0974	1320.76	.466	.641	.026
	Boost*Age Group	.1691	.0974	1320.76	1.737	.083	.096
Abstract Difference Waves	Intercept	.1572	.2618	33.98			
	Age Group	.0783 .3677	34.89	.213	.833	.072	
Boost Difference Waves	Intercept	.1794	.2551	33.52			
	Age Group	-.2928	.3586	34.50	-.817	.42	-.278

N400 & Verbal P600 — Lexical Boost & LCC

N400 effects on Boosted verbs were not identified in any ROI (all ps > .05), contrary to expectations. Table 17 shows results from the time window and ROI where LCC effects were most pronounced (450–600ms post-onset; specified ROI as per Table 13). However, N400 effects elicited on Second Filler verbs in the Lexical Control Condition (LCC) were apparent, such that repeated verbs evoked a more negative–going N400 than unrepeated verbs ($t(517) = -2.52$, $p < .05$, $d = -.222$), an effect which was consistent in both groups based on difference wave models (ps > .05; $BF_{LCC} = 1.486$). The direction of the N400 effect is contrary to expectations of repetition-based N400 attentuation, which would suggest a 'flattening' of the N400 when verbs are repeated. The opposite pattern was observed in the current data.

Verbal P600 effects relating to Primed and Boosted conditions on Target verbs were additionally examined following the univariate analysis (see Table 18). Verbal P600 effects were

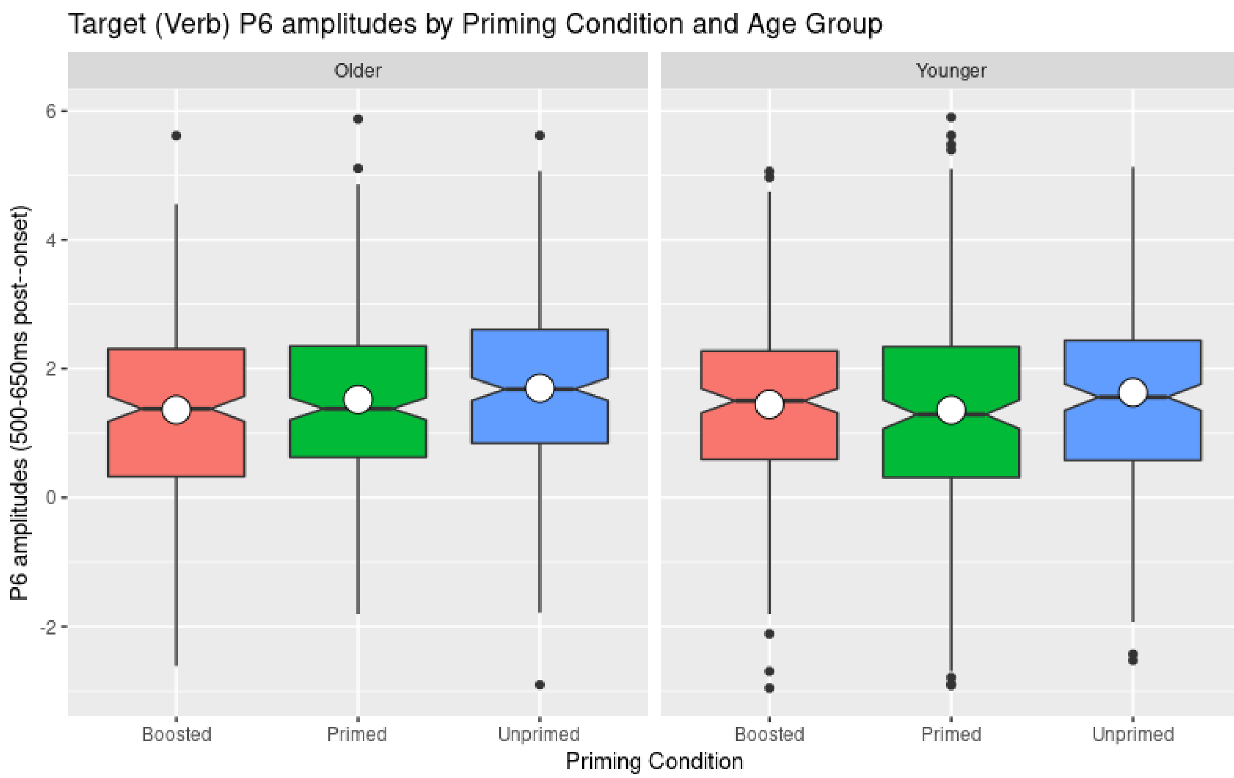
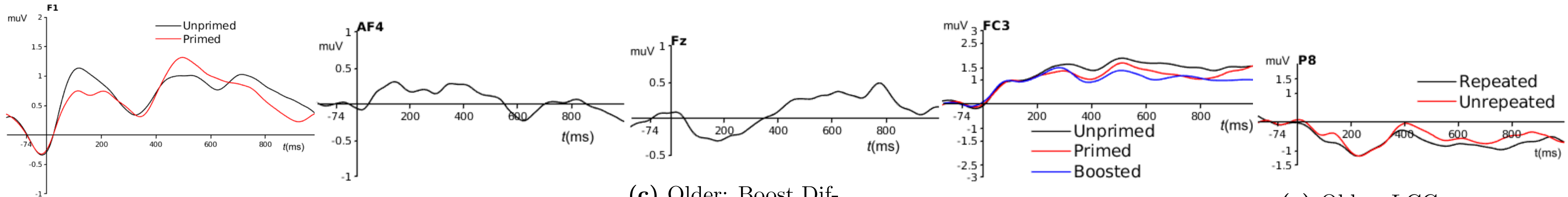


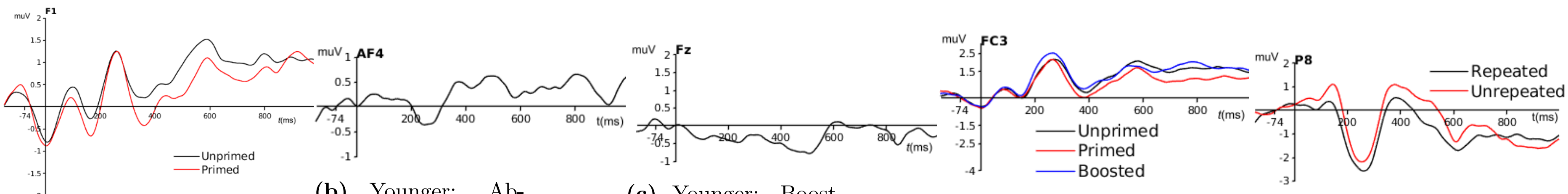
Figure 22 – Plot of average ERP amplitudes between 500 and 650ms post–onset of Verbs in Targets, showing a step–wise attenuation of the P600 in Primed and Boosted trials in both groups.

found between 500 and 650ms post–verb onset for abstract priming ($t(1321)$ = -2.511, p < .05, d = -.138) and the lexical boost ($t(1321)$ = -2.624, p < .05, d = -.144). The Verbal P600 effect captured a step–wise facilitation of P600 amplitudes from Unprimed to Primed to Boosted, further visualised in Figure 22. It therefore mirrored the behavioural facilitation as seen in Figure 18. Crucially, there were no age–related changes on difference waves for the Verbal P600, which was confirmed in traditional models (p > .05) while Bayesian evidence was ambivalent ($BF_{Abstract}$ = .982, BF_{Boost} = 1.284). Older and Younger adults therefore exhibited similar neural responses on the measure most sensitive to syntactic priming manipulations.



(a) Older: Target (By)
(b) Older: Abstract Difference
(c) Older: Boost Difference
(d) Older: Target (Verb)
(e) Older: LCC

Figure 23 – Plots of Event-Related Potential Waveforms in the Older Group. The electrode sites visualised correspond to selected ROIs for specific effects and groups.



(a) Younger: Target (By)
(b) Younger: Abstract Difference
(c) Younger: Boost Difference
(d) Younger: Target (Verb)
(e) Younger: LCC

Figure 24 – Plots of Event-Related Potential Waveforms in the Younger Group. The electrode sites visualised correspond to selected ROIs for specific effects and groups.

4.5 Discussion

The current study elicited syntactic priming in older and younger adults' behavioural and electrophysiological comprehension responses. Two age groups (Younger: M = 21.4, SD = 2.28, [18,27]; Older M = 69.6, SD = 4.01, [64,79]) read reduced relative sentences containing a temporary syntactic ambiguity which were either Primed with a preceding reduced relative, Boosted by a preceding reduced relative containing an identical verb, or Unprimed by an unrelated syntactic structure. Priming effects were recorded on reading times and Event-Related Potentials (ERPs) around the disambiguating region. Behavioural performance showed no age–related changes except on lexis–only priming, but some indications for underlying electrophysiological age differences were evident from the data.

4.5.1 Age Effects: What Changes and What Doesn't?

Both age groups experienced abstract syntactic priming (in the absence of verbal overlap) and lexical boost effects (where both syntactic and verbal overlap were included): in both groups, Boosted Targets were read faster than Primed Targets, which were in turn read faster than Unprimed Targets, and Verbal P600s showed the same step-wise attenuation. This reinforces recent evidence suggesting older adults are as susceptible to syntactic priming as younger adults in behavioural responses (Hardy et al., 2017, 2020a; see also Study 1), and contradicts past literature suggesting sentence processing declines with age (e.g. Norman et al., 1992; Poulisse et al., 2019; Zhu et al., 2018). This study suggests this dichotomy is due to previous investigations' focus on declarative, explicit measures, while syntactic priming relies on implicit, non-declarative cognitive skills (see further Heyselaar et al., 2021; as well as Study 1). This study therefore makes the case for further investigations into older adults' sentence processing using implicit tasks. Furthermore, this experiment is the first to confrim older adults' sensitivity to syntactic priming in comprehension electrophysiologically. Both age groups showed clear priming and boost effects on Verbal P600 waveforms, and no age–related differences on the strength of these P600 modulations were found. Nevertheless, indications for ERP differences between groups were apparent in the analyses of other waveforms, which are discussed below.

The inclusion of the Lexical Control Condition (LCC) in Second Fillers (where verbs from the Prime were either repeated or not) points to an intriguing difference: older adults did *not* read repeated verbs faster than unrepeated verbs in Second Fillers, but they *did* exhibit lexical boost facilitation, which also consists of verb repetition. It could therefore be the case that syntactic overlap *facilitates* lexical processing in older adults, or at the very least facilitates recognition of verbal information, even across several intervening filler sentences. Past research has emphasised the *compensatory nature* of older adults' cognition (e.g. Tomaszewski Farias et al., 2018) – that is, declining performance in one area of cognition is compensated for by conscious and unconscious strategies based on age–invariant cognitive functions. Some authors have extended this line of thought to language. For instance, Zhu et al. (2018) and Federmeier (2007) suggest older adults place greater reliance on predictive processing in the presence of lexical–semantic impairments. Following this account, the older sample could have experienced greater lexical processing facilitation in predictable contexts: given that reduced relative structures were the most frequently read grammatical type in this experiment while second fillers comprised random, unrelated sentence types, the predictability of reduced relatives would have been greater than that of second filler items. Syntactic context – and the prediction thereof – could, then, have benefitted older adults' lexical processing.

Behavioural syntactic priming effects did not differ by group, unlike LCC patterns. However, as mentioned above, differences between groups became apparent on some – though not all – ERP measures. First of all, the distribution of ERP components differed between age groups. While the P600 (verbal and on "by") was front–left distributed in younger adults, the older group exhibited a wider frontal distribution, including front–right channels. Similarly, N400 effects were centered around right–parietal sites in the younger group, but were found in right–posterior and right–occipital sites in older readers as well. This wider spread of activation across the scalp is a well–attested finding in older adults (Leckey and Federmeier, 2020; Peelle, 2019), and may – if it enhances behavioural performance – be tied into increased reliance on compensation strategies in older age. For example, Manenti et al. (2013) found older adults exhibited wider prefrontal activation on transcranial magnetic stimulation measures to compensate for declines in naming ability and lexical access. Syntactic compensation effects were found by Wingfield and Grossman (2006), who found more widespread functional magnetic resonance imaging activation in older compared to younger adults during processing of long and complex syntactic structures (see further Diaz et al., 2016, for a review). The current study adds some tentative evidence to these compensation strategy accounts.

Further, dissociations between behavioural and ERP findings were discovered: behavioural results show highly robust abstract priming and lexical boost effects on reading times in and around the disambiguating "by" in Targets, yet P600s on "by" were not modulated by priming condition as robustly as Verbal P600s. Reading times therefore captured syntactic priming more sensitively around the disambiguation region. Moreover, stronger and more defined priming and boost effects were found on younger participants' P600s on "by" than in older adults, despite age–invariant behavioural priming. Again, reading time results tell a different story than the neural findings.

It could be the case that older adults' ERP responses showed delays compared to those in younger participants (e.g. Duarte et al., 2006), which made the selected time windows and ROIs less accurate in detecting both groups' waveforms. This would correspond to older adults' significantly lower scores on the measure of processing speed. Alternatively, given that the most robust behavioural effects were recorded in the Spillover ROI (corresponding to words four and five post–"by", which include the verb), but effects were absent on By–ROI reading times, the main effects of syntactic priming in comprehension could simply be manifested more robustly in the verbal rather than the "by" region. This notion could integrate this Study's behavioural and ERP findings. The scarcity of syntactic comprehension priming studies using self–paced reading methods nevertheless makes this a difficult point to substantiate theoretically.

While the age group difference on "by" P600 patterns must therefore be interpreted with caution, electrophysiological differences in spite of intact behavioural performance could again be tied to older adults' compensatory processing. Therefore, while some basic linguistic processes may show electrophysiological changes, older adults' greater linguistic experience (Ramscar et al., 2014), more efficient allocation of attentional resources (Peelle, 2019), or even increased efficiency of some parts of the inhibitory control network (Veríssimo et al., 2022), could have combined to achieve successful behavioural performance. This study suggests that cognitive perspectives on older adults' compensation strategies in combination with implicit language processing must form a central angle of inquiry in future studies.

In summary, this study did find intact syntactic priming and lexical boost effects in older adults, in spite of potential underlying ERP differences. Younger but not older adults were facilitated by lexis–only overlap, suggesting syntactic context is a necessary factor for successful lexical processing in greater age.

4.5.2 Implications for Syntactic Comprehension Priming and ERPs

The current study suggests syntactic priming in comprehension can be recorded independently from lexical overlap on behavioural and ERP measures. This counters past suggestions of comprehension priming effects being reliant on lexical overlap (for a review, see Tooley and Traxler, 2010), and concurs with the few investigations which have similarly found syntactic comprehension priming on ERPs (e.g Ledoux et al., 2007; Tooley et al., 2009). Nevertheless, several unexpected patterns emerged: First, only weak priming effects on P600 waveforms in response to the disambiguating "by" in reduced relatives were found, contradicting results obtained by Ledoux et al. (2007). Second, the P600 effects that did emerge showed a frontal distribution as opposed to the frequently reported centro–parietal topography. And finally, analyses of the N400 in response to Target verbs returned nothing significant, but the N400 on Lexical Control Condition items was clearly apparent.

The frontal topography of the Verbal P600 was unexpected, but not entirely uncommon. Leckey and Federmeier (2020) summarise evidence suggesting the P600 may shift from its frequently observed centro–parietal distributions to a frontal topography in older adults especially. More to the point, Guillem et al. (1995) make the suggestion that frontal P600 components, as opposed to the posterior P600, is related to recognition. This account could explain the current data: it is not unlikely that syntactic comprehension priming (and especially the lexical boost) is related to recognising words and patterns. Possibly, priming in comprehension could be more directly related to recognition than in production, and the lack of studies investigating the links between recognition and priming is therefore not surprising given that the vast majority of syntactic priming studies have focused on production. Incidentally, a recognition–based account concurs with findings of syntactic comprehension priming across up to four intervening fillers in Study 4. This study therefore offers tentative evidence for the importance of recognition to syntactic priming in comprehension, and suggests future investigations into effects of recognition could be extremely fruitful.

Finally, returning to the LCC and its variable effects, a significant N400 on LCC trials was found, where verbs from Primes were repeated in Second Fillers. Nevertheless, the N400 did not appear on verbs in Boosted trials, which were similarly repeated or unrepeated. Ledoux et al. (2007), who used similar stimuli to the present experiment and also recorded ERP responses, did find a significant attentuation of the N400 when verbs were repeated in Targets. A possible reason for the absence of this effect in this experiment is the longer lag between Primes and Second Fillers on the one hand (1 intervening sentence) and Primes and Targets on the other (at least 2, up to 4 intervening sentences). Indeed, N400s elicited with word repetition appear to decrease in magnitude relatively quickly (see Swaab et al., 2004, for a discussion), and while Ledoux et al.'s (2007) study did include intervening fillers, the amount of fillers is not specified.

Overall, this study supports past findings of lexically–independent syntactic priming in comprehension. Both priming and lexical boost effects were evident on ERP measures, although age-related differences in topography were observed. The expected centro–parietal P600 component took a frontal topography (front–left in younger adults) while verbal N400s could not be captured in the data. Instead, this study suggests verbal P600 waveforms may account for the recognition–based aspects of syntactic priming in comprehension.

4.6 Conclusions

The current study found intact syntactic priming in older and younger adults' comprehension. Both age groups read Primed sentences faster than Unprimed items, and lexically Boosted sentences were read even faster. Thus, this study contradicts literature suggesting older adults' sentence processing is subject to declines, and instead concurs with recent findings of intact implicit processing. Electrophysiologically, both older and younger adults experienced facilitation on a verbal P600 component, possibly related to recognition of previously–processed syntactic and verbal information, and a control condition aimed to capture lexis–only priming further showed no age differences.

Nevertheless, age differences were found on some other electrophysiological measures. All components had a wider distribution in older compared to younger adults in line with neural spreading accounts of cognitive aging. Younger but not older adults showed priming effects on disambiguating P600 components, possibly reflecting delayed processing in older adults. EEG differences in spite of intact behavioural performance is further suggestive of older adults' highly successful sentence processing strategies, which may in part be based on compensating for certain declining cognitive functions.

Lastly, these findings have important implications for literature around syntactic priming. This study suggests priming in comprehension may rely on recognition of words and syntax more so than in production, and that comprehension paradigms are therefore an important tool to discern between competing accounts of priming. A highly worthwhile angle of inquiry for future research could comprise recording measures of recognition memory and investigating its effects on syntactic priming.

5 Study 4 – Persistence of the Lexical Boost in Syntactic Comprehension Priming

Studies 1 and 3 demonstrated the value of syntactic priming as a tool for linguistic research, and generated informative evidence for theories of the underlying mechanisms of syntactic priming. Study 4, resulting from additional manipulations worked into the experiment for Study 3, was designed to test several competing accounts of syntactic priming by varying the number of fillers presented between prime and target. Lexical overlap between prime and target has previously been found to be particularly short-lived, however the limitations of Study 1, which included only two fillers, prevented the testing of lexical effects in comprehension priming. Study 4 is dedicated to an analysis of these filler manipulations with the aim of informing accounts of syntactic priming from a comprehension viewpoint.

5.1 Abstract

Studies of syntactic priming in production have found abstract priming, in the absence of lexical overlap, to be long-lived, while effects of lexical matching between Prime and Target is generally considered a short-lived effect. However, no studies of priming in comprehension have been conducted to inform this dichotomy, and it is further unclear to what extent memory and processing speed effects may impact priming patterns. This study explicitly manipulated the number of fillers presented between Prime and Target to investigate the longevity of syntactic and lexical effects. Participants paced through Prime–Filler–Target trials including two, three, or four fillers. Targeted structures included Reduced Relatives (RR; e.g. “The man hounded by the dog expected a lift to the hospital”), and could either be Primed with a preceding RR; Boosted with a preceding RR including the same verb; or Unprimed with a random structure. Reading times around the disambiguating “by” and pre–tests of Working Memory and Processing Speed were recorded. Significant effects of abstract priming and lexical boost were discovered in the form of faster reading times on

Primed and Boosted items. Effects were not dependent on or affected by the number of fillers presented between Prime and Target; even Boost effects persisted across four fillers. These results speak against declarative accounts of the lexical boost and make the case for the inclusion of results from comprehension priming in theoretical syntactic priming models.

5.2 Introduction

Syntactic priming paradigms have become a popular tool for linguists and psychologists to investigate the underlying representations of syntactic structure (Bock, 1986; Branigan, 2007; Raissi et al., 2020). Priming paradigms have informed theories of linguistic processing (Schoonbaert et al., 2007), contributed to memory research (Heyselaar et al., 2021), and have even helped shape profiles of linguistic and cognitive impairments (Lee and Man, 2017). Despite the wealth of syntactic priming research, however, the mechanisms underlying priming are still not fully understood. The current study aimed to elucidate some of the cognitive mechanisms behind syntactic priming in comprehension by manipulating the amount of information presented between prime and target.

Syntactic (or structural) priming in production occurs when speakers are biased to using a particular syntactic structure after processing the same structure earlier in an experimental sequence (Bock, 1986; Tooley et al., 2019), or even in an earlier experimental session (Bernolet et al., 2016). In comprehension, syntactic priming generally manifests as a processing advantage for repeated structures, either as faster reading times (see Study 1), facilitated eye-tracking measures (Traxler et al., 2014), or attenuations on Event-Related Potentials (Tooley et al., 2009). For reviews of effects in comprehension, see Tooley and Traxler (2010) and Tooley et al. (2019).

