EXAMINING AGE-RELATED CHANGES IN KNOWLEDGE USE DURING LANGUAGE COMPREHENSION USING BRAIN ELECTROPHYSIOLOGY

BY

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THESIS

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ABSTRACT

Prior work has shown that general event knowledge can be rapidly used during language comprehension and shapes word understanding. However, little is known about how this use of event knowledge might be affected by normal aging, which is associated with increases in world knowledge but also decreases in processing speed. In the current study, the N400, an event-related potential component linked to meaning access, was measured as younger and older adult participants read short descriptions of real-world scenarios that ended with the most predictable word or one of two types of contextually anomalous words, either related or unrelated to the larger event being described. Results from younger adults replicated Metusalem et al. (2012): N400s were reduced to predictable compared to anomalous words and, among anomalous words, were reduced for those related to the larger event compared to unrelated anomalies. Older adults also showed N400 reductions for predictable compared to anomalous words, but they did not show N400 facilitation for event-related compared to unrelated anomalies. Thus, whereas young adults seem to broadly activate and maintain information about the event being described, even when that information is not relevant for the unfolding language sequence, older adults do not. However, older adults did differentiate the two types of anomalous words in a later time window encompassing the Late Positive Complex, indicating that they appreciated the event-relatedness of the words more slowly, in a perhaps more explicit manner. These results thus show that the use of event knowledge during language comprehension is impacted by normal aging.

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CHAPTER 1: INTRODUCTION

Consider this sentence: *You'll be sorry if you go out without wearing your wetsuit or at least a shirt*. Without any preceding context, there is no way to anticipate "wetsuit" out of the many things that are possible to wear. However, when provided with more context (*Living in San Diego is great if you love to surf. The downside is that the water can be freezing during the winter. You'll be sorry if you go out without wearing your wetsuit or at least a shirt*.), it is much easier to narrow down the list of possible items the third sentence might suggest you wear. Most people have some sense of what would be typical of a surfing scenario, even if they have never gone surfing themselves. This structured knowledge about everyday events is known as event knowledge, and can come from first-hand experience, watching television, reading, or even listening to others talk about their own experiences (McRae & Matsuki, 2009). Event knowledge plays a significant role in language comprehension, with some researchers concluding that event representations are necessary for effective comprehension (Altmann & Mirković, 2009; Kamide et al., 2003). The interplay between prior knowledge and current input underpins successful — and rapid — comprehension.

1.1 EVENT KNOWLEDGE USE AND LANGUAGE COMPREHENSION

An appreciation of the role of event knowledge in comprehension is long-standing. For example, in a now-classic study, Bransford and Johnson (1972) asked people to listen to a passage describing an everyday event, such as doing laundry. When participants were given the topic of the passage before it was read, they provided higher ratings of their ability to comprehend the passage and they also recalled more about it compared both to groups that were given no

information about the topic and to groups that were given the topic, but only after the passage was read (Bransford & Johnson, 1972). When context is limited, it is more difficult to link the meaning of the words to a message-level understanding, and this reduces comprehension and memory, even if the information is eventually provided to the comprehender.

Other studies have shown similar patterns at the sentence and single-word level. Kamide et al. (2003) used eye-tracking to reveal knowledge-based anticipatory effects. For example, participants were presented with an image that included a young girl, a man, a motorbike, and a carousel, and heard the sentence: "The girl will ride the carousel." Participants consistently looked at the carousel before the onset of the word "carousel," indicating that they had already activated their knowledge about what a girl would typically ride and decided that the carousel was more likely before hearing the entire sentence (see also Kamide et al., 2003). Using single words, Hare et al. (2009) found that participants were faster to answer questions about people and objects if they were primed with a related event noun. For example, participants responded more quickly to the word "shoes" if the preceding word was "marathon" (Hare et al., 2009). This suggests that the noun activated event knowledge, facilitating response times for other things that would be commonly associated with that event. A similar pattern was seen in Matsuki et al. (2011) for reading times on nouns if they were paired with an instrument typically associated with that noun. These studies support the idea that event knowledge rapidly influences expectations and comprehension.

Complementary to behavioral studies of knowledge use, studies that involve the concurrent measurement of brain electrical activity (the electroencephalogram, or EEG) can examine how knowledge is activated and used with high temporal precision. Importantly, beyond revealing whether or not event knowledge is used for language comprehension, EEG studies have provided

insight into when and how event knowledge shapes comprehension. Many studies examine EEG signals time locked to specific words — so-called event-related potentials (ERPs). In particular, studies focused on comprehenders' ability to build meaning representations have focused on the N400, a negative-going wave peaking around 400 ms after the onset of a meaningful stimulus, largest over central and parietal areas of the scalp (Kutas & Federmeier, 2011).

The N400 was first observed to be sensitive to the fit between an incoming word and its context, with, for example, larger N400s to words that are anomalous in context compared to those that are contextually supported (e.g., to *dog* compared with *sugar* in "He takes his coffee with cream and …"; e.g., Kutas & Hillyard, 1980). Further studies showed that the N400 is not influenced by grammatical errors (Kutas & Hillyard, 1983) or changes in the physical appearance of words (Kutas & Hillyard, 1980), suggesting that it is not just a general response to detecting violations or unexpected stimuli, but is more specific to the analysis of semantics. However, the N400 is also not a semantic plausibility detector as such. For example, Fischler et al. (1983) found that the N400 was reduced if exemplar and category matched in a statement, regardless of whether that statement was true/plausible; that is, "a robin is a bird" and "a robin is not a bird" elicit similarly-sized N400 responses, both facilitated compared to "a robin is/is not a vegetable." Instead, the N400 has been found to be part of the normal response to meaningful stimuli, including words in all modalities. Its amplitude is reduced when available context information — or other factors, such as repetition and word frequency — ease semantic processing (Kutas & Federmeier, 2009).

During sentence processing, the amplitude of the N400 has been shown to be closely correlated with cloze probability, or the proportion of people who give a particular word as the most likely completion of a sentence (Taylor, 1953). Higher cloze probabilities are associated with more

reduced N400s (Kutas & Hillyard, 1984), and words that are semantically related to a word with high cloze probability also elicit smaller N400s, suggesting that the N400 is sensitive to the fit between an incoming word and the semantic information that has been made available previously from the context, either directly or through comprehender-generated expectations. For example, Federmeier and Kutas (1999a) used sentence pairs to build an expectation for a specific noun and compared responses to the expected word and two types of semantically anomalous words — one that was unrelated to the expected noun and another that came from the same semantic category as (and therefore shared semantic features with) the expected noun. They observed a graded effect on the N400, with the smallest amplitude associated with the expected noun and the largest amplitude associated with the anomalous word from a different semantic category. Anomalous words from the same semantic category elicited N400 responses of intermediate amplitude, indicating that comprehenders used the context information to pre-activate semantic features of the most expected word (Federmeier & Kutas, 1999a).

A similar design has been used to probe whether or not knowledge broadly associated with an event being described is active and can shape semantic access (as indexed by the N400). Metusalem et al. (2012) presented young adults with short passages like the one below:

My friend Mike went mountain biking recently.

He lost control for a moment and ran right into a tree.

These sentences established an event context. A third sentence was then presented, one word at a time:

It's a good thing he was wearing his _____ or he could have been seriously hurt.

This sentence contained a noun that was either an expected continuation of the sentence (*helmet*), an anomalous noun related to the event described (*dirt*), or an anomalous noun unrelated to the