Additionally, facilitation by syntactic priming appears to be reinforced by introducing lexical overlap between prime and target, a phenomenon known as the *lexical boost* (e.g. Hartsuiker et al., 2008; Segaert et al., 2013). In comprehension, syntactic priming was long thought to be dependent on lexical overlap (Tooley and Traxler, 2010). Findings of *abstract* syntactic priming (in the absence of lexical overlap) in comprehension were generally elusive. Nevertheless, recent research suggests lexically–independent syntactic comprehension priming can be recorded (Tooley et al., 2019; Husain and Yadav, 2020; see also Study 1).

Despite the large volume of literature on syntactic priming and the lexical boost, there is as yet no agreement on the causes underlying these phenomena. Most recent studies of priming support types of implicit learning mechanisms as the main cause of abstract syntactic priming (such as models by Chang et al., 2006; Reitter et al., 2011; Traxler et al., 2014), but explanations for the lexical boost are more divergent. Boost effects generally exhibit reduced longevity compared to abstract priming: syntactic overlap has been shown to affect responses across multiple intervening filler sentences and even across different experimental sessions (Heyselaar and Segaert, 2022; Messenger, 2021), while the lexical boost decays far more quickly (e.g. Hartsuiker et al., 2008). The following sections discuss this longevity in further detail.

5.2.1 Persistence of Abstract Priming

Bock and Griffin (2000) summarised how long–term abstract priming, elicited in production, can persist across as many as ten intervening fillers. Bock and Griffin used a picture description task where participants read and repeated a prepositional-dative (e.g. "The credit card company mailed an application to the student") or double-object (e.g. "The credit card company mailed the student an application") description of a picture showing a transitive event, before being asked to describe further pictures by themselves. Intervening fillers were inserted between prime and target pictures, resulting in conditions with a minimum of 0 and a maximum of 10 fillers. Participants produced more primed than unprimed structures even in the Lag 10 condition, indicating that priming effects are very long–lived.

Bock and Griffin's (2000) results were replicated by Kaschak (2007), who used a sentence completion task which again primed participants to produce either a prepositional-dative or double-oject construction. A priming phase, in which participants were biased towards using double-objects, was followed by a longer sentence completion phase to measure the persistence of priming. Kaschak found highly significant priming effects across the sentence completion phase. Even when a week intervened between the priming and completion phases, participants still exhibited priming. Kaschak (2007) suggests this is highly indicative of implicit learning abilities being at the root of syntactic priming effects.

Messenger (2021) reported a recent replication of this effect with passive and active priming in children and adults, both in tests immediately following a priming phase and tests where a different, non-related task intervened between priming and test phase. Furthermore, Heyselaar and Segaert (2022) extended the Kaschak (2007) paradigm by introducing a month–long delay between priming and testing phases. Younger adults showed significant priming after a month intervening between prime and testing phase, however older adults – the focus of the Heyselaar and Segaert study – did not. This, the authors claim, is in line with implicit learning theories of priming and recent developments in cognitive gerontology suggesting long–term implicit learning declines with age.

All of the above studies found some form of long–term, sometimes even cumulative, syntactic priming, and therefore support some type of implicit learning mechanism as underlying cause for priming effects. Error–based implicit learning accounts (such as models by Chang et al., 2006, 2012; Traxler et al., 2014) are currently among the most supported syntactic priming hypotheses by the available evidence. In this context, implicit learning is defined as the unconscious acquisition of information and processing strategies over time (Tooley and Traxler, 2010), and repeated exposure to a specific type of information (for instance, a syntactic structure) facilitates learning of that information. Fine et al. (2013) and Jaeger and Snider (2013) supplemented implicit learning accounts by introducing a prediction–error–based component: the greater the prediction error associated with the primed structure (i.e. the less expected that structure is) the greater the priming effect. These models account for the finding that less frequent structures are more primable than more frequent types (Bernolet and Hartsuiker, 2010; Kaschak et al., 2011).

In short, abstract syntactic priming persists reliably across multiple intervening fillers and across a long timescale. This persistence aligns well with implicit learning accounts of priming, in which repeated exposure to a grammatical structure facilitates learning of processing strategies associated with that structure. However, results from lexical boost manipulations in production are more contentious, and cast doubt on implicit learning mechanisms explaining the entirety of syntactic priming effects.

5.2.2 Persistence of the Lexical Boost

A seminal study by Hartsuiker et al. (2008) demonstrated the longevity of syntactic priming and contrasted this with the short–livedness of the lexical boost. Using chat–based dialogues in tandem with picture descriptions, Hartsuiker et al. (2008) found reliable abstract syntactic priming and lexical boost effects in sequences where targets immediately followed primes. However, the lexical boost decayed extremely quickly, with lexical effects dropping from nearly 50% in their Lag 0 condition to under 10% in Lag 2. At Lag 6, almost no lexical boost effect was observed. While abstract priming effects also decayed as lags increased, significant effects of syntactic structure were still found in Lag 6. Hartsuiker et al. suggest that while abstract priming may rely on implicit learning, only models that include a different underlying mechanism for the lexical boost can reliably account for syntactic priming (see further Mahowald et al., 2016, for a meta–analysis of priming effects in production).

One such model is given by Reitter et al. (2011). Under this account, abstract syntactic priming is grounded in implicit learning, while the lexical boost is the result of residual, spreading activation through the mental lexicon. Since activation is thought to be far more transient and less long–lived than implicit learning, this model would predict Hartsuiker et al.'s (2008) results accurately. "Dual-mechanism" accounts of syntactic priming such as Reitter et al.'s (2011) model have since gained traction (for a review, see Tooley, 2020), however, these accounts have been formulated almost exclusively based on findings in production.

The lexical boost in comprehension appears to relate to syntactic overlap differently than in production. Evidence for the boost in comprehension across fillers was presented by Pickering et al. (2013), who used a sentence–picture matching task in which participants were primed to attach an ambiguous prepositional phrase to either one of two noun phrases (for instance, “The policeman is prodding the doctor with the gun”, from Pickering et al. (2013)). Participants were found to prefer the choice of attachment they had been primed with through pictures showing the primed interpretation. Moreover, both abstract priming and lexical effects persisted reliably across two fillers. The Pickering et al. (2013) study presents the only findings of syntactic comprehension priming with filler manipulations to date. Nevertheless, given that Pickering et al. presented a maximum of only two intervening fillers, a more extensive test of boost persistence in comprehension is warranted.

Further discussion of distinctions between priming effects in production and comprehension is given by Ziegler and Snedeker (2019), who summarise that syntactic priming in comprehension is far more variable and elusive than in production. Ziegler and Snedeker (2019) tested the grammatical and lexical aspects underlying this relationship with several eye–tracking experiments, and report lexically–independent priming patterns in all experiments. However, lexical overlap did generally enhance priming magnitude. Of particular interest to the discussion around the decay of priming is Ziegler and Snedeker’s (2019) focus on *information* priming – the notion that priming in comprehension relies more on informational overlap (in the form of thematic actors, animacy, topicalisation, or indeed, verbs) than priming in production. This could be one of the causes of the dissociation between comprehension and production studies (though cf. Segaert et al., 2013).

Alternatively, patterns of priming decay in comprehension may differ from those in production due to comprehenders’ ability to *recognise* structures and words without high–level processing of those structures and words. Explicit recognition of words has been reliably shown to persist across a large number of fillers (Gaskell and Dumay, 2003), and perceptual memory – which facilitates recognition – can have long–lasting effects (Endress et al., 2009; Magnussen and Greenlee, 1999). Perceptual memory has recently been integrated into models of syntactic priming (Heyselaar et al., 2021), however no evidence from comprehension has thus far been presented to support this notion.

5.2.3 The Present Study

In short, an open question remains around the persistence and decay of the lexical boost in relation to comprehension. It is unknown at what rate the lexical boost decays in comprehension, and whether this decay differs from that seen in production. Given the variability of priming and boost effects in comprehension compared to production (e.g. Tooley and Traxler, 2010), there is reason to suspect lexical boost effects are at least partially grounded in different cognitive mechanisms compared to effects in production (Ziegler and Snedeker, 2019), especially given past difficulty in recording comprehension priming effects in the absence of lexical overlap. Nevertheless, evidence against different mechanisms underlying priming in production and comprehension also exists (for instance, see Segaert et al., 2013, who found similar neural substrates underlying priming in production and comprehension).

While previous syntactic comprehension priming studies have included intervening fillers, it is often unclear precisely how much material intervened between prime and target or whether this affected the recorded effects. For instance, Ledoux et al. (2007) found syntactic priming and lexical boost when “at least two” fillers intervened between prime and target, but explicit manipulations of filler numbers were not included. The only study that did explicitly manipulate filler numbers included no more than two fillers in its trial set (Pickering et al., 2013). Given this, a minimum of two fillers was presented in this study, and intentional manipulation of prime–target lag by careful control of the number of presented fillers was emphasised.

By using a self–paced reading paradigm with a stimuli set that recorded reliable abstract priming in past studies (Ledoux et al., 2007; Traxler, 2008; see also Study 1), this study aimed to examine the robustness of the lexical boost across intentional filler manipulations. Given that comprehension priming appears more elusive and variable than in production, and may partially rely on other mechanisms such as recognition and perceptual memory, more persistent priming was expected in this Study than in most production experiments. Relatedly, this study aimed to record whether two cognitive functions key to language comprehension, Working Memory (hereafter WM) and Processing Speed (PS), affected priming across multiple fillers. For instance, if the lexical boost is indeed grounded in explicit abilities, a correlation between the strength of the lexical boost and WM ability may be expected, but to what extent this affects the longevity of abstract priming is not known. This study hypothesised that (1) both abstract effects and lexical boost effects should be observable across at least two intervening fillers, (2) the lexical boost is more likely to decay as more fillers intervene between Prime and Target, and (3) the lexical boost may relate to WM capacity.

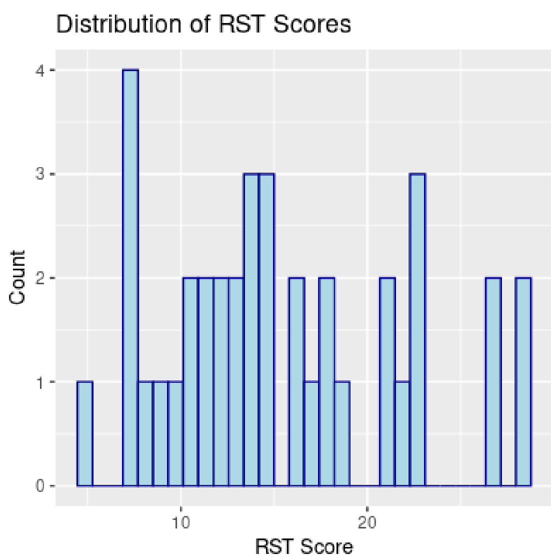
5.3 Methods

5.3.1 Participants

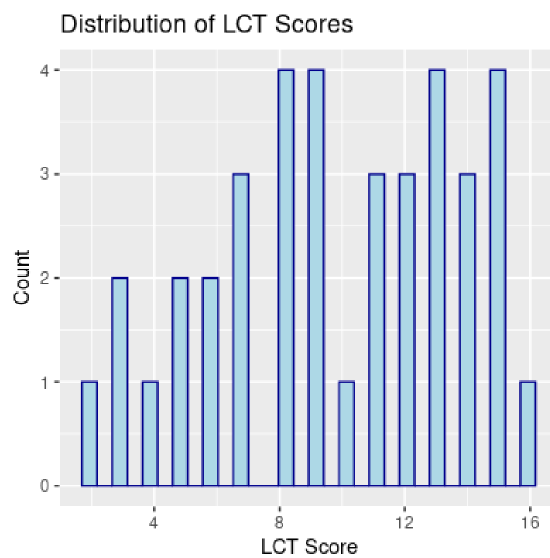
Participants for this study ($n = 20$) comprised the younger group in Study 3), which examined age differences on priming in comprehension. The results reported here were generated from additional manipulations added into Study 3. All participants self-reported dominance in English, and a further summary of participants' demographic details is given in Table 19, and distributions of pre-test scores are visualised in Figure 25. Participants provided informed, written consent before participating in the study; they were further reminded their participation was voluntary and they were free to withdraw from the study at any time without detriment to them. Procedures for participation received full ethical approval from the University of Essex Social Sciences Ethics Sub–Committee.

Table 19 – Summary of participant demographics. [a]Education level was measured along the International Standard Classification of Education (UNESCO Institute for Statistics, 2012). For full education level details, please refer to Appendix G.

Age	M = 21.4; SD = 2.28; [19,27]
Gender	18 F, 2 M
Years in Education	M = 15.49, SD = 2.45; [8,20]
Education Level	$Mode$ = 3[a]
LCT Score	M = 8.37; SD = 4.30; [2,20]
RST Score	M = 17.57; SD = 6.12; [7,28]



(a) Histograms of RST Scores in Study 4.



(b) Histograms of LCT Scores in Study 4.

Figure 25 – Histograms of pre–test scores in Study 4, indicating a variable range of scores across participants.

5.3.2 Materials

Pre-tests

Participants completed the Letter Comparison Test (hereafter LCT; Salthouse, 1991a; Salthouse and Babcock, 1991) as a measure of Processing Speed, and a Reading Span Task (RST; Daneman and Carpenter, 1980) as a WM measure. The LCT asks participants to judge whether two character strings presented on–screen are identical or different, and to respond as quickly as possible. A participant's LCT score was calculated as the amount of correctly–answered trials in a thirty–second period, after which the test timed out. Therefore, the LCT involves no processing demand and is extremely swift to administer. LCT strings comprised either three, six, or nine letters (equally subdivided) and were checked for similarity to words or English morphemes. Participants pressed the "z" key to indicate a *different* response (such as for KLWGCS and ROTPWL) and the "m" key for *matching* strings. The maximum number of presented strings was 48, and five practice trials preceded the main test.

The RST aims to tap conscious recall of information that is subject to concurrent processing, which is essential to the dynamics of WM (Baddeley, 2010). The RST presented incrementally longer sets of sentences to participants, and asked them to remember the final word of each sentence as well as rate all sentences for appropriateness. Participants again used the "z" and "m" keys to respond "appropriate" or "inappropriate" respectively, and typed recalled words on the keyboard at the end of every set. For example, the sentence "Dusty library books were the man's house" targeted an "inappropriate" response and recall of the word "house". Sentence sets ranged from three to seven sentences. RST sentences included no compound or complex clause grammar, and had an average length of 6.97 words (SD = 1.44). Performance on the RST was scored in line with the recommendations of Conway et al. (2005): whole points were awarded for recall of the correct word in the correct order, while half points were given for words recalled in the incorrect order but the same trial. A participant's RST score was the total sum of points across all trials.

Main study

Ninety priming trials consisting of prime, target, and different numbers of filler sentences were presented as part of the main experiment. Prime, Target, and half the filler items were were sourced from Tooley et al. (2009), Manouilidou and Almeida (2009), and Traxler (2008). The remainder of the filler sentences was newly constructed. All experimental sentences, including fillers, appear in Appendices B and F. All target items were reduced relative sentences (hereafter RRs), such as "The man hounded by the dog expected a lift to the hospital." RRs are not a frequent grammatical structure and have elicited reliable priming in past studies (e.g. Ledoux et al., 2007). RRs evoke a temporary syntactic ambiguity, where the first verb ("hounded" in the above example) can be interpreted as a matrix verb with the first actor ("the man") as subject, or as a participle with the first actor as patient/subject. This ambiguity is resolved when the reader reaches "by", and priming effects can be recorded at and after this ambiguity resolution.

Trials were either (1) Unprimed, where no syntactic or lexical overlap between prime and target existed; (2) Primed, with syntactic overlap only; and (3) Boosted, where primes comprised RRs with the same relative clause verb as targets. For instance, for the above example, a Primed condition prime could be "The doctor examined by the inspector began running away", and a Boosted prime could comprise "The doctor hounded by the inspector began running away." Fillers included complex or compound sentence types matched in length to primes and targets, but no RRs were included in filler items. Sentences across conditions and types ranged from 7 to 14 words, and the average length of items was 9.66 words. There were no significant differences between the lengths of Prime and Target items ($t(169)$ = -.77, $p > .05$).

A minimum of two and a maximum of four fillers were presented between prime and target: there was a 50% chance of trials presenting three fillers (a condition hereafter termed *Lag 3*) and a 25% chance of presenting four (hereafter *Lag 4*). Thus, 45 trials presented at least three fillers, with 22–23 trials presenting four.

5.3.3 Procedure

Participants completed the LCT and RST after giving informed consent, and before taking part in the main experiment. The main study was divided into five blocks of eighteen trials each (trials were randomly assigned to a block), which were fully randomised across participants. The sequence of trials within blocks was further randomised for each participant. Both pre–tests and the main study were presented using OpenSesame 3.3 (Mathôt et al., 2012) running on Ubuntu 20.04, and presented on a 21.5-inch Iiyama ProLite B2283HS monitor. Participants provided responses on a wired Microsoft 600 keyboard. The main study took most participants around 50 minutes to complete, for a total study time of between an hour and 90 minutes, depending on participants taking the opportunity for breaks after each study block.

The main study combined self–paced and externally–paced reading to minimise straining of participants' finger movements. Targets and second fillers required participants to pace through sentences word–by–word using the space bar, while all other sentences were extenally paced at between 200 and 500ms per word (generated randomly for each word). Second fillers were self–paced as including another set of self–paced sentences introduced more variation in an experiment that included an average of 450 sentences and helped participants to pay attention. Figure 26 provides a schematic overview of externally paced and self–paced sentences. Both types of sentence were preceded by a fixation cross, which was surrounded by a yellow block in self–paced trials that allowed participants to recognise they should start reading through by themselves. Participants were trained to recognise these blocks in the eight practice trials that preceded the main experimental phase.

Further, yes/no comprehension questions were designed to monitor participants' attention to the task. Questions queried the main action statement of the sentence (and either the main or the relative clause action statement in RRs). For instance, for the example "The man hounded by the dog expected a lift to the hospital" above, comprehension questions could be "Was the man hounded by the dog?" or "Did the man expect a lift?" — a randomly–selected 50% of questions proposed an incorrect statement (e.g. "Was the man hounded by the cat?") while the other 50% required a correct answer. Participants used the "z" key to give an affirmative answer and the "m" key to respond "NO". There was a 50% chance of comprehension questions appearing after *any* sentence, including primes and targets.

5.3.4 Analysis

Reading times (RTs) on targets were recorded, focusing on the disambiguating region around the "by" and a spillover region. Thus, the *By ROI* was defined as "by" and the following two words ("by the dog" in the above example) and the *Spillover ROI* comprised two words following the *By ROI* ("expected a" in the example). Reading times in each of these ROIs were residualised by character count, and these Residualised RTs (RRTs) were then log–transformed and trimmed by participant, such that all data points above or below more than 2.5 standard deviations from the mean of each participant's RRTs were discarded. Trials with incorrect comprehension question responses on target sentences were also eliminated from the analysis.

These trimmed and transformed RRTs were then enter into linear mixed regression models in R (R Core Team, 2020). The *lme4* package was used for modelling (Bates et al., 2015), *sjPlot* and *ggplot2* for model visualisation (Lüdecke et al., 2021; Wickham, 2011), *EMAtools* for generation of effect sizes (Kleiman, 2017), and *brms* and *bridgesampling* for confirmatory Bayesian linear mixed models (Bürkner, 2017; Gronau et al., 2017). Linear mixed models included random effects for Participant and Trial to account for inter–subject and inter–trial variation, as well as fixed effects for Priming Condition, Filler Number, RST Score, LCT Score, and interactions of these parameters. Before being added to any model, LCT and RST scores were centered, and both the Priming Condition and Filler Number parameters were contrast coded. For Priming Condition, the first contrast examined Unprimed vs. Primed trials to investigate abstract priming, and the second contrast focused on Primed vs. Boosted trials to examine the lexical boost. The Filler Number parameter was backwards difference coded such that it compared Two vs Three fillers on the one hand (thereby comprising the Lag 3 condition), and Three vs. Four fillers on the other (to specify Lag 4).

To follow up on findings of null results, additional Bayesian linear mixed models were constructed, which can express the likelihood of null results with greater confidence than frequentist methods (Matzke and Wagenmakers, 2009; Wagenmakers, 2007). Two Bayesian models were constructed for each parameter of interest: the first included this parameter or interaction, while the second (the null model) included all effects *except* the parameter or interaction of interest. All models were fitted with weakly informative exponential Gaussian distributions which are appropriate for RT data (see further Wagenmakers, 2007). Models were then compared to generate Bayes Factors (BFs), which indicate the likelihood of a hypothesis being true. BFs of < 1 provide evidence for the null hypothesis (in this case, that an interaction was *not* present), while BFs greater than 1 provide evidence for the full model (for a practical guide, see Lee and Wagenmakers, 2014). Appendix I includes the code used for both the frequentist and Bayesian analyses.