event (*table*). Similar to the three-way effect observed by Federmeier and Kutas (1999a), N400 amplitudes were smallest for the expected word and largest for the unexpected, event-unrelated word, with the unexpected, event-related word falling in between. This indicates that young adults were activating knowledge of the larger event while reading, allowing them to more readily access words in memory that were related to the event, even if the word was inappropriate in the immediately unfolding language context (Metusalem et al., 2012). Interestingly, although activations of likely upcoming words and their semantic categories (Federmeier & Kutas, 1999a) and activation of event knowledge (Metusalem et al., 2012) both create similar "related anomaly" effect patterns on the N400, there is evidence that these effects arise from different neural networks. Visual half-field studies, probing for hemispheric processing asymmetries, have shown that left hemisphere processes are critical for building language-sequence-based expectations (Federmeier and Kutas, 1999b). In contrast, there is a right hemispheric bias for event knowledge use. Using the same design and similar materials as Metusalem et al. (2012), Metusalem et al. (2016) presented target words either to the left visual field (right hemisphere) or the right visual field (left hemisphere). Once again, a reduced N400 amplitude for event-related, anomalous words was observed, but only with left visual field/right hemisphere presentation, suggesting that right hemisphere processes play an important role in the activation and/or use of event knowledge.

Taken together, these studies suggest comprehenders activate and use multiple sources of information, including their knowledge of typical events, during on-line comprehension. However, the literature reviewed thus far has been conducted only with young adults. As reviewed next, normal aging changes comprehension processes in several ways, raising questions about how event knowledge may shape language processing across the life span.

1.2 AGE-RELATED CHANGES IN LANGUAGE USE

Language comprehension is multi-faceted, recruiting multiple brain networks to rapidly assess language and event context and make predictions about upcoming words. It follows that changes in processing ability, such as with normal aging, would affect language use. Understanding which aspects of language processing are preserved and which change with age is important for thinking about how older adults may — or may not — make use of event knowledge during comprehension.

Vocabulary knowledge typically grows across the lifespan, with adults showing increased vocabulary into at least their 60s (Salthouse, 2019). This preservation/augmentation of word knowledge is in line with other work showing that general knowledge (or crystallized intelligence) is maintained for most of the lifespan, while reasoning and novel problem-solving typically declines (Salthouse, 2012; Wang & Kauffman, 1993; Horn & Cattell, 1967). Thus, we would expect that event knowledge is largely preserved across the lifespan as part of the knowledge one accumulates about the world.

While accumulated knowledge may be preserved, aging is associated with changes in processing speed, both in perception and reaction time (Earles & Salthouse, 1995), and reductions in working memory capacity (Craik & Byrd, 1982). Older adults have also been shown to struggle with word retrieval in certain contexts. In particular, older adults seem to experience more tip-of-the-tongue (TOT) states when asked to recall proper names, but not when asked to recall biographical information, possibly suggesting greater difficulty retrieving words with fewer semantic relationships in memory (James, 2006). More TOT states were also observed in older adults when a word had low phonological neighborhood frequency (i.e., words that are similar to the given word do not occur often in spoken language), again suggesting that information that is

more weakly linked into the lexico-semantic network becomes more difficult for older adults to retrieve (Vitevitch & Sommers, 2003). Thus, even when knowledge is preserved, older adults may experience difficulties with timely/rapid retrieval of that knowledge.

Other studies have suggested that lexical retrieval difficulties in older adulthood are the result of reduced inhibition. Hartman and Hasher (1991) presented sentences to older and younger adults, but instead of using the expected (high cloze probability) ending ("She ladled soup into her *bowl*."), participants were shown an unexpected but comprehendable ending ("She ladled the soup into her *lap*."). Whereas younger adults only showed retention of the word that was actually shown ("lap"), older adults showed retention of both the word they actually saw and the expected ending that was never shown ("bowl"), indicating an inhibition deficit. Similarly, Sommers and Danielson (1999) found a relationship between inhibitory abilities and recognition of words with high neighborhood density. However, there is also an indication that more information allows older adults to overcome these possible inhibition deficits. For example, while Hartman and Hasher (1991) found that older adults struggled to inhibit expected endings when they were not shown, Hasher et al. (1997) found that this effect disappeared when older adults were given an additional sentence that interpreted the target word.