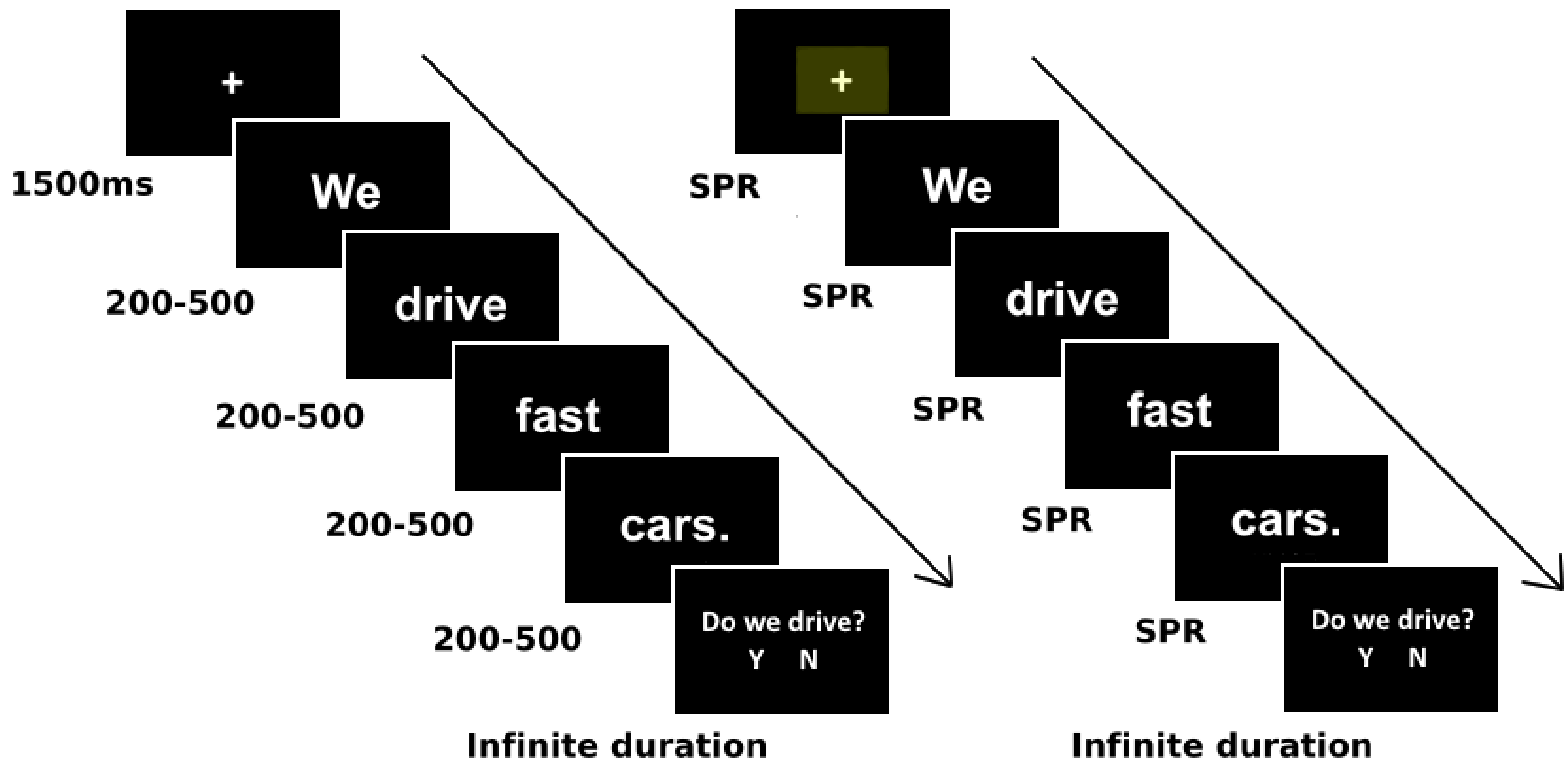


Figure 26 – Sequence of externally paced (left) and self–paced (right) sentences in the main study. Comprehension questions appeared after a random 50% of trials.

5.4 Results

5.4.1 Abstract Priming and Lexical Boost

This study first presents findings of abstract priming and lexical boost before listing filler manipulation results. The defined Spillover ROI was more sensitive in capturing both priming effects than the By ROI. Indeed, only RST score significantly affected reading times in the By ROI ($t(17) = 2.33$, $p < .05$, $d = 1.13$) – surprisingly, this effect was non–facilitating, suggesting that reading times increased with greater WM spans. All other effects returned insignificant results (see Table 20 for a full overview). The Spillover ROI did return a clear abstract priming effect ($t(90) = \text{-}2.57$, $p < .05$, $d = \text{-}.54$) and a large lexical boost ($t(90) = \text{-}4.10$, $p < .001$, $d = \text{-}.89$), which is further visualised in Figure 27. Priming and boost effects did not interact with pre–test scores (all ps $> .05$), though RST score as a main effect had a significant impact on reading times with a similar non–facilitatory effect as found in the By ROI ($t(17) = 2.68$, $p < .05$, $d = 1.30$).

5.4.2 Impact of Intervening Fillers

Models including an additional interaction between Filler Number and Priming Condition were constructed to examine whether Filler Number parameters affected reading times. First, model comparisons including the current models and the condition-only models reported above were conducted. These comparisons suggested Filler Number models were no more accurate in predicting reading times than condition-only models in the By ROI ($\chi^2(6) = 5.50$, $p > .05$) or the Spillover ROI ($\chi^2(6) = 6.20$, $p > .05$).

Examining lag models more closely, as with priming condition–only models, effects in this set of models were more pronounced in the Spillover than the By ROI. In this By ROI, a significant effect only of RST span was found ($t(17) = 2.312$, $p < .05$, $d = 1.14$), which was again in a non-facilitatory direction. No other effects significantly predicted reading times (ps $> .05$). However, the Spillover region showed moderate effects of abstract priming on reading times ($t(88) = \text{-}2.713$, $p < .01$, $d = \text{-}.58$) and large effects of the lexical boost

Table 20 – Summary of priming condition linear mixed model output in the By and Spillover ROIs. Reading Span Task (RST) and Letter Comparison Test (LCT) scores were centered before being added to any model. Abbreviations: "Est", Estimate; "SE", Standard Error; "DF", Degrees of Freedom. Effect sizes were calculated as Cohen's d (Sawilowsky, 2009). Significant values are represented in **bold**.

ROI	*Parameter*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
By	Intercept	4.414	.0519	22.22			
	Priming	-.0085	.0275	92.05	-.309	.758	-.064
	Boost	-.0014	.0274	91.64	-.051	.959	-.011
	RST	.1032	.0443	16.99	2.330	**.032**	1.131
	LCT	.0760	.0505	17.01	1.503	.151	.729
	Priming * RST	-.0069	.0074	1507	-.927	.354	-.048
	Boost * RST	-.0053	.0074	1507	-.716	.474	-.037
	Priming * LCT	-.0079	.0086	1508	-.915	.360	-.047
	Boost * LCT	.0009	.0085	1507	.107	.915	.006
Spillover	Intercept	4.332	.0551	30.25			
	Priming	-.1044	.0407	89.83	-2.566	**.012**	-.542
	Boost	-.1667	.0406	89.57	-4.101	<**.0001**	-.887
	RST	.1158	.0433	16.99	2.677	**.016**	1.299
	LCT	.0741	.0494	17.02	1.502	.152	.728
	Priming * RST	-.0099	.0080	1511	-1.235	.217	-.064
	Boost * RST	-.0030	.0080	1511	-.377	.706	-.019
	Priming * LCT	-.0004	.0093	1511	-.043	.966	-.002
	Boost * LCT	.0048	.0093	1511	.519	.604	.027

($t(88)$ = -4.111, $p < .001$, d = -.88). Neither priming condition interacted with either lag parameter, suggesting priming effects were roughly equal across fillers, and lag conditions did not affect reading times when considered as main effects either (ps > .05). Reading times again *increased* as RST scores became higher ($t(17) = 2.698$, $p < .02$, $d = 1.31$), and RST scores further interacted with the Lag 4 parameter ($t(1506) = 2.405$, $p < .05$, $d = .12$) — specifically, participants with higher RST scores suffered more severe slow–downs on Lag 4 compared to Lag 3 trials, which is further visualised in Figure 28. Bayesian models confirmed the absence of priming condition * Lag interactions (By-ROI and Spillover BFs < .0001).

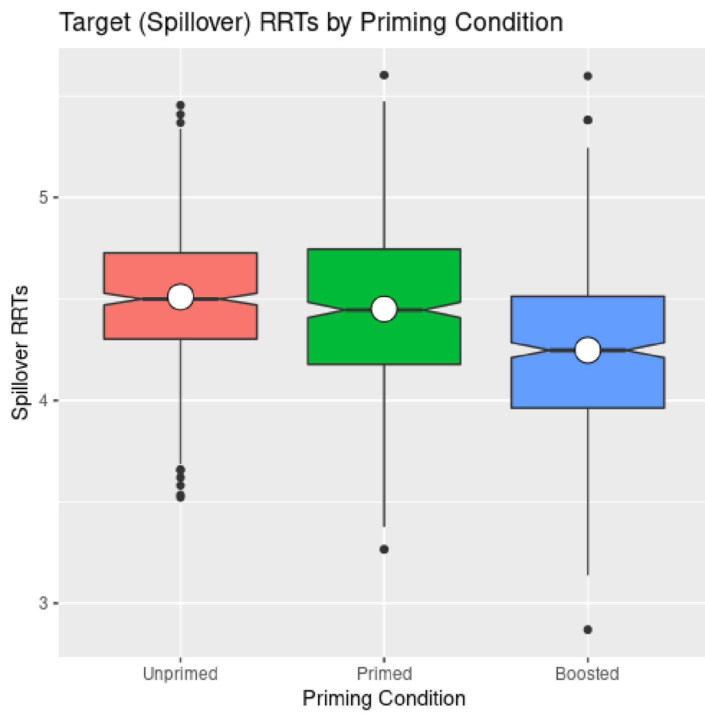


Figure 27 – Plot of residualised reading times by priming condition in the Spillover ROI, showing a large effect of lexical boost and a smaller yet significant abstract priming effect. Means by condition are represented by white circles.

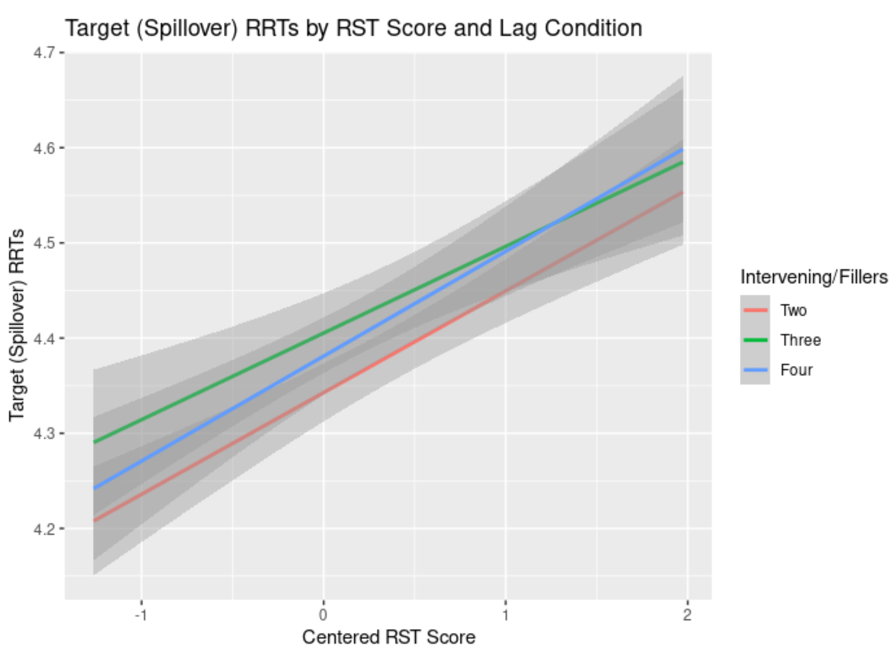


Figure 28 – Plot of residualised reading times in the Spillover ROI by centered RST score and numbers of intervening fillers, showing indications that higher–span participants experienced more slow–downs on Four–filler trials than Three–filler trials.

Table 21 – Summary of Filler Number by Priming Condition linear mixed models in both the By and Spillover ROIs. RST and LCT scores were centered before being added to models. Abbreviations: "Est", Estimate; "SE", Standard Error; "DF", Degrees of Freedom. Effect sizes were calculated as Cohen's d (Sawilowsky, 2009). Significant values are represented in **bold**.

ROI	*Parameter*	*Est.*	*SE*	*DF*	*t*	*p*	*d*
By	Intercept	4.412	.0521	22.31			
	Priming	-.0179	.0273	.8787	-.655	.514	-.144
	Boost	-.0047	.0727	.8784	-.172	.864	-.026
	Lag 3	-.0094	.0081	1512	-1.170	.242	-.067
	Lag 4	-.0007	.0091	1511	-.078	.938	.003
	RST	.1027	.0444	17.03	2.312	**.033**	1.135
	LCT	.0760	.0507	17.07	1.499	.152	.728
	Priming * Lag 3	-.0150	.0095	1511	-1.586	.113	-.121
	Boost * Lag 3	-.0042	.0094	1512	-.453	.651	-.062
	Priming * Lag 4	-.0007	.0107	1511	-.067	.947	-.028
	Boost * Lag 4	.0113	.0108	1515	1.044	.297	.043
	Lag 3 * RST	-.0009	.0072	1511	-.129	.8977	-.025
	Lag 4 * RST	.0021	.0082	1511	.257	.797	-.000
	Lag 3 * LCT	-.0004	.0083	1510	-.051	.959	.024
	Lag 4 * LCT	-.0065	.0097	1511	-.669	.504	-.015
Spillover	Intercept	4.332	.0553	30.36			
	Priming	-.1101	.0406	.8745	-2.713	**.008**	-.580
	Boost	-.1668	.0406	87.47	-4.111	<**.001**	-.879
	Lag 3	-.0064	.0088	1511	-.735	.463	-.038
	Lag 4	-.0107	.0099	1510	-1.079	.281	-.056
	RST	.1171	.0434	17.04	2.698	**.015**	1.307
	LCT	.0733	.0496	17.10	1.478	.158	.715
	Priming * Lag 3	-.0057	.0103	1510	-.557	.578	-.029
	Boost * Lag 3	-.0013	.0101	1510	-.132	.895	-.007
	Priming * Lag 4	.0083	.0115	1510	.724	.469	.037
	Boost * Lag 4	.0025	.0117	1512	.217	.828	.011
	Lag 3 * RST	.0086	.0078	1510	1.100	.271	.057
	Lag 4 * RST	.0213	.0088	1511	2.405	**.016**	.124
	Lag 3 * LCT	-.0027	.0090	1510	-.296	.767	-.015
	Lag 4 * LCT	-.0011	.0105	.0015	-.103	.918	-.005

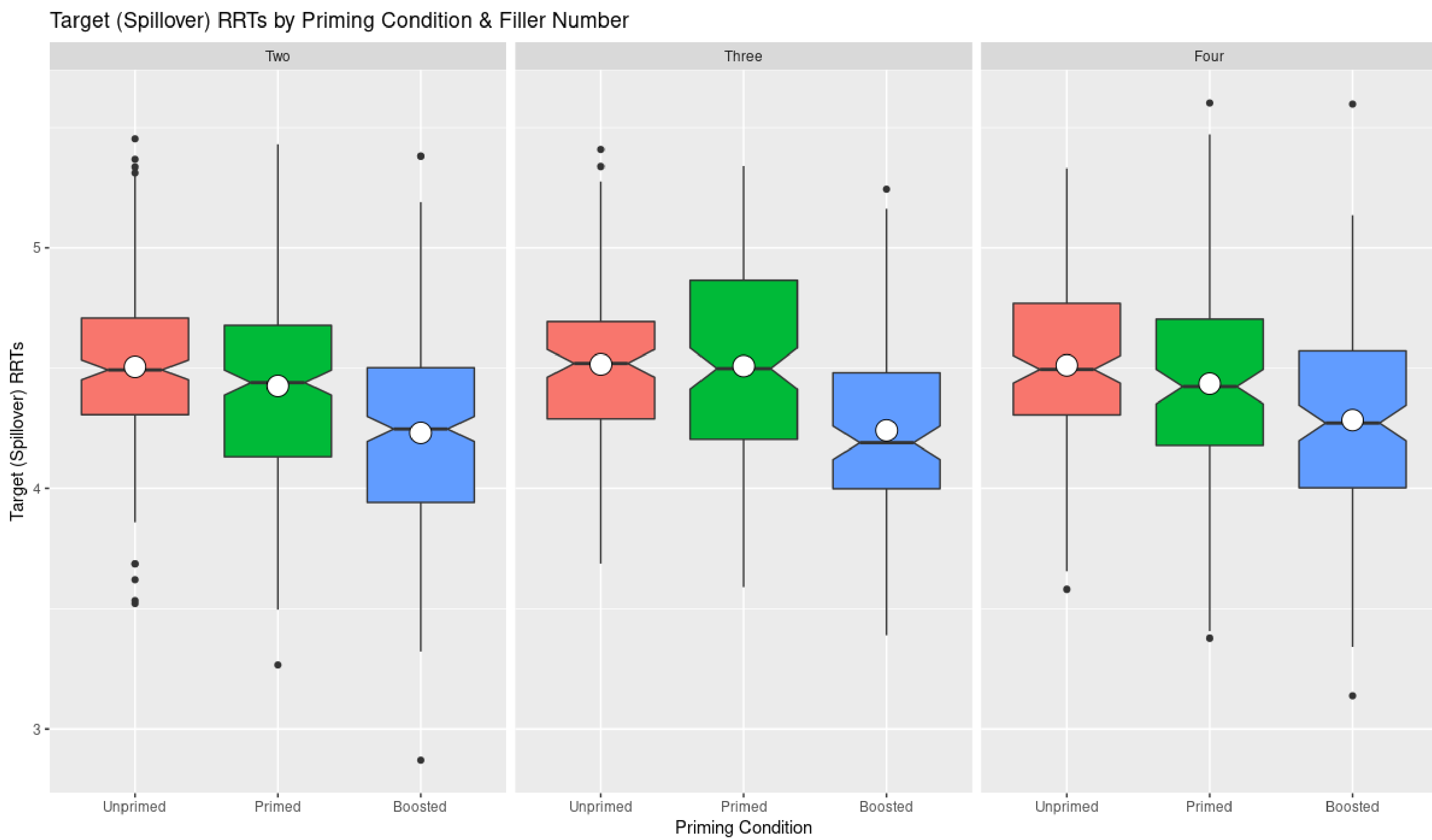


Figure 29 – Plot of residualised reading times in the Spillover ROI by Lag and Priming condition, showing continued abstract priming and lexical boost effects after 4 intervening fillers. The strength of the priming and boost effects show a possible slow decay when more fillers intervene between prime and target, however interactions between Lag and Priming condition returned insignificant results, and Bayesian modelling further dismissed this interaction.

5.5 Discussion

This study used a self–paced reading paradigm to record syntactic priming and lexical boost effects in comprehension, while manipulating the number of fillers presented between prime and target. Reading times on reduced relative (or RR) sentences were recorded, which were either Unprimed, Primed by a preceding RR sentence, or Boosted by a preceding RR sentence with a matching verb. Frequentist and Bayesian linear mixed regression models were fitted to reading times in two Regions of Interest (ROIs; *By* and *Spillover*), and additional models examining the effects of cumulative syntactic priming were fitted.

5.5.1 Syntactic Priming in Comprehension

Robust abstract syntactic priming and lexical boost effects in comprehension were discovered. This follows previous reports of recorded comprehension priming with RR sentences during reading (e.g. Ledoux et al., 2007; see also Studies 1 and 3) and replicates recent studies that have aimed to elicit syntactic priming in comprehension (e.g. Husain and Yadav, 2020; Ledoux et al., 2007; Tooley et al., 2019; Tooley and Traxler, 2018). This study therefore makes the case for the independence of priming in comprehension from lexical overlap. The data do not support the notion that syntactic priming in comprehension relies on explicit lexical overlap (e.g. Arai et al., 2007).

The surprising and counterintuitive interactions found between reading times and RST scores deserve some attention. Across models, *longer* reading times were associated with *higher* RST scores, when previous research suggested *faster* reading times should be connected to larger WM spans. This could be a result of the comparatively small sample size presented. This Study therefore briefly examined the possibility of a particular skew of WM spans in the sample, see Figure 25a. The distribution of span sizes in the sample was not normal and included several highly frequent scores. This implies any RST-related results should be interpreted with caution. Another possibility is that the measure of WM is not tied to reading *speed* as strongly as expected. A recent study by Johann et al. (2020) suggested WM can be robustly tied to reading comprehension in children (particularly when declarative measures are used to assess understanding), but that WM is not related to reading speed (see also Memisevic et al., 2020, for a corroboration). Given this nevertheless unexpected negative relationship between reading speed and WM, interactions involving RST score are interpreted with some caution.

5.5.2 Effect of Lag

Crucially, neither abstract priming nor lexical boost effects interacted with Lag 3 or Lag 4 conditions. Priming effects therefore remained consistent across fillers. While the longevity of abstract priming is a well–established phenomenon, the current results from the lexical boost challenge much of the established literature. This section therefore focuses on boost effects specifically. The persistence of the lexical boost in the current results speaks against accounts that consider the boost the result of residual activation (Hartsuiker et al., 2008; Pickering and Branigan, 1998). There was, moreover, no relationship between RST scores and the lexical boost effect in the data, further showing that the boost does not rely on explicit recall from memory (cf. Bock and Griffin, 2000).

Instead, this study corroborates and expands upon the results obtained by Pickering et al. (2013), who tested comprehension priming across one and two fillers, and similarly supports unified models of syntactic priming. The inclusion of Lag 3 and 4 conditions in this experiment makes this study the first to demonstrate comprehension priming and boost effects across three or four intervening fillers. While there were indications that the strength of priming effects, and particularly the lexical boost, declined somewhat when more fillers intervened between prime and target (see Figure 29), this was not reflected in the models or in the Bayesian analysis. This persistence, especially that of the lexical boost, supports models that consider both abstract priming and the boost the result of the same, unified mechanism (e.g. Chang et al., 2012; Fine et al., 2013; Heyselaar et al., 2021), thereby challenging dual–mechanism accounts of priming (Reitter et al., 2011; Traxler et al., 2014).

The current results further demonstrate the crucial importance of considering *both* production *and* comprehension priming when building theoretical models of underlying priming mechanisms. This Study emphasises the distinction between production and comprehension in light of the current findings, and makes the case for more syntactic comprehension priming studies to confirm the current results. As suggested in the review of existing literature on priming in comprehension and production, the lexical boost in comprehension could rely to a greater degree on *word recognition* of the verb, as opposed to in production, where such recognition is absent.

However, this Study stops short of directly tying syntactic priming to *recognition memory*, as no measures of recognition memory were collected and it is unclear to what extent recognition of syntactic structure (relating to abstract priming) exists in the first place. Additionally, the evidence presented here makes the case for a non-declarative foundation of syntactic priming, which complicates the inclusion of recognition memory (a sub–domain of declarative memory) in the interpretation of results. Nevertheless, given the findings that word recognition can persist across many intervening words and sentences, recognition ability could be included in future models of priming (for reviews of word recognition literature, see Grainger, 2018; Snell et al., 2018). Any future account involving recognition memory in comprehension priming must additionally be verified with priming studies on older, memory–impaired, and language–impaired groups, which have great potential to confirm the cognitive resources necessary for priming (Heyselaar et al., 2020; see also Studies 1 and 3).

On another note, methodological aspects could also play a role in explaining the apparent dichotomy between production and comprehension that these results expose. Tooley et al. (2014) suggest the grammatical structures and the measure of priming used should be kept constant when comparing priming in production and comprehension, and offer evidence of equal priming and boost in both modalities using similar methods. This Study does not discount this possibility: reduced relative priming has generally been conducted in comprehension rather than production (e.g. Ledoux et al., 2007; Tooley et al., 2019; Tooley and

Traxler, 2018; Wei et al., 2018, 2019) due to the relative ease of determining where in the sentence effects might occur (around the disambiguating "by"). A worthwhile future investigation comparing reduced relative priming in comprehension and production, with the same participants, and possibly in the same experiment, could therefore yield intriguing results.

This study raises the question of at what point the lexical boost in comprehension does start to decay. The scarcity of syntactic comprehension priming studies explicitly investigating filler Lag makes this a difficult question to answer. If word recognition is indeed involved in the lexical boost in comprehension, a long lag of many intervening fillers might be necessary to record decay. Alternatively, future research may focus on manipulating *temporal* rather than filler lag, which may be an easier way to investigate priming decay (e.g. Heyselaar et al., 2021). A short discussion of this study's temporal lag is presented below.

The average presentation time for first fillers in this study, assuming a mean presentation rate of 350ms per word and taking into account the average number of words per sentence ($M = 9.11$, $SD = .93$), was around 3.1 seconds. For self–paced second fillers, the average reading time per word was 371ms. At an average of 9.11 words per second filler ($SD = 1.02$), this results in a mean reading time of around 3.3 seconds. Third fillers, at a mean presentation rate of 350ms per word and a mean length of 9.73 words ($SD = .85$), would have taken approximately 3.4 seconds, and fourth fillers at 9.7 words on average ($SD = .88$) and 350ms per word would similarly have taken 3.4 seconds on average. Thus, there was an approximate temporal lag of 9.8s between prime and target in Lag 3, and of 13.2s under Lag 4 conditions. The temporal lag between primes and targets, in either filler Lag condition, was therefore minor, especially compared to previous studies which have demonstrated priming in production across days and weeks. Nevertheless, further investigations of temporal lag in comprehension priming are required to elucidate this further.

Finally, a further potential limitation of the approach taken in this study concerns the absence of a fully–crossed paradigm, where lexical overlap in the absence of structural matching was not investigated. Expectation effects may have resulted when participants encountered a matching verb in Targets, as a matching reduced relative structure always followed a matching verb. While this possibility exists, and should be resolved with future, larger–scale studies of the lexical boost in comprehension, evidence from the other studies presented in this project suggest the paradigm used in this study was effective: Studies 1 and 3 included a Lexical Control Condition where only lexical overlap was manipulated, which found that while lexis–only overlap can be recorded in self–paced reading items, effects were less pronounced, smaller, and less robustly observable on Event-Related Potential signals than lexical overlap in combination with syntactic matching. This study, which presents a sub–set of data from Study 3, therefore suggests that the effects observed are a 'true' reflection of the lexical boost. Despite this, and given that these are the first results observing lexical boost effects after four fillers, future replications of this study are entirely warranted.

5.6 Conclusions

The current study is the first to report intact abstract lexical boost effects in syntactic comprehension priming across three and four intervening fillers, building on previous work that confirmed priming effects after two fillers and casting doubt on models that consider the lexical boost the result of explicit or activation–based mechanisms. Boost effect occured unrelated to Working Memory or Processing Speed scores and, while indications for a reduction in boost strength when fillers increased did exist, modelling showed significant effects of lexical overlap in each Lag condition. This study makes the case for serious consideration of priming effects in comprehension when formulating models of syntactic priming, which past accounts have largely neglected, and calls for future investigations into the apparent dichotomy between production and comprehension priming. This Study also directs attention to word recognition as a potential factor in the strength of the lexical boost in comprehension, and suggest this could be a worthwhile angle for future research. Finally, expansions of the current paradigm to manipulate temporal rather than filler lag could yield further implications for models of syntactic priming.

6 General Discussion

This project combined three different experiments and four studies with the aim of uncovering implicit changes in sentence processing with age. Study 1 manipulated syntactic priming in comprehension with older adults, while Study 2 investigated attachment preferences and susceptibility to similarity-based interference. Study 3 expanded on Study 1 with an Event-Related Potential paradigm, and manipulating the number of fillers intervening between Prime and Target. These filler manipulations were analysed in Study 4. Measures of Working Memory and Processing Speed were also collected in every experiment to examine the effects of these factors on sentence processing in aging.

6.1 Age Invariance

The overall evidence presented in these experiments suggests sentence processing is preserved in older adults. None of the three experiments found behavioural differences between younger and older groups on reading times, susceptibility to experimental conditions, or bias when processing ambiguities. Older and younger adults were syntactically primed in Study 1; both age groups showed the same disambiguation preferences in Study 2; and Study 3 replicated the behavioural priming results from Study 1 and further suggested older adults also showed electrophysiological signs of syntactic priming (though see Section 6.2 below for a detailed discussion of ERP patterns).

This lack of main age effects was consistent and replicated: all presented experiments showed largely age-invariant performance on its main measures, and two highly similar syntactic priming effects returned the same pattern of results. This project further found no evidence of memory-induced changes to sentence processing ability (as suggested by Just and Carpenter, 1992). All experiments therefore make the case for a substantial nuancing of the notion that sentence comprehension declines with age (cf. Norman et al., 1992; Obler et al., 1991; Poulisse et al., 2019). The discussions presented in the above Studies suggest the main grounds for this lack of age effects (which contradicts common findings in linguistic aging) is rooted in the distinction between age effects on *explicit* processing tasks compared with the absence of such effects on *implicit* tasks.

In a commentary on Just and Carpenter's (1992) model of individual difference-based processing, which suggests memory capacity is the most important predictor of performance on linguistic tasks, Waters and Caplan (1996a) suggested memory effects are not consistent across task types and that therefore, the capacity-based model was incomplete. Waters and Caplan stress the importance of distinguishing explicit tasks, where information must be consciously retrieved from memory, and implicit processing, which is automatic and fully unconscious. More recent literature has also emphasised how critical this distinction is using data from older adults: implicit memory and learning show far weaker age-related declines, if any, than effects on explicit memory (e.g. Salvato et al., 2016; Ward et al., 2013; Ward, 2022).

The current project offers substantial evidence to support this distinction. The particular focus of all three experiments was on implicit measures for this exact reason, and it is therefore far less surprising that age effects were not discovered and the impact of Working Memory (hereafter WM) pre-tests was minor (see further Section 6.3). Study 2, however, speaks to the dichotomy between implicit and explicit processing most directly through the inclusion and analysis of memory recall prompts, performance on which was indeed affected by scores on the Reading Span Task (RST) used to gauge WM capacity. These prompts, which necessitated active recall from memory and were therefore an explicit measure, also showed near-significant trends towards age group effects, again emphasising how past studies that used explicit measures may have conflated explicit memory demands with sentence processing itself (see Norman et al., 1992; Poulisse et al., 2019, for examples of age-related studies based on declarative tasks).

Nevertheless, past studies exist which show null effects of age on more explicit paradigms than those involving priming or reading times (e.g. Meunier et al., 2014; Tyler et al., 2010).

For instance, Davis et al. (2014) used a paradigm in which participants listened to sentences and were required to perform a grammaticality judgement task only on a subset of those sentences. While no-task conditions resulted in similar neuroimaging results across the lifespan, Davis et al. (2014) found positive correlations between age and levels of activation in the task condition. Importantly, these effects were found while behavioural performance remained stable (cf. for a partial replication Campbell et al., 2016). These findings, however, do not necessarily contradict the case made by the studies presented here regarding explicit task demands. While grammaticality judgements, as used by Davis et al. (2014) and Campbell et al. (2016), are not tasks taxing explicit memory significantly, the requirement of making a conscious judgement about processed information is nevertheless a more explicit paradigm than those used in the studies presented here. Indeed, the findings of age–invariance under no task demands but indications for by–age differences when task demands are increased is in line with the findings presented here.

Perhaps most surprisingly, the current results further suggest age invariance on measures of memory interference (Study 2). Both older and younger adults showed significant slowdowns under interfering memory loads when reading disambiguated relative clauses, in the same direction and with roughly the same effect sizes. Given the reliable past findings of memory declines in older adults (Bopp and Verhaeghen, 2005; Verhaeghen, 2003), it was expected that the older group showed greater memory interference effects. However, results from Study 2 suggest that WM capacity does not equate to WM quality (in line with findings by Gordon et al., 2002; Van Dyke and Lewis, 2003): even though the amount of information the WM system is capable of storing may decline across the lifespan, the evidence presented in this project suggests the operations of encoding, storage, and retrieval themselves might not be subject to the same declines. Alternatively, the conceptualisation of WM as a limited-capacity system which is subject to size constraints may not paint a complete and accurate picture of memory dynamics in older adults (for an alternative, see MacDonald and Christiansen, 2002). In any case, the current results call more balanced approaches when considering the relationship between sentence processing and WM: not only the quantity of WM capacity should be measured, but the quality of WM operations must be taken into account in future research as well. Section 6.3 expands on the current project's implications for WM and linguistics further.

6.2 Age Differences

Despite the general finding that sentence processing was not impaired in older participants, minor age differences were uncovered on some aspects of the reported studies. Particularly, group differences became apparent on the electrophysiological component in Study 3. Figure 17 displays scalp plots of both older and younger groups' averages on Unprimed, Primed, and Boosted trials, showing a different distribution and intensity of effects in older compared to younger adults. Indeed, the Mass Univariate Analysis conducted for Study 3 suggested different electrode sites were sensitive to experimental manipulations in Older compared to Younger groups. Specifically, while younger participants experienced a left frontal P600 in response to the disambiguating "by" in reduced relatives, this positivity was more central and widespread in Older adults. Similarly, N400 effects in the Younger group were centred in right centro-parietal sites, while older adults' N400s were found across right temporal, parietal, and even occipital electrodes.

This project is not the first to find different scalp distributions of effects in different age groups: Kemmer et al. (2004) and Zhu et al. (2018) also reported slight yet significant shifts in the locus of ERP findings in older compared to younger adults. Indeed, Kemmer et al.'s (2004) results also suggest a robust *frontal* distribution of P600 effects in older adults, the same findings presented in Study 3. It could therefore be the case that older adults specifically rely on different neural resources during syntactic processing, including – as Study 3 suggested – recognition of previously-processed information. Moreover, these patterns could also be related to the well-established findings in past literature of a 'smearing out' of neural activity across older adults' scalps (Peelle, 2019), where activation becomes less intense and more widespread as people age. This project offers some tentative evidence in support of this notion.

Both Older and Younger groups nevertheless showed robust sensitivity to syntactic priming manipulations on ERPs, in particular on the Verbal P600, recorded on Target verbs. However, younger but not older adults also showed attenuations of the P600 on the disambiguating "by"; this effect did not reach significance in the Older group. It could be the case the electrodes selected were insufficiently sensitive to the dynamics of both groups, or, in line with established literature, older adults may have shown individually-variable delays on ERP signals (e.g. Gajewski and Falkenstein, 2014; Kropotov et al., 2016). The relatively small sample size used in Study 3 may have resulted in large inter-participant variation in ERP component onset, resulting in an insignificant group-level effect. One of the main avenues for future research this project emphasises is, therefore, work with Older adults' syntactic priming and ERP measures for this exact reason (see further Section 6.6 below).

Finally, as mentioned above in Section 6.1, indications of group differences were found in the analysis of load word recall prompts in Study 2. While not quite reaching the threshold for statistical significance, there was a trend for older adults to show more severe slow-downs on recall prompts following dispreferred NP2-biased structures compared to NP1-biased items, an effect not observed in the younger group. Similarly, participants with lower RST scores showed a trend towards lower accuracy on recall prompts following NP2-biased items compared to NP1-biased sentences, while higher-span readers showed smaller by-condition differences (see Figure 12 in Study 2). All of these behavioural differences occured on the only *explicit* measure this project recorded. Recall sequences prompted participants to search through memory for load words processed before reading of a sentence, actively engaging short-term and Working Memory resources. Again, therefore, this project offers evidence for the conflation of memory demands with sentence processing itself in past studies. Recording processing in the *absence* of those demands resulted in age-invariant findings across Studies and experiments.

6.3 Working Memory & Sentence Processing

These cognitive demands were tentatively investigated in this project with the inclusion of WM and Processing Speed measures in all studies. WM was assessed with Daneman and Carpenter's (1980) Reading Span Task, or RST, which taps concurrent storage and processing. Nevertheless, the RST failed to uncover differences between age groups in Studies 1 and 2 (despite a weak correlation between age as a continuous variable and RST in Study 2). Given that age-related declines on WM are among the most robust and frequently reported cognitive aging patterns (see Bopp and Verhaeghen, 2005, for a discussion), this was surprising. A potential cause for this discrepancy could have been that the samples in Studies 1 and 2 were recorded online, while the in-lab participants in Study 3 did show group differences. It could therefore have been the case that the online version of the RST allowed older participants to rehearse the RST items, or allowed both groups additional time to complete the task compared to the in-person version. Replicating Study 2 in a lab setting will therefore be an important future step.

The RST may therefore have been less effective than anticipated: there were no age group differences on the task, and scores on the RST were further unrelated to all RT measures (the foundations of the Just and Carpenter, 1992, individual differences account) and even to measures of memory interference. Given these findings, this project cannot make inferences about the effects of individual differences in WM capacity on implicit linguistic processing. Where RST scores did interact with conditional parameters was when considering recall prompt accuracy in Study 2. After a random 50% of disambiguated relative clause sentences, participants were prompted for recall of one of three memory load words presented before the sentence, and accuracy and response times on these prompts were considered in an additional analysis in Study 2. Increased accuracy was related to higher RST scores, however there was greater RST-related facilitation on NP2-biased compared to NP1-biased items (see Figure 12). Age group effects trended towards significance in some of these models as well, as discussed above. Again, therefore, this evidence suggests a highly influential implicit vs.

explicit distinction in the older sample, where trends towards age effects were observed in explicit, declarative measures. On the contrary, the lack of such effects on implicit measures of processing suggests it is conscious, declarative demands which resulted in past studies' findings of deficient sentence processing in older adults.

6.4 Processing Speed

One of the most robust findings across Studies was the slower reading speeds older adults exhibited compared to younger groups. In all experiments, moreover, older adults showed significantly decreased performance on the measure of Processing Speed (the Letter Comparison Test or LCT), and age was correlated with speed scores across studies (except Study 1, which instead showed a significant correlation between RST and LCT scores). These correlations may have been at least partly responsible for the general lack of LCT effects found in large parts of this project. There was, generally, no impact of speed scores in any Study or experiment, except an Abstract Priming by LCT interaction in Study 3. This weak yet significant interaction suggested that higher LCT scores resulted in more facilitated reading times on Primed compared to Unprimed items, an effect observed across age groups. Boosted trials, where syntactic *and* lexical overlap existed between Prime and Target, showed similar facilitating effects to Primed trials. While the skewed and irregular distribution of LCT scores in Study 3 made it difficult to interpret these results, the interaction of Processing Speed and syntactic priming is a worthwhile avenue for future studies into priming and aging (see further Section 6.6).

The measurement of Processing Speed used in this project, the Letter Comparison Task, was selected specifically for its low demand on the processor and absence of memory confounds. The LCT is not the most frequently used measure of speed, however, and as such a short justification of its use is provided in the remainder of this section. Not all Processing Speed tests are as reliable and accurate as others, and a large body of research has been produced discussing the validity of commonly accepted tests (e.g. Webber and Soble, 2018).

Arguably the most frequently used test of Processing Speed is the digit symbol substitution subtest (DSST) of the Wechsler Adult Intelligence Scale, or WAIS-IV (Hartman, 2009; Wechsler, 1955). This test presents participants with a list of symbols that are tied to a numbered list. Participants are given a select time window (usually 90 or 120 seconds) to memorise what pattern corresponds to what number, before being presented with a sequence of random numbers and asked to draw the corresponding symbol from the list they just memorised. Total scores comprise the number of correctly drawn symbols within a 120-second time limit.

However, critics of the DSST claim it is unclear what specific cognitive skill this test measures – in particular, the DSST may involve reliance on WM or explicit retrieval of information (Jaeger, 2018; Salthouse, 1992). While the full list of symbol–digit pairings is provided to participants during the symbol drawing stage (ostensibly to tap into visuospatial processing), participants may rely on their memorisation of pairings during the initial phase (Salthouse, 1992). This is not a problematic issue for many studies of cognitive aging, since the DSST has been reliably shown to correlate with increasing age (e.g. Hoyer et al., 2004). For the current project, however, it was important to discern exactly between tasks that require memory retrieval and those that do not. The LCT, much like its non-linguistic counterpart, the Pattern Comparison Test (Salthouse, 1992), places virtually no demand on memory (no cues require memorisation during a trial), effortful visuospatial processing, or inhibition. This, ultimately, made the LCT the more reliable Processing Speed test for use in this project.

6.5 Impact on Syntactic Priming Theory

While informing theoretical accounts of syntactic priming was not the main aim of this project at its inception, the older adult findings presented in Studies 1 and 3 and the additional results of Study 4 have a potentially significant impact on current theory surrounding syntactic priming. This section discusses this impact and reiterates some of the main points from Studies 3 and 4.

The field of syntactic priming has largely moved away from considering priming the result of residual activation alone (Pickering and Branigan, 1998). Under this account, processing of a grammatical structure activates lexical and grammatical nodes, and lingering activation of those nodes facilitates processing of the same grammatical structure subsequently. The finding that *abstract* syntactic priming (in the absence of lexical overlap) can persist for weeks after an experimental session (Bock and Griffin, 2000; Kaschak et al., 2011) nevertheless contradicts a residual activation account. Subsequent research focused on the importance of implicit learning to syntactic priming (e.g. Chang et al., 2006, 2012), suggesting that priming is the result of participants' learning to process grammatical structures more efficiently. However, the dissociation between the persistence of abstract priming compared to the relatively short-lived effects of lexical overlap (also known as the lexical boost) led to the formulation of several dual-mechanism accounts of syntactic priming, where abstract priming results from implicit learning, but the lexical boost is caused by lingering activation of lexical nodes (e.g. Hartsuiker et al., 2008; Reitter et al., 2011; Traxler et al., 2014).

Older adults' data are of critical importance when considering theories of syntactic priming. Given the robust findings of slower Processing Speed (Salthouse, 1996), which affects the quality of residual activation, and declining WM spans (Bopp and Verhaeghen, 2005), a residual activation account of syntactic priming fails to account for intact priming in older adults. Conversely, implicit learning and memory skills appear far less affected by the aging process (Ward et al., 2013; Ward and Shanks, 2018); as such, findings of intact priming and lexical boost effects in older adults could support the suggestion that implicit abilities underpin both abstract priming and the boost. The current study reinforces this view: residual activation cannot be the underlying cause for syntactic priming, as both in Studies 1 and 3, older adults showed robust priming and boost effect even across up to four intervening fillers. This project therefore concurs with accounts which suppose a purely implicit underlying cause for both abstract and lexical effects (e.g. Chang et al., 2012; Heyselaar et al., 2021).

Implicit accounts of priming have, however, mainly been informed by priming studies from production (even those with older adults such as studies by Hardy et al., 2017; Heyselaar et al., 2021). This project emphasises the importance of considering findings from *comprehension* priming when determining the validity of priming accounts. For instance, while production priming studies have led to the robust finding that abstract priming is long-lived while the lexical boost decays radpidly (Hartsuiker et al., 2008), this project found no evidence for that notion. Study 4 suggests that in comprehension, lexical boost effects are observable across as many as four fillers (even in older adults), while ERP findings from Study 3 may suggest that priming in comprehension relies more on recognition of words and structures than in production, leading to distinct priming effects in production and comprehension. Integrating the implicit basis of priming effects (see for instance Heyselaar et al., 2021) with studies of recognition memory and the influence of recognition in comprehension may, therefore, be of critical importance in future studies and could lead to accurate, reliable accounts of syntactic priming that take into account findings from older adults and priming in comprehension.

6.6 Future Directions & Review

The studies presented in this project raised a wealth of important and potentially worthwhile avenues for future research and a number of recommendations for future studies in the field. This review section summarises those future directions and recommendations.

First and foremost, a lab-based replication of Study 2 would help confirm the unexpected memory interference patterns that were observed. As discussed below, online data collection for Study 1 was replicated in Study 3, however a replication of Study 2 could not yet be conducted. While the observed patterns of reversed disambiguation preferences under interfering memory load were robust and statistically very persistent, given that this is the first project to highlight such patterns a replication effort is among the main future steps to be taken following this project. Additionally, given that the older sample in Study 2 did not show significantly lower WM spans compared to the younger sample, it would be of interest to conduct a similar study with populations showing different levels of WM capacity, to investigate whether capacity and susceptibility to interference are at all linked.

Second, Study 1 observed a weak yet significant interaction between LCT scores and abstract priming, across groups. Reading times on Primed items were additionally facilitated by high LCT scores compared to Unprimed sentences. The distribution of LCT scores, which followed an age-related decline in the older but not the younger group, made this effect difficult to interpret. Nevertheless, individual differences in Processing Speed have the potential to affect syntactic priming drastically, especially if (following Salthouse, 1996) age-related speed declines are the result of a gradual reduction in available residual activation. For future investigations it may be worthwhile to match different groups for Processing Speed to directly compare whether high-speed participants exhibit greater abstract priming facilitation than their low-speed counterparts.

Perhaps most significantly, all reported studies suggest future research into older adults' language processing *must* take into account effects of explicit, declarative processing demands. The conflation of older adults' declining ability to retrieve information stored in any memory system with sentence processing is one of the main fallacies this project points out. Declining accuracy on comprehension questions does not equate to declining ability to process linguistic information. The importance of non-declarative measures, such as self-paced reading and ERPs, is emphasised by the studies in this project. Additionally, it would be worthwhile to expand the current findings to other implicit paradigms, such as eye-tracking measures. Recent studies by Harel-Arbeli et al. (2021) and Zhao et al. (2019) suggest gaze focuses shift during older adulthood, as increased attention is devoted to processing semantically rich and lexically predictable linguistic information at the expense of other parts of the sentence. Integrating older adults' eye-tracking data with syntactic priming (as in Traxler et al., 2014) or memory interference (as in Gordon et al., 2006) may therefore be extremely worthwhile.

Finally, Studies 3 and 4 establish the foundations for large expansions of syntactic comprehension priming paradigms. Evidence from these experiments adds to the growing number of studies that are finding lexically-independent syntactic priming in comprehension (cf. Tooley et al., 2019) and makes the case for the inclusion of comprehension priming evidence in theoretical account of priming (see below). Additionally, Study 4 showed that comprehension priming may well be more persistent and less susceptible to rapid decay than priming in production. These combined findings raises the question of at what point syntactic priming in comprehension decays beyond the point of measurement. While some evidence for a gradual weakening of priming effects was observable in Study 4, both abstract and boost effects were still significant in the Lag 4 condition. Expansions of Study 4 to include more filler items between Prime and Target would be a straightforward way of further elucidating this issue.

Investigating the role of recognition and recognition memory in syntactic comprehension priming should be another priority for future research. The ERP findings in Study 3 are suggestive of a significant influence of recognition memory on syntactic comprehension priming — this could be tied into the Heyselaar et al. (2021) account which suggests priming is at least partially based on *perceptual* memory, which is naturally closely related to recognition of incoming stimuli. Priming in comprehension could, therefore, be of great interest to clarify this account. Relatedly, the value of ERPs and EEG data to syntactic priming research is emphasised by the current project, and future investigations should aim to use neuroimaging methods alongside traditional behavioural paradigms.

The above findings of persistent priming in comprehension as opposed to swiftly decaying effects in production generate an important recommendation to syntactic priming researchers, and indeed to psycholinguists more generally: considering *both* production *and* comprehension appears critical to formulating psycholinguistic theory. Models cannot be based on one modality alone, yet most if not all models of syntactic priming have mainly included evidence from production (e.g. Hartsuiker et al., 2008; Heyselaar et al., 2021; Reitter et al., 2011). This project offers evidence suggesting that comprehension priming must be an integral part of any theory of underlying priming mechanisms.

6.6.1 Methodological Issues

This project also generated several methodological challenges and subsequent recommendations. The data for Studies 1 and 2 were collected online, and Study 1 was then replicated in a lab setting in Study 3. Online platforms have become a productive source of psychological and linguistic data since the COVID–19 pandemic (Newman et al., 2021), but each platform comes with its own benefits and challenges: it is more difficult to verify the demographic characteristics of participants through online forums, and monitoring for attention is similarly problematic. It was therefore important to this project to replicate at least one of its studies in a lab-based setting. Study 3 found the same syntactic priming results as reported in Study 1, showing that the online sample was a reliable equivalent to a lab sample.

More generally, none of the frequently reported issues with online data collection (such as poor data quality and 'fraudulent' responses, see Newman et al., 2021) were at play in this project. This may have been the case for several reasons. First, data was collected through Prolific (Prolific, 2014), which maintains a high standard of participant screening and, consequently, compensation. Second, both Studies 1 and 2 included rigorous attentional measures and excluded participants with substandard performance on comprehension questions. This, then, is an important recommendation for future studies using online data platforms: the inclusion of attentional prompts, rigorous exclusion of participants who do not meet attentional thresholds, and the selection of a reliable online platform with adequate levels of screening.

It is important to acknowledge the possible presence of early cognitive impairments in self–reported "healthy" samples, and the limitation that the studies reported here did not include assessments of cognitive health such as the Mini–Mental State Examination or the Montreal Cognitive Assessment. Early degenerative conditions such as Mild Cognitive Impairment (MCI) appear to be widespread even in samples of older adults who self–report as cognitively healthy (Jongsiriyanyong and Limpawattana, 2018; Petersen and Negash, 2008). Conducting cognitive screening in the studies presented here could have caught some of these instances. Instead, all studies relied on patients' self–reporting of an absence of dementias and cognitive impairments, and while it is not assumed participants explicitly refused to give honest information, it is likely that some older participants presented with early clinical symptoms that screening may have identified. In future, studies of sentence comprehension and aging may therefore want to consider including cognitive health screenings in its pre–test battery.

Relatedly, a correlational individual differences approach is also not without limitations. Determining the effects of WM and Processing Speed on older adults' syntactic priming and attachment preferences, which was one of the aims of this project, supposes that all other participant characteristics are kept constant in either age group, which is an unrealistic and impossible aim when obtaining data from real human groups. Furthermore, when studying a complex and multi–faceted phenomenon like aging, the course of which is affected by a multitude of biological, environmental, and cognitive factors, it is important to acknowledge that correlational approaches like the ones taken in the studies presented here are inherently limited in scope. The relationships between WM, PS, and sentence processing may be modulated by a variety of factors not further measured in the presented studies. Nevertheless, this does not imply that studying individual differences in cognitive function and relating those to sentence processing is a vain effort: indeed, correlational approaches have the potential for uncovering relationships and interactions between variables that could be of great theoretical importance, and the studies presented here made important contributions to theory by including measures of WM and PS in its analyses (for a discussion of correlational approaches, see Seeram, 2019).

A further recommendation generated by this project concerns treatment of null results. When examining cross-sectional age differences in sentence processing, null effects are often used to inform theoretical accounts. However, interpreting statistically 'insignificant' results as evidence for the absence of an effect is fundamentally problematic (Aberson, 2002; Sainani, 2013). To ensure that the absence of group effects reported in all four Studies was reliable, this project reports additional Bayesian analyses to confirm null effects of group. This practice is slowly gaining traction across psychological and linguistic science (for example, see Husain et al., 2014; Frank et al., 2016; Hardy et al., 2017; Chaminade et al., 2018; and for practical guides, see Hoijtink et al., 2019; Heck et al., 2022), and the value of these analyses is further underscored in the current project. While traditional, frequentist statistics indeed create problems with the interpretation of null results, Bayesian likelihood estimation (in the current case, through Bayes Factors) does not formally distinguish between 'significant' and 'insignificant' results, but rather estimates the likelihood of a given data distribution to be 'true' (see further Nicenboim and Vasishth, 2016). In the case of group differences especially, this is a critical improvement over frequentist models. The four Studies reported here therefore make the case for a wider application of Bayesian methodology in the field to improve the reliability of reported null effects. Appendix I further includes the full code used for the analysis in each Study, including for Bayesian methods, in an effort to promote the practising of *both* frequentist and Bayesian statistics in the discipline of sentence processing.

7 Conclusions

This project set out to investigate age-related sentence processing declines, and whether these are affected by the type of measure used, or by Working Memory or Processing Speed capacity. Three experiments and four studies discovered an absence of such age-related sentence processing deficits. Older and younger adults showed robust syntactic comprehension priming effects in Studies 1 and 3, and both age groups showed the same consistent relative clause disambiguation preferences in Study 2. Furthermore, Study 2 also demonstrated age-invariance in susceptibility to similarity-based memory interference during sentence processing. These findings challenge traditional and contemporary research that proposes sentence processing is subject to declines in older age, and suggests past research has conflated explicit memory demands (which are generally impaired in older age) with sentence processing.

The effects of Working Memory and Processing Speed capacity were minor across Studies and experiments, suggesting the impact of memory and speed declines on sentence processing is limited. Analyses of Working Memory and declarative aspects of the reported studies nevertheless revealed significant relationships, again illustrating the distinction between explicit or declarative and implicit or non-declarative measures of processing. However, effects of Working Memory *interference* in Study 2 resulted in shifting relative clause disambiguation strategies: under interfering memory load, both older and younger adults attached clauses to the referent which was dispreferred under non-interfering loads, evidencing a highly important mutual interaction between the Working Memory and sentence processing systems.

Studies 1 and 3 demonstrated that older adults show syntactic priming facilitation in sentence comprehension. Taken together with Study 4, these results make highly important contributions to syntactic priming theory. These findings contradict priming accounts based on residual activation of either syntactic or lexical information (thereby including dual-mechanism models), in favour of theories that suppose a purely implicit cause for syntactic priming. Measures of Working Memory and Processing Speed were almost universally independent from priming manipulations, further suggesting that these cognitive functions are not directly related to syntactic priming in comprehension. Additionally, Study 4 reported a novel finding of the persistence of the lexical boost across four intervening fillers, where previous research has suggested the boost decays much more rapidly. Different mechanisms may therefore underpin syntactic priming in comprehension as opposed to production.

Following from the current findings, this project suggests multiple avenues and makes several recommendations for future research. First, linguistic research in older adults must evaluate the explicit and implicit memory demands of commonly used paradigms such as paragraph comprehension and psychometric tests. As emphasised in all Studies, age-related cognitive declines are far greater on explicit, declarative measures, which past studies of sentence comprehension have conflated with sentence processing itself. Second, the consideration of measures grounded in both production and comprehension when formulating (psycho-)linguistic theory is underlined by the syntactic priming results from Studies 1 and 3. Potential avenues for future inquiry include the expansion of syntactic priming paradigms in comprehension across more fillers than reported in Study 4 to investigate when syntactic priming effects truly begin to fade. Additionally, the locus and timeframe of Event-Related Potential effects of syntactic priming in comprehension remains poorly understood despite the findings in Study 3, and future investigations could make an important contribution to the field by narrowing this down further.

This project began by quoting activist and author Betty Friedan, who called older age "a new stage of opportunity and strength." While past research on older adults' sentence processing has largely disagreed with this notion, finding age deficits on many sentence comprehension measures, the Studies presented here make a consistent and united case against this notion of age-related sentence processing declines. Together, they make an important contribution to our understanding of aging as a non-unitary phenomenon: not all cognitive faculties decline with age, and sentence processing (in the absence of declarative memory demands) is one of those faculties.

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Appendix A: Reading Span Sentences

Sentences used in the Reading Span pre-test are given below (appropriateness is marked with either an "A" for "Appropriate" or an "N" for "not appropriate"). This list includes practice sentences.

Yesterday I climbed a mountain.	A	The headphones were too red.	N
The rocks in the park waved in the gale force winds.	N	Dusty library books were the man's house.	N
The small rabbit fled into his hole.	A	Opening the windows during the snowstorm was a mistake.	A
Filter coffee is the superior drink.	A	The squeaky chair was the woman's job.	N
Birds suffered in the financial crash	N	Consumer confidence was at a restaurant.	N
Climate change was a huge tower block.	N	Wolves are returning to the European mainland.	A
Indian food can be very spicy.	A	Robots are taking over many job.	A
The protests do not lead to any coffee.	N	Social media has both pros and cons.	N
The worker was injured in an accident.	A	Some butterflies migrate south.	N
Excalibur was a very famous button.	N	The soldier lost a leg.	A
The doctor was overworked and fell asleep quickly.	A	Clouds gathered and bottles started falling.	N
Many plants found outside are plastic.	N	The umbrella broke in the bad weather.	A
Window cleaning is a dangerous job.	A	Books are a great way to throw.	N
I had an ice cream for notebooks.	N	Berries are a great source of leaves.	N
We have a lot of rain in summer.	A	The stranger officiated the meal.	A
His goal was to improve on yesterday.	A	The blanket reflected the sunlight.	N
My shoes tie up in a bow.	N	She had the big room all to herself.	A
The man is holding a car.	N		

Appendix B: Study 1 (Materials)

Sentences used in Experiment 1 are given below. This list includes practice sentences, and is ordered by trial set and condition.

Prime	*First Filler*	*Second Filler*	*Target*	*Condition*
The soldier was issued a special travel pass.				Practice
The explorer confronted by the lawyer denied everything.				Practice
The chef boiled potatoes for five hours.				Practice
The general marched his army northwards.				Practice
The speaker selected by the group would work perfectly for the programme.	The janitor considered the rice to have magical properties.	The reader was enthralled by the book for weeks.	The architect selected by the manager was educated at Oxford.	(1)
The director observed by the constable was in a very bad part of town.	The Turkish merchant living in Ankara was very poor.	The mother lovingly sent a postcard to her daughter abroad.	The mouse observed by the cat was hiding under the table.	(1)
The assistant graded by the professor was very interesting.	The island inhabitants believed prayer appeased the nature gods.	The care package arrived at the hotel just in time.	The leader graded by the participants was well liked.	(1)

The thief identified by the victim was held for questioning.	The boy inspected the sky with his telescope.	The lunch lady served mash and peas to the children.	The victim identified by the doctor was in bad shape.	(1)
The postman expected by the secretary arrived too late.	The British patriot admired her picture of Winston Churchill.	The lawmaker was highly critical of the board's plans.	The deliveryman expected by the woman was right on time.	(1)
The troops assaulted by the rebels suffered heavy losses.	The architect described the house he had built as luxurious.	The salesman convinced the shoppers of his product's worth.	The army assaulted by teh terrorists moved forward quickly.	(1)
The prisoner transported by the gurds was closely watched.	The children feared the thunder that passed over their house.	The parliamentarian genuinely disbelieved the witness testimony.	The hostage transported by the captors was very worried.	(1)
The client wanted by the advertiser was worth a lot of money.	The public admired the statue of the war hero for years.	The planter had a backache after working all day.	The actress wanted by the director was hesitant to confirm.	(1)
The teacher loved by the class was very easy to understand.	The minister was saddened by the nation's raging poverty.	The unknown composer considered his third symphony a masterpiece.	The singer loved by the fan was unable to make it to the concert.	(1)
The driver stopped by the policeman had been drinking.	The circus performance with the clowns perplexed the spectators.	The dictator imprisoned the critical journalist for life.	The child stopped by the lifeguard looked very upset.	(1)
The protesters angered by the policeman shouted obscenities.	The class pondered the mathematical problem for hours without result.	The scientist was mesmerised by the revealing discovery.	The conservative angered by the liberal plotted revenge.	(1)

The voter convinced by the mayor was very pleased.	The rowdy students were removed from the exam room.	The drug trafficker was arrested by the border guard.	The consumer convinced by the salesman was pleasantly surprised.	(1)
The rebels battled by the security forces fled into the jungle.	The actress secretly envied the singer's pure voice.	The representative verbally attacked his colleague in the debate.	The insurgent battled by the regiment was unable to triumph.	(1)
The actor copied by the understudy performed brilliantly.	The famous author resented the editor's critical remarks.	The immigrant was cruelly treated by the population.	The genuis copied by the children was running late.	(1)
The soldiers encircled by the enemies were very worried.	The community tolerated the diversity of its inhabitants.	The Turks constantly besieged the Hapsburgs throughout the sixteenth century.	The lions encircled by the hunters paced nervously.	(1)
The dog discovered by the hunter had a broken leg.	The commentator was disgusted by the opponent's remarks.	The careful gardener repotted the frail basil plant.	The bird discovered by the scientist acted calm and unbothered.	(1)
The child scolded by the babysitter went up the stairs.	Theteacher led the students outside during the fire drill.	The persistent rain cased the guard to shiver.	The man scolded by the policeman was very embarrassed.	(1)
The spy captured by the MI5 agent disappeared forever.	The gardener talked to his carrots when nobody listened.	The pilot could not control the plane during the crash.	The criminal captured by the detective was in a state of panic.	(1)
The countess offended by the peasant swore revenge.	The company was forced to fire many loyal employees.	The driver lost control over her vehicle and hit the wall.	The tutor offended by the delinquent stormed out of the room.	(1)

The motorist injured by the lorry driver had to go to the hospital.	The hostess truly illuminated the room with her presence.	The tourist was robbed of his camera by the thief.	The child injured by the dog breathed heavily.	(1)
The trapper hunted by the cougar escaped in the end.	The hunter finished off the deer that had eluded him.	The beggar repeatedly hassled the politician on live television.	The own hunted by the eagle circled frantically.	(1)
The homeowner frightened by the burglar ran outside.	The swimmer said thanks to the lifeguard that saved her.	The critical historian judged the seventeenth century harshly.	The horse frightened by the boy hurried away.	(1)
The passengers delayed by the pilot were furious.	The king banned all poets in his kingdom for ten years.	The melancholic poet wrote about his love life in his diary.	The woman delayed by the taxi driver started to shout.	(1)
The students helped by the counselors were very grateful.	The policeman chased the criminal into the residential estate.	The writer was criticsed by many journalists after publishing.	The surgeons helped by the nurses were exhausted.	(1)
The miners rescued by the paramedics recovered slowly.	The art thief stole the painting from the famous museum.	The old locomotive enthused the trainspotter immensely.	The man rescued by the sailor was soaking wet.	(1)
The deer killed by the lorry caused a large accident.	The cleaner mopped the floor with the wrong bleach.	The travel agent arranged a cheap flight for the customer.	The turkey killed by the farmer would be eaten at Christmas.	(1)
The MP advised by the general spoke to the press.	The playful mother tickled the child for ten minutes straight.	The council staffer delivered food parcels to her neighbours.	The girl advised by the parent stayed home that night.	(1)
The teenager ignored by the service assistant was very frustrated.	The 1970s film bored the audience for three hours.	The farmer was scorched by the hot weather on the fields.	The hobo ignored by the train guard snuck aboard.	(1)

The carpenter questioned by the inspector wanted to go home.	The writer of the famous book had blonde hair.	The tax collector extorted the peasant for some pennies.	The butler questioned by the widow remained calm.	(1)
The woman hated by the deliveryman was always rude.	The valley with the beautiful views enthused the tourists.	The soldier was struck down by a lance to the head.	The doctor hated by the patients had terrible manners.	(1)
The girl fascinated by the monkey gave him her ice cream	The bad drugs hurt everyone that used them.	The musketeer shot his opponent in the leg.	The racehorse inspected by the doctor was able to race the next day.	(2)
The child captivated by his friend got very excited.	The lawyer was bothered by her opponent's strategies.	The trainer archer loosed his arrow with perfect technique.	The cat checked by the judge won a prestigious award.	(2)
The army trapped by the revolutionaries sued for peace.	The bishop preached positive thoughts to the congregation.	The statesman proposed new laws that everyone liked.	The child thrilled by the movie smiled broadly.	(2)
The lion mauled by the bear was removed from the circus.	The factory manager awarded all his employees a pay rise.	The leader modernised the country with great effect.	The girl excited by the actor on television completely forgot herself.	(2)
The lion attacked by the bear was sore for weeks.	The miner was struck down by a falling rock.	The well-known swimmer failed to cross the Channel last year.	The juror accused by the judge was not allowed back in court.	(2)
The king pleased by the gift was in good spirits.	The conductor thanked the orchestra after the performance.	The postman was burdened by the amount of letters he carried.	The photographer mangled by the tiger let out a loud cry.	(2)

The baby delighted by the toy finally stopped crying.	The hikers were scared by the fangs of the animal.	The rock band enticed the audience with a stellar performance.	The employee blamed by the supervisor was asked not to come back.	(2)
The prates ambushed by the prisoners lost all of their gold.	The famous chef was admired by all restaurant patrons.	The concert was called off after heavy rain was forecast.	The turtle buried by the landslide dug furiously.	(2)
The woman amazed by the product bought five boxes.	The verbose student talked to his colleague at length.	The crying toddler raced towards his mother and father.	The child astounded by the spaceship launch started reading science fiction books.	(2)
The girl yanked by her father wanted to stay at the zoo longer.	The activist heavily critiqued the government's actions.	The beer enthusiast swiftly poured himself another glass.	The man hoisted by the elephant was not very confident.	(2)
The dog startled by the intruder let out a deafening howl.	The newsreader was given the wrong lines at 6PM.	The illustrator produced well over twenty pictures per week.	The monkey lifted by the trainer was hoping for a treat.	(2)
The goalkeeper shoved by the referee became very upset.	The supplier gave the firm the wrong product by mistake.	The vocalist was in tears after losing her voice yesterday.	The man shunned by the woman left the pub and went straight home.	(2)
The lady grabbed by the man narrowly missed getting hit by a car.	The recycling plant interested the visitors last Monday.	The autocrat dealt with his opponents ruthlessly.	The student rejected by the classmate learned to hate school.	(2)
The mouse seized by the eagle was frozen with fright.	The granny supported her son through the painful divorce.	The archaeologist discovered a stunning Celtic treasure hoard.	The actor replaced by the director thought his career was over.	(2)
The lawyer pulled by the boy made a stern face.	The chemistry teacher secretly sold drugs to his students.	The stay-at-home dad was encouraged to learn a new hobby.	The policeman interrogated by the commission swore he was innocent.	(2)

The man kidnapped by the spy refused to tell him what he knew.	The judge sentenced the suspect to six months in prison.	The yoga teacher kissed one of her students.	The child cheered by the teacher spelled the word incorrectly.	(2)/(3a)
The player grilled by the policeman swore he was innocent.	The baeker photographed the doctor who strived to sue him.	The commentator was invited by the magazine's latest edition.	The player praised by the talent scout was soon offered a scholarship.	(2)/(3a)
The child teased by the bully was not at school the next day.	The stray dog followed the frightened man for two hours.	The footballer constantly bullied his much younger brother.	The manager ransacked by the protesters called the police immediately.	(2)/(3a)
The mother kissed by the toddler gave him a hug in return.	The lawyer leaked the critical information to the media.	The umpire heavily critiqued the tennis player after the match.	The girl tormented by the boy promised never to talk to him again.	(2)/(3a)
The woman abducted by the stalker managed to escape.	The politician lost her cool and slapped the journalist.	The referee was degraded swiftly after deducting two points.	The girl smooched by the celebrity got so excited that she fainted.	(2)/(3a)
The professor honoured by the dean received a large office.	The store assistant encouraged the customer to come back immediately.	The train driver remembered the legacy of his old locomotive.	The accountant hired by the law firm was arrested for drug possession.	(2)/(3a)
The secretary revered by the company got an extra day off.	The cook never trusted the lawyer that he had hired.	The train guard disliked the police and their actions.	The girl drenched by the clown never went to another circus.	(2)/(3a)
The swimmer fatigued by the coach had to quit early.	The young student was saddened by a lack of friends.	The constable clearly tired himself with excessive exercise.	The man tricked by the magician did not want to receive another prize.	(2)/(3a)

The doctor cured by the specialist went back to work.	The butcher felt the coldness of the fresh meat.	The able sociologist conducted a study in his back garden.	The policeman fooled by the disguise let the man go free.	(2)/(3a)
The supplier conned by the manufacturer refused to carry their product.	The mapmaker told the students of the island's existence.	The political scientist convinced ten people to believe falsehoods.	The principal fired by the school board had been missing work.	(2)/(3a)
The landlord cheated by the couple was not paid any rent.	The professor claimed the research was completely false.	The famous artist achieved her most desirable goal.	The waitress preferred by the customer got a large tip.	(2)/(3a)
The baker hired by the market made eight different kinds of bread.	The secretary was up in arms over her pay reduction.	The prolific banker hired advisors to prepare for the crash.	The solicitor favoured by the judge was always on time.	(2)/(3a)
The manager employed by the owner had to work seven nights per week.	The barista served the customer an awful espresso.	The library assistant employed the help of her superior.	The girl washed by the mother was covered in spaghetti.	(2)/(3a)
The man coahced by the gym owner lost two stone.	The child was forgotten by her mother at the garden centre.	The estates manager coached her trainee very well.	The man burned by the flames covered his face and ran.	(2)/(3a)
The student instructed by her mother got straight As.	The builder had not bought enough concrete for his work.	Thebin collector instructed the restident to separate her waste.	The singer missed by the conductor left was at the theatre.	(2)/(3a)
The queen angrily pushed the countess from her balcony.	The landscaper hired cheap labour from Poland last spring.	The art critic pushed the painting off the stool.	The doctor cleaned by the nurse was prepping for surgery.	(3b)

The king unexpectedly surprised the slave with some kind words.	The producer faked multiple scenes in his new documentary.	The young student surprised the lecturer with her knowledge.	The chid skipped by teh teacher did not receive a biscuit.	(3b)
The serf briefly enjoyed the spring sun until his master shouted.	The TV host was unamused by the practical joke.	The factory owner enjoyed counting coins when the workman laboured.	The stylist spoiled by the magazine decided not to take a job there.	(3b)
The cashier reluctantly gave the footballer fifty pence in change.	The wizard presented the gullible students with a cheap magic trick.	The estate agent gave the keys away.	The applicant assessed by the supervisor was not right for the job.	(3b)
The man quickly went to McDonalds and gave the cashier a cheque.	The manager held a great speech for all her staff.	The fastidious steward went down to the lower decks.	The woman compensated by the bank began to rebuild her home.	(3b)
The reporter immediately investigated the scene of a shot businessman.	The cyclist was injured by the antisocial driver.	The suspicious contractor investigated the collapsing foundation.	The superhero crushed by the train got back up to chase the villain.	(3b)
The knight swiftly charge forth at the warrior.	The pedestrian shouted at the cyclist for cutting him off.	The armed knight charged forth on his steady steed.	The chef punished by the manager had to work three extra shifts.	(3b)
The guitarist accidentally hit the drummer during his stunt.	The resident was annoyed by the influx of tourists into town.	The careless solicitor hit the assistant with his arm.	The captain worried by the storm stayed awake all night long.	(3b)
The burglar warmly hugged the mayor after he was forgiven.	The linguist criticsed her colleague's poor use of grammar.	The elated astronomer hugged his colleague after the discovery.	The chemist contaminated by the toxins spent two weeks in hospital.	(3b)

The general sternly warned the politician about the enemy.	The scientist demanded to see the politician's evidence.	The grave economist warned about a recession once again.	The girl embraced by the grandparents felt nice and warm.	(3b)
The baker desperately begged the salesman for more flour.	The manufacturer started producing face masks last spring.	The ship's mate begged the captain for more food.	The player eamined bt the doctor was allowed to finish the game.	(3b)
The policeman verbally reprimanded the skating child.	The demonstrator threw a milkshake at the popular journalist.	The wizard angrily reprimanded his student for messing up.	The woman registered by the attendant left to find her classroom.	(3b)
The samurai extensively honoured the master in a traditional dance.	The friend wrote a letter expressing her thanks.	The car owner honoured his Audi with a personalised licence plate.	The baby soothed by the warm bath went straight to sleep.	(3b)
The customer loudly yelled at the waiter for spilling some wine.	The doctor presented the man with twenty different pills.	The county councillor yelled at her colleague after the discovery.	The defendant analysed by the psychologist was found to be mentally stable.	(3b)
The fisherman greatly disappointed the coast guard by fishing illegally.	The caretaker was horrified by the state of the toilets.	The beautiful cup disappointed everyone at the auction yesterday.	The woman hassled by the beggar did not have any cash.	(3b)
The snide secretary intimidated her boss into giving her a raise.	The statistician attacked different software packages for hours.	The painter sneakily intimidated the sculptor for five years.	The boy enlisted by the parents did not want to start school.	(3b)
The train driver forced the train to brake.	The calligrapher drew a beautiful capital letter this morning.	The tennis player forced the cancellation of the match.	The cook criticised by the customer used too much salt.	(3b)

The disgraceful footballer beat up the referee after he missed a foul.	The priest took care of the woman after her eviction.	The mafia member beat up the rival in an alleyway.	The student despised by the housemate never cleaned up.	(3b)
The order police shot the demonstrator with a rubber bullet.	The stroke patient gradually regained the ability to speak.	The greengrocer scarily shot the burglar in the leg.	The lady calmed by the rain smiled to herself.	(3b)
The proud sheriff presented the king with two captured criminals.	The young man was left jobless after his redundancy.	The CEO proudly presented the quarterly figures with glee.	The rats tainted by the rabid dog had to be destroyed.	(3b)
The popular designer showed her work to a large audience.	The passenger tutted at the crying child for ten minutes.	The genius simply showed the layperson the complex technique.	The parents worried by the teenager decided to talk to him.	(3b)
The successful violinist was commended by the conductor last performance.	The commuter was rain-soaked after his train delay.	The positive analyst commended the nation's progress in a recent report.	The auctioneer surprised by the antique raised the bid.	(3b)
The stressed vet attempted to save the dog but to no avail.	The visitors were impressed by the museum pieces.	The hasty employee attempted to cut corners and make more money.	The minister interrupted by the MP got very cross.	(3b)
The failing lancer failed to spot the enemy until it was too late.	The diligent student wrote down everything carefully.	The bad newspaper failed to enthuse its readership.	The athlete shoved by the player started a fight.	(3b)
The amazing singer received a standing ovation from the audience.	The secret agent was directed by the hotel employee.	The friendly emissary was received by the delegate with dignity.	The painter scared by the mouse fell from his ladder.	(3b)

The famous architect honoured the statesman with a grand tomb.	The warrior took the opponent prisoner after the battle.	The Prime Minister honoured the successful athlete last week.	The cook reprimanded by the head chef never cooked again.	(3b)
The sneaky woman secretly plotted against her own sister.	The frustrated man kicked the cat that blocked the path.	The clever criminals plotted a large jewellery heist worth thousands.	The cleaner abandoned by the salesman felt free like never before.	(3b)
The unfailing hero ensured everyone was safe.	The knight lied to the king and was promptly executed.	The great teacher ensured no student was left behind.	The film showed by the salesman was full of evident lies.	(3b)
The popular inventor killed his assistant in an unfortunate accident.	The arrogantdriver caused many accidents this year.	The annoyed worker killed all flies in his room.	The dealer apprehended by the policeman denied any wrongdoing.	(3b)
The scandalous hooligan destroyed the sculptor's valuable artwork.	The undercover agent filmed ten crimes today.	The tank commander destroyed an enemy vehicle.	The husband divorced by the wife became a raging alcoholic.	(3b)

Appendix C: Study 1 (Participant Biodata)

PPT ID	*Age*	*Age Group*	*Gender*	*Years in Education*	*Education Level*	*Country of birth*	*WM Span*	*LCT Score*
1434	67	Old	Male	20	7	UK	15	6
1555	65	Old	Male	12	3	UK	10.5	17
2115	71	Old	Male	12	3	UK	31	24
2316	77	Old	Female	11	3	UK	25.5	15
2344	67	Old	Female	19	5	UK	22	18
3014	65	Old	Female	12	3	UK	20.5	22
3662	66	Old	Female	13	3	UK	26	18
3881	73	Old	Male	14	3	UK	24	15
4212	71	Old	Male	17	6	UK	21	15
4343	65	Old	Male	18	6	UK	29.5	21
4707	70	Old	Female	12	3	UK	24	14
5695	67	Old	Male	20	3	UK	1	11
6040	69	Old	Male	17	6	UK	22.5	18
6416	69	Old	Male	20	7	UK	30	11
6771	65	Old	Male	10	5	India	11.5	14
7286	69	Old	Male	14	3	UK	22.5	17
7379	65	Old	Female	12	2	UK	24	14
7413	77	Old	Male	13	4	UK	16	18
7601	75	Old	Female	12	2	UK	23	20
7673	66	Old	Female	20	7	UK	24	26
7922	66	Old	Female	18	7	UK	30	24
8155	65	Old	Female	19	7	UK	30.5	23

8238	76	Old	Male	16	7	UK	22.5	13
8761	70	Old	Male	14	5	UK	23	16
8900	68	Old	Male	12	4	UK	20.5	20
9042	66	Old	Female	18	4	UK	12	8
9093	66	Old	Female	11	3	UK	31	9
9215	69	Old	Female	18	6	UK	17	23
9216	68	Old	Male	11	3	UK	22	7
9224	69	Old	Male	16	4	UK	27.5	14
1161	24	Young	Female	13	4	UK	25	32
1198	25	Young	Female	17	6	UK	21	26
1278	21	Young	Male	14	1	Hungary	13	27
1306	22	Young	Female	15	6	UK	32	29
1501	23	Young	Female	15	4	US	22	33
2414	23	Young	Male	17	7	UK	32	29
2534	25	Young	Female	17	7	UK	24.5	31
2731	21	Young	Female	16	5	Italy	27	29
3505	21	Young	Male	16	3	Italy	23	29
3532	24	Young	Male	19	7	UK	23	21
4708	23	Young	Female	10	4	UK	30	36
4851	20	Young	Male	15	3	UK	15	21
4923	22	Young	Female	16	6	UK	27	33
5145	25	Young	Male	17	6	UK	22	31
5376	20	Young	Female	20	6	South Africa	22.5	14
5487	25	Young	Female	20	7	UK	21.5	34
5614	19	Young	Female	14	3	Poland	27.5	23
5631	22	Young	Female	12	6	UK	26.5	30

6159	21	Young	Male	18	6	Portugal	16.5	24
6610	18	Young	Female	14	3	US	19	30
6728	19	Young	Male	13	3	Poland	16.5	23
6800	21	Young	Male	14	3	Italy	20.5	17
7258	18	Young	Female	12	2	Hungary	31	29
7353	25	Young	Female	16	6	UK	22	25
7701	18	Young	Female	15	3	UK	28	27
7894	21	Young	Male	15	6	UK	11	16
7950	18	Young	Male	16	4	UK	12.5	28
9427	19	Young	Male	18	3	Poland	27	17
9529	19	Young	Female	12	3	N/A	19	27
9647	25	Young	Female	15	5	Ireland	31	27

Appendix D: Study 2 (Materials)

Load 1	*Load 2*	*Load 3*	*Sentence*	*Bias*	*SBI Condition*
vehicle	chauffeur	motor	The driver of the car that had the moustache was pretty cool.	NP-1	Interf.
book	writer	letter	The chapter of the author that had the preface is causing a stir.	NP-1	Interf.
author	pen	script	The writer of the letter that had the round spectacles arrived.	NP-1	Interf.
decoration	building	home	The house of the painter that had the small windows was large.	NP-1	Interf.
priest	mass	preach	The bishop of the church that had the funny eyebrows made us cry.	NP-1	Interf.
friar	prelate	shrine	The church of the bishop that had the large spires faced a lake.	NP-1	Interf.
foliage	deer	tree	The animals of the forest that had the big fangs frightened us.	NP-1	Interf.
glen	tulip	grass	The valley of the flowers that had the old castle excited a girl.	NP-1	Interf.
troll	hill	realm	The king of the mountains that had the sideburns impressed Arthur.	NP-1	Interf.
horse	cowboy	field	The plains of the tribe that had the rich topsoil looked strange.	NP-1	Interf.
produce	foreman	worker	The manager of the factory that had the loud voice was efficient.	NP-1	Interf.
voter	church	representative	The councillor of the parish that faced losing the election campaigned for more votes.	NP-1	Interf.
writing	redactor	revision	The thesis of the editors that had the misspellings was rubbish.	NP-1	Interf.
lawyer	association	dress	The solicitor of the company that had the new tuxedo bothered me.	NP-1	Interf.
crime	amount	stock	The supplier of the drugs that had the grimace killed a kid.	NP-1	Interf.
quilt	knight	skirt	The tartan of the clan that had the stripes lay in the castle.	NP-1	Interf.
value	metal	pit	The gold of the miner that had the impurities isn't worth much.	NP-1	Interf.
chef	firm	supervisor	The boss of the factory that was reading a book received a phone call.	NP-1	Interf.
artist	performance	lyrics	The singer of the song that had long eyelashes is pretty stupid.	NP-1	Interf.
food	client	dinner	The restaurant of the patron that had the blue tiles pleased us.	NP-1	Interf.
science	creator	tool	The inventor of the machine that had the goatee is amazing.	NP-1	Interf.
agent	snoop	country	The spy of the nation that had the pistol was very intimidating.	NP-1	Interf.

king	state	land	The ruler of the country that had two wives punished the convict.	NP-1	Interf.
sport	ball	nation	The goalkeeper of the nation that shoved the referee feigned innocence.	NP-1	Interf.
market	shine	dealer	The merchant of the gold that raised prices was disliked by many.	NP-1	Interf.
thief	art	museum	The robber of the painting that had four fingers got away with everything.	NP-1	Interf.
navy	admiral	ship	The commander of the fleet that had a big hat was very stern.	NP-1	Interf.
university	subject	learning	The student of the topic that drank too much failed all classes.	NP-1	Interf.
guard	ticket	railway	The conductor of the train that had an angry face was not well liked.	NP-1	Interf.
flight	steward	pilot	The hostess of the plane that wore a grey suit directed the crew.	NP-1	Interf.
instance	leader	friendship	The inhabitant of the island that prayed for salvation was not heard.	NP-1	Non-interf.
hormone	awareness	safety	The monarch of the realm that was interested in magic was deposed.	NP-1	Non-interf.
town	track	series	The teacher of the school that said the wrong lines was fired.	NP-1	Non-interf.
village	language	office	The chef of the restaurant that mixed the right ingredients was praised.	NP-1	Non-interf.
helmet	situation	meal	The audience of the film that was bored left the room.	NP-1	Non-interf.
solution	loss	operation	The chef of the restaurant that was working very late was noticed.	NP-1	Non-interf.
musket	event	arrival	The doctor of the hospital that was preparing to go home was trusted.	NP-1	Non-interf.
measurement	volume	love	The reporter of the newspaper that was moving to a new office spoke to someone.	NP-1	Non-interf.
bathroom	populace	cigarette	The princess of the castle that was loved by everyone was rescued.	NP-1	Non-interf.
lake	independence	soup	The headmaster of the college that smiled at the pupils was eating chocolates.	NP-1	Non-interf.
way	phone	equipment	The inspector of the bureau that watched the policemen witnessed the crime.	NP-1	Non-interf.
revolution	perception	oven	The researcher of the problem that was sweating profusely nearly found the solution.	NP-1	Non-interf.
temperature	education	health	The journalist of the channel that had hated the soldiers was sitting down.	NP-1	Non-interf.
marriage	tabloid	analyst	The bicycle of the student that had small wheels was still very fast.	NP-1	Non-interf.

device	bet	teaching	The artist of the painting that smiled constantly talked to a model.	NP-1	Non-interf.
draw	poetry	employee	The photographer of the newspaper that was always friendly died yesterday.	NP-1	Non-interf.
story	information	week	The singers of the concert that had noticed the books were reading music.	NP-1	Non-interf.
preparation	chapter	memory	The coach of the club that had raged in anger noticed the crowd.	NP-1	Non-interf.
profession	payment	membership	The hairdresser of the neighbourhood that was wearing a green dress fainted.	NP-1	Non-interf.
birthday	reality	weakness	The instructor of the school that was looking very serious was congratulated.	NP-1	Non-interf.
singer	actor	perspective	The nurse of the ward that was feeling very tired recognised a colleague.	NP-1	Non-interf.
possibility	fortune	trainer	The cameraman of the movie that was preparing the next scene walked to work.	NP-1	Non-interf.
register	committee	success	The driver of the lorry that was talking was favoured by the boss.	NP-1	Non-interf.
presentation	pigeon	salad	The sailor of the yacht that was very unhappy started to riot.	NP-1	Non-interf.
piano	professor	friend	The recruiter of the army that was completely ignored became frustrated.	NP-1	Non-interf.
psychology	republic	death	The lawyers of the offices that were very helpful registered new cases.	NP-1	Non-interf.
classroom	fact	photo	The cleaner of the property that noticed the grime was disgusted.	NP-1	Non-interf.
variation	injury	person	The schoolboy of the college that congratulated his peers was well liked.	NP-1	Non-interf.
physics	punter	menu	The critic of the painting that spoke harsh words was feared by all.	NP-1	Non-interf.
rider	midnight	moment	The architect of the building that had innovative ideas was received well.	NP-1	Non-interf.
player	season	play	The actress of the show that had bad writing was deeply disappointed	NP-2	Interf.
house	area	hall	The neighbour of the mansion that had the big porch was filled with jealousy.	NP-2	Interf.
teller	money	bills	The banker of the branch that was trashed last week was still afraid.	NP-2	Interf.

blaze	water	speed	The fireman of the engine that was recently repainted had pride on his face.	NP-2	Interf.
supper	staff	runner	The waitress of the restaurant that redesigned its menu was still unsure.	NP-2	Interf.
needle	thread	fabric	The seamstress of the clothing that turned out beautifully was handsomely rewarded.	NP-2	Interf.
college	uniform	grade	The schoolgirl of the academy that was redecorated last term performed well.	NP-2	Interf.
print	edition	copier	The editor of the newspaper that sold a thousand copies tried to raise sales.	NP-2	Interf.
choir	fresco	gown	The nun of the convent that had beautiful wall paintings did guided tours.	NP-2	Interf.
cloth	suit	street	The tailor of the town that had a cosy high street worked very hard.	NP-2	Interf.
medicine	doctor	hospital	The surgeon of the clinic that was recently rebuilt saw twenty people today.	NP-2	Interf.
cleaner	mansion	butler	The maid of the mansion that was built in the 18th century felt lucky.	NP-2	Interf.
concert	conductor	cello	The violinist of the ensemble that consisted of three players received a thunderous applause.	NP-2	Interf.
joke	tent	acrobat	The clown of the circus that was built up in 3 hours was very popular.	NP-2	Interf.
peddler	vacuum	sweeper	The salesman of the hoovers that ran out of power bothered the whole neighbourhood.	NP-2	Interf.
battle	man	officer	The general of the army that lost half its soldiers was reprimanded strongly.	NP-2	Interf.
castle	woman	nobility	The heiress of the estate that included two castles was aching to inherit.	NP-2	Interf.
attendant	workman	business	The plumber of the company that faced bankruptcy worked twice as hard.	NP-2	Interf.
soil	plant	horticulture	The gardener of the flowers that basked in the sun admired the garden.	NP-2	Interf.
music	band	sound	The director of the orchestra that played well received an ovation.	NP-2	Interf.

military	wave	sea	The admiral of the fleet that sailed for two weeks was commended for bravery.	NP-2	Interf.
dramatist	passage	bard	The poet of the text that was printed far and wide became hugely popular.	NP-2	Interf.
clerk	enterprise	management	The secretary of the company that sold mortgages received a generous remuneration.	NP-2	Interf.
criminal	purse	shout	The thief of the handbag that contained no money was later let free.	NP-2	Interf.
assistant	assembly	discussion	The clerk of the council that passed two new laws resigned.	NP-2	Interf.
mortgage	property	residence	The owner of the house that needed desperate renovation appealed for help.	NP-2	Interf.
tutor	coach	club	The trainer of the team that had never won a match felt the pressure.	NP-2	Interf.
monarch	rule	control	The leader of the country that was a safe haven for refugees spoke proudly.	NP-2	Interf.
security	council	protection	The guard of the parliament that was years old took her job seriously.	NP-2	Interf.
chairman	principal	scholar	The dean of the university that enrolled ten thousand students had a huge workload.	NP-2	Interf.
topic	storage	foundation	The agent of the company that had grown by 20% was very proud.	NP-2	Non-interf.
director	relation	requirement	The burglar of the house that had the valuable artwork made off with millions.	NP-2	Non-interf.
cabinet	version	goal	The scientist of the lab that had twenty microscopes made an important discovery.	NP-2	Non-interf.
passion	basis	concept	The lecturer of the class that was attended by nobody was saddened by the apathy.	NP-2	Non-interf.
speech	rubbish	economics	The engineer of the train that had developed a defect spent hours working.	NP-2	Non-interf.
departure	organisation	day	The emperor of the realm that was the home of millions was completely lonely.	NP-2	Non-interf.
appointment	sword	chocolate	The slave of the landowner that ate delicacies all day was scorched.	NP-2	Non-interf.

oblique	income	baseball	The knight of the army that had invaded the rival country pretended to be heroic.	NP-2	Non-interf.
winner	complaint	buyer	The lifeguard of the beach that had a treacherous current was busy every day.	NP-2	Non-interf.
advice	girlfriend	armour	The butcher of the shop that lost all its customers felt desperate.	NP-2	Non-interf.
speaker	patience	presence	The cashier of the supermarket that had a wide selection of produce was bored.	NP-2	Non-interf.
aspect	stranger	trial	The sheriff of the town that had no tourists lived a quiet life.	NP-2	Non-interf.
luck	resource	diamond	The astronaut of the agency that employed thousands was sent into space.	NP-2	Non-interf.
bend	people	power	The foreman of the workforce that went on a collective strike was hugely enraged.	NP-2	Non-interf.
affair	city	sailor	The ballerina of the ballet that toured the world was secretly very unhappy.	NP-2	Non-interf.
balance	unit	setting	The pupil of the wizard that had a long grey beard tried her first spell.	NP-2	Non-interf.
funeral	landlord	reaction	The designer of the clock that fell to pieces never emotionally recovered.	NP-2	Non-interf.
audience	craft	linen	The teller of the bank that had 250 members worked hard every day.	NP-2	Non-interf.
fridge	plunger	primate	The fisherman of the village that was built ten years ago longed for company.	NP-2	Non-interf.
ram	recession	tomorrow	The chemist of the laboratory that stored lots of poisons locked the doors securely.	NP-2	Non-interf.
compass	duffel	father	The professor of the subject that everyone found difficult explained very slowly.	NP-2	Non-interf.
hole	night	price	The paramedic of the ambulance that ran out of fuel was stuck.	NP-2	Non-interf.
break	point	light	The murderer of the widow that had inherited a fortune never apologised.	NP-2	Non-interf.
bother	buck	cascade	The member of the gang that ruled the neighbourhood was a novice.	NP-2	Non-interf.
liberty	spectacle	tornado	The caretaker of the building that was never cleaned had a tough job.	NP-2	Non-interf.

trading	call	division	The countess of the land that had a bountiful harvest raised taxes.	NP-2	Non-interf.
granola	cover	knife	The carpenter of the closet that didn't fit through the door was paid well.	NP-2	Non-interf.
confidence	sneaker	squeeze	The sculptor of the statue that was placed in the square became famous overnight.	NP-2	Non-interf.
ascent	crew	rescue	The representative of the nation that threatened to close its borders was criticised.	NP-2	Non-interf.
farm	mail	metro	The chairman of the board that advised on government policy resigned after the scandal.	NP-2	Non-interf.
caretaker	trousers	beans	The janitor wearing the blue overalls considered the rice to have magical properties.	Filler	Interf.
commerce	poverty	trader	The Turkish merchant living in Ankara was very poor and had nothing to eat.	Filler	Interf.
religion	native	archipelago	The island inhabitants believed prayer appeased the nature gods.	Filler	Interf.
stars	heaven	glass	The boy inspected the sky with the telescope he got as a gift.	Filler	Interf.
nationalist	loyalty	war	The British patriot lovingly admired her picture of Winston Churchill all day.	Filler	Interf.
design	jeans	boast	The architect wearing grey trousers described the house he had built as luxurious.	Filler	Interf.
boy	weather	fright	The children feared the raging thunder that passed over their house last night.	Filler	Interf.
monument	reverence	conflict	The public admired the statue of the war hero in the capital's square for years.	Filler	Interf.
secretary	shame	government	The minister for food was immensely saddened by the nation's raging poverty.	Filler	Interf.
festival	amusement	fool	The silly circus performance with the funny clowns perplexed the spectators.	Filler	Interf.

student	issue	logic	The class pondered the mathematical problem for hours without any type of result.	Filler	Interf.
ruckus	noise	test	The rowdy students were detected and instantly removed from the exam room.	Filler	Interf.
film	bar	chords	The famous actress secretly envied the unknown singer's pure and clear voice.	Filler	Interf.
note	typist	comment	The famous author resented the editor's critical remarks and ignored them completely.	Filler	Interf.
immigrant	neighbourhood	ethnicity	The community keenly tolerated the diversity of its inhabitants and newcomers.	Filler	Interf.
reporter	debate	anger	The commentator was disgusted and offended by the vicious opponent's remarks.	Filler	Interf.
educator	procedure	school	The conscientious teacher led all the students outside during the fire drill.	Filler	Interf.
botanist	vegetable	problem	The gardener talked to his carrots when nobody listened, but they never answered.	Filler	Interf.
manager	shop	redundancy	The company involved in paper sales was forced to fire many loyal employees.	Filler	Interf.
hotel	radiance	hospitality	The hostess of the famous London hotel truly illuminated the room with her presence.	Filler	Interf.
woods	game	prey	The hunter finished off the deer that had eluded him for so many weeks.	Filler	Interf.
surfer	beach	observer	The swimmer who was caught by the current thanked the lifeguard that saved her.	Filler	Interf.
ruler	autocracy	sultan	The king banned all poets in his kingdom and other possessions for ten years.	Filler	Interf.
constable	hunt	race	The policeman chased the criminal into the industrial estate, where he managed to escape.	Filler	Interf.

artefact	illustration	gallery	The art thief stole the painting from the famous museum located in Paris.	Filler	Interf.
soap	wipe	tile	The cleaner mopped the floor with the wrong bleach and ruined some expensive bricks.	Filler	Interf.
parent	itch	daughter	The playful mother tickled the child for ten minutes straight until he was exhausted.	Filler	Interf.
cinema	picture	length	The 1970s film about a desperate love affair bored the audience for three hours.	Filler	Interf.
pixie	record	barber	The writer of the famous book featuring elves and orcs had blonde hair.	Filler	Interf.
nature	creek	visitor	The valley with the beautiful views and abundance of sheep enthused the tourists.	Filler	Interf.
dope	consumer	hallucination	The bad drugs that caused terrible medical issues hurt everyone that used them.	Filler	Interf.
solicitor	competition	tactic	The lawyer was bothered by her opponent's strategies that lost her the case.	Filler	Interf.
hope	flock	gathering	The bishop preached positive thoughts and peaceful wishes to his congregation.	Filler	Interf.
mill	raise	zip	The factory manager who always wore a bow tie awarded all his employees a pay rise.	Filler	Interf.
coal	accident	danger	The miner was struck down by a falling rock in the unfortunate and deadly accident.	Filler	Interf.
maestro	depletion	violin	The exhausted yet happy conductor thanked the orchestra after the stellar performance.	Filler	Interf.
rocks	wildlife	adventure	The hikers were scared by the fangs of the animal that appeared suddenly.	Filler	Interf.
restaurant	cook	customer	The famous chef who cooked extremely well was admired by all restaurant patrons.	Filler	Interf.

argument	monologue	question	The verbose student talked to his colleagues at length about all sorts of topics.	Filler	Interf.
protest	criticism	dissident	The activist heavily critiqued the government's actions over the last few years.	Filler	Interf.
television	broadcast	mistake	The newsreader was given the wrong lines at 6PM and caused national embarrassment.	Filler	Interf.
delivery	stock	error	The supplier gave the firm the wrong product by mistake and paid compensation.	Filler	Interf.
tourist	factory	apparatus	The recycling plant with the newest machinery interested the visitors last Monday.	Filler	Interf.
family	separation	grandchild	The granny supported her son through the painful divorce with biscuits and tea.	Filler	Interf.
biology	instructor	narcotic	The chemistry teacher secretly sold drugs to his students and was never found out.	Filler	Interf.
law	lockup	court	The judge sentenced the suspect to six months in prison after the jury convicted her.	Filler	Interf.
bread	case	nurse	The baker photographed the doctor who sued him for baking poisonous bread.	Filler	Interf.
animal	chase	run	The stray dog followed the frightened man who was scared of animals for two miles.	Filler	Interf.
breach	tip	journalist	The lawyer leaked the critical information about the famous court case to the media.	Filler	Interf.
hand	scuffle	media	The politician lost her cool and slapped the journalist, who did not fight back.	Filler	Interf.
marketing	patron	discount	The store assistant encouraged the customer to come back immediately for a refund.	Filler	Interf.
chef	audit	distrust	The cook never trusted the accountant that he had hired to settle his finances.	Filler	Interf.

loneliness	buddy	pupil	The young student was saddened by a lack of friends after moving schools.	Filler	Interf.
chill	protein	craftsman	The butcher felt the coldness of the fresh meat he had just bought.	Filler	Interf.
chart	globe	remoteness	The mapmaker told the student about the remote and abandoned island's existence.	Filler	Interf.
investigation	fellow	lie	The professor angrily claimed the inadequate research was completely false.	Filler	Interf.
remuneration	rebate	company	The secretary was up in arms over her pay reduction and threatened to resign.	Filler	Interf.
coffee	cashier	disappointment	The barista served the customer an awful espresso at 9am this morning.	Filler	Interf.
minor	place	flower	The saddened child was forgotten by his mother at the massive garden centre.	Filler	Interf.
contractor	material	cement	The builder had not bought enough concrete for his work and was forced to quit.	Filler	Interf.
shears	research	tripod	The landscaper hired cheap labour from Poland last spring to build three sheds.	Filler	Non-interf.
clone	curl	riot	The producer faked multiple scenes in his new documentary about crime and punishment.	Filler	Non-interf.
Turkey	view	enquiry	The TV host was unamused by the practical joke that involved a banana peel.	Filler	Non-interf.
frigate	trooper	workout	The wizard presented the gullible students with a cheap magic trick to win them over.	Filler	Non-interf.
algebra	scratch	tank	The manager held a great speech that motivated everyone at the company.	Filler	Non-interf.
thistle	culvert	cannon	The cyclist who wanted to turn right was gravely injured by the antisocial driver.	Filler	Non-interf.
action	beauty	concentration	The pedestrian shouted at the cyclist for cutting him off on the shared pavement.	Filler	Non-interf.

help	outline	strip	The resident was annoyed by the huge influx of tourists into the small town.	Filler	Non-interf.
snow	wax	weight	The linguist constantly criticised her colleague's poor use of grammar in the assignments.	Filler	Non-interf.
judge	snake	party	The scientist demanded to see and consider the controversial politician's evidence.	Filler	Non-interf.
stop	things	trail	The manufacturer started producing face masks last spring and made huge profits.	Filler	Non-interf.
trip	hose	son	The demonstrator threw a milkshake at the popular journalist who was hit in the face.	Filler	Non-interf.
ray	train	curve	The friend wrote a letter expressing her thanks for the emotional support and care.	Filler	Non-interf.
lace	addition	box	The doctor prescribed the man twenty different pills to combat his medical issues.	Filler	Non-interf.
straw	sand	month	The caretaker was horrified by the state of the public toilets in the shopping centre.	Filler	Non-interf.
shade	shake	drink	The statistician relentlessly attacked different software packages for hours without stopping.	Filler	Non-interf.
lettuce	cactus	territory	The calligrapher drew a beautiful and aesthetically pleasing capital letter this morning.	Filler	Non-interf.
dolls	cheese	badge	The priest took care of the woman after her eviction and housed her.	Filler	Non-interf.
face	pretzel	force	The stroke patient gradually regained the ability to speak over multiple months.	Filler	Non-interf.
popcorn	horn	finish	The young man was left jobless and destitute after being fired from his job.	Filler	Non-interf.
adjustment	wine	labourer	The passenger tutted at the crying child for ten minutes but solved nothing.	Filler	Non-interf.

bead	toad	public	The commuter was rain-soaked after his train delay, the third one this week.	Filler	Non-interf.
yoke	crisp	brass	The visitors were impressed by the museum pieces and wanted to come back soon.	Filler	Non-interf.
chip	zinc	iron	The diligent student wrote down everything carefully in a black and green notebook.	Filler	Non-interf.
sheet	shirt	vessel	The secret agent was detected by the hotel employee and had to evacuate the area.	Filler	Non-interf.
alien	pets	appliance	The warrior took the opponent prisoner after the battle, in which one side emerged victorious.	Filler	Non-interf.
week	clicker	whiteboard	The frustrated man kicked the cat that blocked the path and immediately regretted it.	Filler	Non-interf.
gun	haircut	fuel	The knight lied to the king and was promptly executed on charges of treason.	Filler	Non-interf.
course	comparison	cherry	The arrogant driver caused many accidents this year and was charged by the police.	Filler	Non-interf.
request	hurdle	spear	The undercover agent filmed ten crimes today and was awarded a pay rise.	Filler	Non-interf.
push	loaf	riser	The reader was enthralled by the book about two lovers in trouble for weeks.	Filler	Non-interf.
basket	idea	seminar	The mother lovingly sent a postcard and some money to her daughter abroad.	Filler	Non-interf.
activity	lobby	timetable	The care package arrived at the hotel just in time for the grand introduction party.	Filler	Non-interf.
calendar	seashore	board	The lunch lady served mash and peas to the children, who were not impressed.	Filler	Non-interf.
base	cat	nest	The lawmaker was highly critical of the board's plans to build more houses.	Filler	Non-interf.

caption	bird	rhythm	The salesman convinced the shopper of his product's worth after 2 hours of negotiating.	Filler	Non-interf.
guide	muscle	volley	The parliamentarian did not believe the witness testimony and voted against the motion.	Filler	Non-interf.
shelf	circle	frame	The planter had a backache after working all day and was referred to occupational health.	Filler	Non-interf.
cellar	top	bread	The unknown composer considered his third symphony his one true masterpiece.	Filler	Non-interf.
waste	scissors	roll	The ruthless dictator imprisoned the critical journalist for life without chance of parole.	Filler	Non-interf.
prize	van	tin	The scientist was mesmerised by the revealing discovery about stars and distant galaxies.	Filler	Non-interf.
soda	frog	attraction	The drug trafficker was arrested by the border guard after being found with cocaine.	Filler	Non-interf.
quartz	leather	burst	The representative verbally attacked his colleague in the debate and was called to order.	Filler	Non-interf.
sauce	plane	fish	The immigrant was cruelly treated by the population for having a different background.	Filler	Non-interf.
button	yak	vein	The Turks attacked the Hapsburgs throughout the 1680s but with little success.	Filler	Non-interf.
friends	angle	rice	The careful gardener repotted the frail basil plant after the storm nearly killed it.	Filler	Non-interf.
sister	finger	rub	The persistent rain made the Queen's guard shiver all day in front of the palace.	Filler	Non-interf.
partner	throne	plastic	The pilot could not control the plane during the crash, which led to ten deaths.	Filler	Non-interf.
tray	boundary	beginner	The drunk driver lost control over her small vehicle and smashed into the wall.	Filler	Non-interf.

dust	sheep	cabbage	The tourist was robbed of his camera bag by the thief in the city centre.	Filler	Non-interf.
roadside	name	champion	The beggar hassled the politician on live television and was rudely dismissed by security.	Filler	Non-interf.
temper	member	gentleman	The critical historian judged the seventeenth century harshly for its cruel warfare.	Filler	Non-interf.
loaf	doll	giraffe	The melancholic poet wrote about his love life in his diary, published posthumously.	Filler	Non-interf.
rod	lady	river	The writer was criticised by many journalists after publishing the controversial article.	Filler	Non-interf.
bomb	ice	cave	The old locomotive used on the heritage railway enthused the trainspotter immensely.	Filler	Non-interf.
roof	hammer	covering	The travel agent arranged a cheap flight to the Mediterranean sun for the customer.	Filler	Non-interf.
sink	bike	crook	The council staffer delivered food parcels to her neighbours during the time of crisis.	Filler	Non-interf.
stick	card	earth	The farmer was scorched by the hot weather on the fields during his day of work.	Filler	Non-interf.
cream	geese	channel	The ruthless tax collector extorted the extremely poor peasants for some pennies.	Filler	Non-interf.
range	yard	snail	The soldier was struck down by a lance to the head during the famous battle.	Filler	Non-interf.

Appendix E: Study 2 (Participant Biodata)

PPT ID	*Age*	*Age Group*	*Gender*	*Years in Education*	*Education Level*	*Country of birth*	*WM Span*	*LCT Score*
1005	73	Old	Female	16	6	UK	31	27
1030	70	Old	Female	16	6	USA	17.5	10
2151	71	Old	Female	16	6	UK	18	19
2721	70	Old	Female	16	6	UK	22.5	22
3191	65	Old	Male	17	3	Ireland	8	19
3579	72	Old	Female	13	3	UK	17.5	29
4006	73	Old	Male	18	7	UK	26	19
4108	65	Old	Female	11	2	UK	28	11
4129	74	Old	Male	17	4	UK	27	21
4135	65	Old	Female	20	6	UK	21.5	17
4262	67	Old	Male	19	7	UK	27.5	11
4471	66	Old	Female	19	7	UK	26	21
4738	73	Old	Male	12	3	UK	17.5	12
5021	66	Old	Male	15	5	USA	25.5	16
5335	65	Old	Female	11	2	UK	26.5	11
5732	68	Old	Male	16	2	UK	20.5	23
6152	71	Old	Female	19	7	US	31	15
6422	65	Old	Male	12	4	UK	18.5	18
6508	66	Old	Female	11	3	UK	24.5	28
6708	76	Old	Female	17	6	UK	20.5	19
6782	65	Old	Male	17	6	UK	11	14
6844	65	Old	Female	20	7	UK	21	4

7175	73	Old	Female	14	4	UK	20	22
8513	65	Old	Female	15	4	UK	30	23
8542	68	Old	Female	16	6	UK	21	10
8905	66	Old	Male	14	6	UK	14.5	21
9360	66	Old	Male	14	3	UK	16	15
9447	66	Old	Male	12	3	UK	16	15
9655	70	Old	Female	18	3	UK	20	19
9830	71	Old	Male	12	6	UK	11.5	8
1533	19	Young	Female	15	4	UK	22.5	21
2132	22	Young	Male	14	3	UK	28.5	17
2244	20	Young	Male	17	3	UK	18.5	34
2510	25	Young	Female	20	6	UK	16	29
2677	22	Young	Female	18	4	UK	19.5	31
2804	22	Young	Female	16	6	UK	28	38
3374	20	Young	Female	15	3	UK	29	34
3734	25	Young	Female	17	4	UK	29	37
3969	22	Young	Female	19	6	UK	23.5	27
4305	20	Young	Female	15	4	UK	16.5	30
4520	24	Young	Female	17	6	UK	14.5	28
4572	24	Young	Female	16	6	UK	28.5	24
4726	22	Young	Male	16	6	New Zealand	24	23
4981	19	Young	Male	16	3	UK	30	21
5560	24	Young	Male	18	7	UK	25	27
5613	21	Young	Male	18	6	Canada	23.5	31
5628	24	Young	Female	19	6	UK	26.5	25
5907	19	Young	Male	15	4	UK	12	27

5986	20	Young	Female	17	3	UK	27	36
6145	21	Young	Female	17	6	UK	31	32
6714	24	Young	Female	18	6	UK	29	28
6785	24	Young	Female	17	6	UK	16.5	33
6995	24	Young	Female	15	3	UK	17.5	18
7726	20	Young	Female	16	4	UK	33	38
8355	25	Young	Female	18	6	UK	29	27
9003	20	Young	Female	15	6	UK	24	20
9103	23	Young	Male	18	6	Ireland	22	31
9194	19	Young	Female	14	3	UK	13	19
9309	19	Young	Male	13	3	USA	16	27
9881	20	Young	Female	18	3	UK	27	28

Appendix F: Study 3/4 (Additional Filler Items)

Filler 3	*Filler 4*
The car driver with the moustache was pretty cool.	The university dean had many responsibilities and a huge workload.
The controversial author of the book caused a stir.	The company agent whose business had grown was very proud.
After two hours the famous writer arrived at the house.	The burglar made millions by selling stolen art.
The painter fell down the ladder while painting the wall.	Scientists make discoveries using microscopes all the time.
The bishop delivered a stirring speech to the churchgoers.	Nobody attended the class taught by the unpopular lecturer.
The church overlooked the lake with the crystal clear water.	The train engineer spent hours working on the same defect.
This new breed of tiger scared us with its big fangs.	Emperors were generally lonely figures despite being in charge.
The girl was immensely happy at seeing the white flowers.	The landowner watched his slaves work in the field.
King Arthur was impressed by the lord of the mountains	The charging knights shouted heroically during the pitched battle.
The tribesmen of the Indian reserve lived a life of peace.	Treacherous currents were a real danger to swimmers here.
The manager of the factory with the loud voice was efficient.	The butcher that lost all his customers felt desperate
The parish councillor that faced losing the election canvassed all morning.	Bored cashiers at supermarkets can be very discouraging to customers.
Many misspellings made the thesis completely unacceptable to the editor.	The sheriff of the town that had no tourists lived quietly.
The solicitor with the new tuxedo was arrogant and bothersome.	The astronaut was sent into space on a massive rocket.
The drugs runner grimaced and ran off from the police officer.	The workforce went onto a collective strike due to hunger.
The colourful tartan with the many stripes lay in the castle.	Ballerinas who are pushed to their limits can be very unhappy.
The impure gold was assessed by the inspector and rejected.	The wizard who tried a new spell had a grey beard.

The factory boss that was reading a book received a call.
The singer that had long eyelashes was pretty stupid.
Blue tiles lined the walls of the famous seafood restaurant.
The inventor of the machine grew a goatee in celebration.
The clever spy never carried a gun and always escaped.
The country's ruler who had two wives punished the convict.
The referee accused the club's goalkeeper of feigning injury.
Everyone disliked the gold merchant that raised prices constantly.
Despite having only four fingers, the robber was extremely rich.
The fleet admiral with the big hat was very stern.
The chemistry student who drank too much failed all his exams.
Everyone liked the train conductor whose announcements were funny.
The airplane crew was directed by the hostess with the hat.
The island inhabitant that prayed for salvation was not heard.
Magic interested the monarch, for which he was deposed.
The teacher was fired for shouting at her students.
A new recipe by the brilliant chef was highly successful.
The bored audience left the cinema after just thirty minutes.
Late working became the standard at the modern restaurant.

The clock designer whose creation fell to pieces never recovered.
The teller of the popular bank worked very hard.
The lonely fisherman begged for friendship and company.
The chemist locked the doors to the ingredients cabinet securely.
The professor of the difficult subject explained everything slowly.
The paramedic got stuck inside the locked ambulance yesterday.
The rich widow was murdered for her large estate.
Gangs had ruled the neighbourhood for the past three years.
The building was never cleaned and the caretaker left his job.
Bountiful harvests resulted from the large amount of rain this summer.
The movers could not get the closet through the door.
Big squares are usually decorated with marble statues in Europe.
The nation that closed its borders suffered from heavy setbacks.
The government resigned after the scandal was published in the news.
The cinema was devoid of customers during the pandemic.
Directions were gladly given to the tourist visiting Amsterdam.
The presenter used fancy technology to wow her audience last month.
The traditional academic still used typewriters on a daily basis.
The invention of the microscope was revolutionary.

Many patients trusted the doctor whose work was exquisite.

The reporter spoke to a witness of the horrible crime.

The princess in the castle was rescued very promptly.

Eating chocolates was the headmaster's favourite activity during school hours.

The policemen witnessed the assault and arrested an angry woman.

A solution to the pervasive scientific problem was never found.

The news anchor finally sat down after hours of presenting.

The small bicycle owned by the student was still very fast.

The painter hired a new model for his latest creation.

The friendly newspaper photographer that constantly smiled died yesterday.

The singers were busily reading music ahead of the concert.

The football club coach that had raged in anger calmed down.

The hairdresser fainted after working in the heat for hours.

Congratulations were given to the school instructor who everyone liked.

The nurse recognised the contribution made by her colleague.

The movie cameraman prepared the next scene by assessing the equipment.

The lorry driver that was favoured by the boss was chatting.

The unhappy sailor began rioting over his pay decrease.

Army recruiters lined the streets looking for strong men.

The Ottomans captured the city of Constantinople in the fifteenth century.

After three hours, the student decided she had studied enough.

Many campaign posters were dotted around town during election season.

She had said the same thing three times in a row.

The position of the sniper would never be expected.

The nervous system is important for our bodies to communicate.

The visitors to the parliament were screened thoroughly.

The medium was examined by the scientist and completely disproven.

People often consider gemstones to have healing properties.

The adaptation of the play was very well received.

The new stadium had a capacity of over forty thousand spectators.

The home brewer was shocked when his beer bottles exploded.

A well organised stationary cupboard is an admirable luxury.

I am thinking of walking off on a random trail.

The conference attendees were bored by the long talk.

Feedback was given to the student who failed the exam.

Te Berlin Wall was finally torn down by crowds of people.

While prescriptions are free in Scotland, the English have to pay.

The lack of rain turned all plants yellow.

Nobody trusted the lawyers who had scammed their clients.
The property cleaner was disgusted at the sight of the kitchen.
The schoolboy was liked by his peers and performed well.
The art critic whose reviews were scathing was feared by all.
Innovative techniques made this architect revered by many.
The show's bad writing made the actress deeply unpopular.
The mansion with the big porch made the neighbour jealous.
The shop that was trashed last week was still in disrepair.
The fire engine that was just repainted gleamed in the sunlight.
After the menu was redesigned, the restaurant did well.
The seamstress produced the most wonderful clothing in the business.
The schoolgirl was decorated for bravery after rescuing a teacher.
Sales of the old newspaper have been declining for decades.
The beautiful wall paintings attracted many tourists to the convent.
The cosy high street was home to several tailors.
The clinician saw twenty patients this afternoon alone.
The maid felt lucky to be employed for so long.
The violinist received a thunderous applause from the crowd.
Circus clowns have become less popular these days.
Hoover salesmen bothered the whole neighbourhood for days on end.

The youths egged the house of the grumpy lady.
The printing press was a revolutionary invention for the world.
Doing algebra has never been one of my strong sides.
Everyone needs a break from work now and then.
The internet has brought the world closer together lately.
Crowns were often worn by famous monarchs throughout history.
Pressing the off button usually shuts down a computer.
Music can have both a focusing and a distracting effect.
Myths and legends are plentiful across Eastern Europe and beyond.
The incidence of insect infestations increases during the summer months.
Cats and dogs are very frequent and loved pets.
In te middle ages, beer was drunk more than water.
Wearing glasses can be a nuisance during a pandemic.
The man who used superflue had to attend the emergency room.
Fluid corrector for writing was invented ages ago.
Alternative cultures are becoming more accepted in many countries.
Our lives are shaped heavily by our notion of time.
The woman tried to make tea but burned herself.
The bookshop was filled to the brink with antique finds.
The letter arrived far too late for the recipient to use.

The general lost half his soldiers in a fierce battle.

The heir was aching to inherit the massive estate.

The plumbers who faced bankruptcy worked twice as hard.

The gardener admired the flowers that were basking in the sun.

The orchestra director played well and received a standing ovation.

Poets are becoming more popular far and wide.

The prankster was assaulted after her jokes went wrong.

Photos lined the lawyer's desk and decorated her room.

The company secretary received a generous bonus for her work.

The handbag thief was later set free without charge.

The council clerk that passed two new laws resigned.

The homeowner appealed for help to fund the renovation.

The team trainer felt the pressure after another loss.

The national leader spoke proudly about her nation's victory.

The parliamentary guard took her job very seriously.

Language learners are often faced with low motivation for learning.

The soldier embraced the comrade that had saved her life.

She grabbed for a tissue after learning about her loss.

The diary was full of scribbles during the busy week.

THe internet connection took over two months to set up.

Constructing buildings is a far more complex task than it seems.

The renovation took far longer than expected and cost tonnes.

Sending text alers to those in danger is a useful development.

The accountant worked nearly a hundred hours per week.

The couple's chances of succeeding at the contest were very limited.

The woman only had four weeks to complete the design.

Eating large amounts of fruit is never a bad thing.

The homeless person gathered beer bottles to return to stores.

Mouldy window frames can be a real health hazard.

Waiting at traffic lights is not something everyone does.

Appendix G: Study 3/4 (Participant Biodata)

PPT ID	*Age*	*Age Group*	*Gender*	*Years in Education*	*Education Level*	*WM Span*	*LCT Score*
OG 1	75	Older	Male	9	2	13.5	8
OG 2	66	Older	Female	11	3	13	13
OG 3	73	Older	Female	17	7	7.5	7
OG 4	67	Older	Female	25	8	16.5	12
OG 5	67	Older	Female	14	3	7.5	9
OG 6	67	Older	Female	21	7	18	7
OG 7	66	Older	Female	11	2	14.5	5
OG 8	67	Older	Male	17	6	26.5	5
OG 9	66	Older	Female	11	3	7	11
OG 10	79	Older	Female	16	5	10.5	9
OG 11	77	Older	Female	15	2	10	3
OG 12	75	Older	Male	12	3	9	2
OG 13	72	Older	Female	16	5	8	4
OG 14	69	Older	Male	18	5	4.5	7
OG 15	71	Older	Female	13	3	13.5	13
OG 16	68	Older	Male	22	6	17	8
OG 17	69	Older	Female	16	5	14.5	10
OG 18	64	Older	Female	18	6	23	7
YG 1	23	Younger	Female	17	7	16	15
YG 2	23	Younger	Male	15	3	21.5	13
YG 3	19	Younger	Female	16	3	7	9
YG 4	20	Younger	Female	14	3	26.5	8

YG 5 (Behavioural Only)	19	Younger	Female	16	3	17.5	6
YG 6	22	Younger	Female	8	3	11	14
YG 7	25	Younger	Female	20	7	17.5	6
YG 8	20	Younger	Female	16	3	23	16
YG 9	25	Younger	Female	19	6	11	11
YG 10	20	Younger	Male	15	3	21	11
YG 11	19	Younger	Female	14	3	28	3
YG 12	19	Younger	Female	14	3	18.5	8
YG 13	20	Younger	Female	16	3	21	15
YG 14	20	Younger	Female	13	3	12.5	9
YG 15	20	Younger	Female	15	3	12.5	15
YG 16	23	Younger	Female	19	6	28	14
YG 17	27	Younger	Female	16	3	14	14
YG 18	25	Younger	Female	16	6	14.5	12
YG 19	20	Younger	Female	15	3	13	13
YG 20	20	Younger	Female	15	3	10.5	15

Appendix H: Biodata, Consent, and Participant Information forms

Biodata Questionnaire

A Matter of Memory: Sentence Comprehension in Healthy Aging

To assist with our data analysis we would like to know some of your basic details and information about your education and background.

Name:

Contact number/email:

I would like to be contacted about the results of this study: **YES / NO**

Age:

Gender:

Number of years in education:

Highest level of education attained:

Country of birth:

I confirm I am dominant in English: **YES / NO**

Note: items in red were asked only in Study 3

Consent Form

1. Taking part in the study

☐ I confirm that I have read and understand the Information Sheet for the above study. I have had an opportunity to consider the information, ask questions and have had these questions answered satisfactorily.

☐ I understand that my participation is voluntary and that I am free to withdraw from the project at any time without giving any reason and without penalty. I understand that any data collected up to the point of my withdrawal will be destroyed unless I indicate otherwise.

☐ I understand that taking part in the study involves providing key pressing responses while being monitored with an electroencephalogram (EEG), which in turn involves a cap being placed on my head and electrodes fitted into the cap.

☐ I understand that taking part in the study involves being touched on the head and scalp by the researcher(s) to fit EEG equipment. I also understand and consent to conducive gel being applied to my head and consequently, after the study has finished, to be washed out by the researcher(s).

2. Use of Information

☐ I understand that my fully anonymised data will be used for statistical data analysis and the production of research papers, and may be published in peer-reviewed journals.

☐ I understand that any of my contact details or identifying information provided will be securely destroyed upon completion of the project.

☐ I understand that the data collected about me will be used to support other research in the future, and may be shared anonymously with other researchers.

☐ I give permission for the responses that I provide to be shared online so that they will be available for future research and learning activities by other individuals.

☐ I agree to take part in the above study.

____________________ ____________________

Participant Signature Date

Participant Information Sheet (Study 1)

1. Study Invitation

We invite you to take part in this study by the Department of Language and Linguistics at the University of Essex. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

The purpose of this study is to explore how the way people comprehend and interpret sentences changes with age and in conditions such as Alzheimer's Disease. You have been selected for this study because you are a native, monolingual speaker of English, and you fall into either a young or an older age bracket. Around 60 other monolingual speakers of English will also be asked to participate. You will be paid for your participation through Prolific.

2. Participation

It is up to you to decide whether or not you wish to take part in this research study. If you do decide to take part you will be asked to provide written consent. You are free to withdraw at any time, without giving a reason. Withdrawal will have no absolutely no impact on you. If you no longer want to take part, please close the study window. It will then be up to you to decide whether we can use the data we have gathered from you up until the time of your withdrawal.

You will be asked to take part in a short memory experiment in which you will be tasked with remembering words in a sequence and recalling that sequence when prompted. These measures will help us establish a composite score of your memory capacity. Additionally, we will look into the strategies you adopt when processing information with a third short questionnaire. These combined experiments should take no longer than 10 minutes to complete.

You will then be presented with several sentences and asked a question about some of these sentences afterwards. The sentences will be presented word-by-word, so you will see the questions at the end of the sentences. You should not think long about the questions and prioritise how quickly you respond. There will be three practice sentences for you to get a feel for the process. Please read the instructions on the screen carefully before you start. In total, we estimate most people will take between 30 and 45 minutes to complete this part of the study.

3. Risks and Benefits

There are no known risks associated with this study. However, if you feel uncomfortable at any time, please pause immediately. It will then be up to you to decide if you want to continue or stop the study.

4. Information

We will collect basic information about you for the purposes of data analysis, including your gender, age, and years/level of education. Any personal data that may be used to identify you (such as your name and contact details) will be stored securely and will be destroyed when the study is complete. We will keep other information about you such as your gender and age for the purposes of data analysis. All data used for this study will be anonymised, digitised, and stored on password-protected university drives and computers. Your personal data will not be shared beyond the research team.

The answers you give will be collected and used to generate scientific publications in peer-reviewed journals. Your responses will also be made available online to other researchers for further study and education. Please indicate if you want to be informed of any results following from your participation on the consent screens following this information screen; in this case you may be contacted by a member of the research team when the study is complete.

If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the principal investigator of the project, Willem van Boxtel, using the contact details below. If you are still concerned or you think your complaint has not been addressed to your satisfaction please contact the University of Essex Research Governance and Planning Manager, Sarah Manning-Press (e-mail sarahm@essex.ac.uk). Please include the ERAMS reference which can be found at the foot of this page. This project is funded by a University of Essex Social Sciences Doctoral Scholarship and has been approved by the University of Essex Social Sciences Ethics Sub-Committee.

5. Research Team

The research team for this study and their contact details are as follows:

RESEARCHER CONTACT DETAILS INPUT HERE

Participant Information Sheet (Study 2)

1. Study Invitation

We invite you to take part in this study by the Department of Language and Linguistics at the University of Essex. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

The purpose of this study is to explore how the way people comprehend and interpret sentences changes with age and in conditions such as Alzheimer's Disease. You have been selected for this study because you are a native, monolingual speaker of English, and you fall into either a young or an older age bracket. Around 60 other monolingual speakers of English will also be asked to participate. You will be paid for your participation through Prolific.

2. Participation

It is up to you to decide whether or not you wish to take part in this research study. If you do decide to take part you will be asked to provide written consent. You are free to withdraw at any time, without giving a reason. Withdrawal will have no absolutely no impact on you. If you no longer want to take part, please close the study window. It will then be up to you to decide whether we can use the data we have gathered from you up until the time of your withdrawal.

You will be asked to take part in a short memory experiment in which you will be tasked with remembering words in a sequence and recalling that sequence when prompted. Additionally, we will look into the strategies you adopt when processing information with a second short questionnaire. These measures will help us establish a composite score of your memory capacity, and should take no longer than 10 minutes to complete.

In the third task, you will be asked to memorise several words before reading a sentence word-by-word; you will be asked to recall some of the words you memorised and/or answer a question about the sentence you read. For instance, you may be asked to recall the words "MUG – CHIP – COFFEE", and read the sentence "The servant of the actress who was looking very happy was in the living room". You may then be asked the questions "Did this word appear in the memory set: MUG" and "Who was in the living room?". Try not to dwell on the questions for too long and try to give your answers quickly. Read the sentences at your normal reading speed before pressing the button to continue to the question and providing your response. We estimate this study will take most people between 45 minutes and an hour to complete.

3. Risks and Benefits

There are no known risks associated with this study. However, if you feel uncomfortable at any time, please pause immediately. It will then be up to you to decide if you want to continue or stop the study.

4. Information

We will collect basic information about you for the purposes of data analysis, including your gender, age, and years/level of education. Any personal data that may be used to identify you (such as your name and contact details) will be stored securely and will be destroyed when the study is complete. We will keep other information about you such as your gender and age for the purposes of data analysis. All data used for this study will be anonymised, digitised, and stored on password-protected university drives and computers. Your personal data will not be shared beyond the research team.

The answers you give will be collected and used to generate scientific publications in peer-reviewed journals. Your responses will also be made available online to other researchers for further study and education. Please indicate if you want to be informed of any results following from your participation on the consent screens following this information screen; in this case you may be contacted by a member of the research team when the study is complete.

If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the principal investigator of the project, Willem van Boxtel, using the contact details below. If you are still concerned or you think your complaint has not been addressed to your satisfaction please contact the University of Essex Research Governance and Planning Manager, Sarah Manning-Press (e-mail sarahm@essex.ac.uk). Please include the ERAMS reference which can be found at the foot of this page. This project is funded by a University of Essex Social Sciences Doctoral Scholarship and has been approved by the University of Essex Social Sciences Ethics Sub-Committee.

5. Research Team

The research team for this study and their contact details are as follows:

RESEARCHER CONTACT DETAILS INPUT HERE

Participant Information Sheet (Study 3)

1. Study Invitation

We invite you to take part in this study by the Department of Language and Linguistics at the University of Essex. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

The purpose of this study is to explore how the way people comprehend and interpret sentences changes with age. You have been selected for this study because you are proficient speaker of English, and you fall into either a young or an older age bracket. Around 60 other proficient speakers of English will also be asked to participate. You will be paid £5 for your participation.

2. Participation

It is up to you to decide whether or not you wish to take part in this research study. If you do decide to take part you will be asked to provide written consent. You are free to withdraw at any time, without giving a reason. Withdrawal will have no absolutely no impact on you. If you no longer want to take part, please inform the researcher. It will then be up to you to decide whether we can use the data we have gathered from you up until the time of your withdrawal.

You will be presented with several sentences and asked a question about some of these sentences afterwards. You should not think long about the questions and prioritise how quickly you respond. The sentences will be presented word-by-word, and you will use the SPACE bar to progress through the sentence. There will be three practice sentences for you to get a feel for the process. Please read the instructions on the screen carefully before you start.

While you are taking part in this experiment, we will be recording the electrical activity on your scalp using a technique called electroencephalography (EEG). This is an entirely safe and non-invasive technique, and will involve placing a cap on your head into which electrodes will be fitted. We will use conductive gel to fit the electrodes to your scalp — you are invited to wash out this gel at the end of the study. In total, we estimate most people will take between an hour and 90 minutes to complete the study.

Before the start of the main experiment, you will be asked to take part in a short memory experiment in which you will be tasked with remembering certain words from sentences presented on the screen, and recalling these words afterwards. Additionally, we will look into the strategies you adopt when processing information with a fourth short study. These combined experiments should take no longer than 15 minutes to complete.

3. Risks and Benefits

There are no known risks associated with this study. However, if you feel uncomfortable at any time, please let the researcher know and the study will be stopped. It will then be up to you to decide if you want to continue or stop the study. You will have the opportunity for a break at several points throughout the study to refresh yourself and avoid eye strain.

4. Use of Information

We will collect basic information about you for the purposes of data analysis, including your gender, age, and years/level of education. Please refer to the biodata questionnaire in front of you. Any personal data that may be used to identify you (such as your name and contact details) will be stored securely behind a double lock and will be destroyed when the study is complete. We will keep other information about you such as your gender and age for the purposes of data analysis. All data used for this study will be anonymised, digitised, and stored on password-protected university drives and computers. Your personal data will not be shared beyond the research team.

The answers you give will be collected and used to generate scientific publications in peer-reviewed journals. Your responses will also be made available online to other researchers for further study and education. Please indicate to the researcher if you want to be informed of any results following from your participation; in this case you may be contacted by a member of the research team when the study is complete.

If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the principal investigator of the project, Willem van Boxtel, using the contact details below. If you are still concerned or you think your complaint has not been addressed to your satisfaction please contact the University of Essex Research Governance and Planning Manager, Sarah Manning-Press (e-mail sarahm@essex.ac.uk). Please include the ERAMS reference which can be found at the foot of this page.

This project is funded by a University of Essex Social Sciences Doctoral Scholarship and has been approved by the University of Essex Social Sciences Ethics Sub-Committee.

5. Research Team

RESEARCHER CONTACT DETAILS INPUT HERE

Appendix I: Analysis Script Links

Please refer to the below URLs for the full R-language code scripts used for analyses in this project.

- Study 1: Behavioural syntactic priming: `https://osf.io/yn5dp/`
- Study 2: Relative clause disambiguation: `https://osf.io/eympz/`
- Study 3: Electrophysiological syntactic priming: `https://osf.io/3yrnv/`
- Study 4: Persistence of the lexical boost: `https://osf.io/8eb3a/`