EEG studies with older adults have also documented age-related changes in on-line comprehension processes. Older adults exhibit preserved lexical processing, such as during word association tasks; however, their semantic access (as indexed by the N400) does not seem to be as facilitated by sentential context (Wlotko et al., 2010). In particular, it has been shown that older adults are less likely to use context to make predictions about upcoming words. For example, Federmeier et al. (2002) showed that, although older adults exhibit facilitated N400 amplitudes to words that fit a sentence compared to anomalous words, they do not show related

anomaly effects like young adults do. Thus, older adults do not seem to use context information to pre-activate semantic information about likely upcoming words, an age-related change that reflects alterations in left-hemisphere functioning (Federmeier & Kutas, 2019).

These findings, in combination with those from behavioral studies, suggest that although older adults continue to comprehend language effectively, they do so using somewhat different sets of mechanisms compared to younger adults.

1.3 EVENT KNOWLEDGE USE IN OLDER ADULTS

Although a number of changes in comprehension as a result of normal aging have been documented, there is evidence that use of event knowledge may be preserved. For example, Radvansky et al. (1990) asked participants to listen to sentences describing an event and then to complete a numerical addition task, which served as a distraction. Following that, participants were presented with a surprise recognition task, in which they were asked to select the sentences they had previously heard among choices that were extremely similar, with a critical difference between the two types of "distractor" sentences. In one distractor case, the change made to the sentence would require a different mental model (receiving a call "in the optician's" or "from the optician"); in the other, the mental model was unaffected by the change to the sentence (getting contact lenses "in the optician's" or "from the optician"; Radvansky et al., 1990). Younger and older adults performed similarly, tending to fall for distractor sentences that did not alter the mental model from the original sentence at the same, much higher rate, indicating that both young and older adults were using mental models of described events.

Other studies have indicated that older adults may rely even more heavily on event knowledge for language comprehension as they experience declines in text-based processing abilities.

Radvansky et al. (2001) asked participants to read texts and complete a recognition task with measures of their use of text-based information and situation models (representations of what the text was about). Whereas younger adults remembered more text-based information, older adults showed similar — and in some cases slightly better — recall of situation model information, indicating that older adults were likely to rely more heavily on situation models to help them recall information. Additionally, a study by Shake et al. (2009) found that older adults remembered elaborated text much better than factoids, with the researchers concluding that more elaboration and context is less demanding of working memory and therefore compensates for memory deficits in older adults.

Although it appears that the use of event knowledge during comprehension is preserved in older adults, there may still be changes in access to that knowledge with age. For example, studies have indicated changes in event segmentation abilities with age; importantly, older adults appear to struggle to perceive changes in goals within a narrative, affecting their memory of events (Kurby & Zacks, 2011). However, there is also evidence to suggest that older adults rely more heavily on knowledge when processing familiar scenarios (Balota et al., 2000). In a recent study by Pitts et al. (2022), participants watched videos of actors performing everyday tasks and explicitly marked the boundaries between events in the video while trying to remember as much about the video as possible. Whereas young adults performed similarly for events that were and were not familiar to them, older adults' performance on both segmentation and memory tasks was better, and matched the performance of young adults, only when they were familiar with the activity shown in the video (Pitts et al., 2022).

Overall, extant results suggest that event knowledge is well-retained into older adulthood, similar to other types of accumulated knowledge (Salthouse, 2012; Wang & Kauffman, 1993; Horn &

Cattell, 1967), and that this knowledge can support comprehension behavior and downstream memory. Indeed, effective use of event knowledge could serve as a potential compensatory mechanism as working memory and processing speed decline. However, there are also indications from the event-segmentation literature that there may be age-related changes in older adults' ability to rapidly access and/or use that knowledge during on-line processing, at least if that knowledge is less well-established. This raises questions about whether there are age-related differences in how event knowledge is brought to bear during language comprehension.

1.4 PRESENT STUDY

Based on previous work, it can be concluded that event knowledge is used during language comprehension and, at least in young adults, has almost immediate effects on processing, as shown by N400 studies. In the case of older adults, although there is evidence that event knowledge is used during comprehension, there is also evidence of changes in online language processing, meaning they may not use event knowledge in the same ways as young adults. While studies have shown that sequential prediction, mediated by left hemisphere processes, may become less efficacious with age, there has not been any study of how event knowledge use, which has been associated with right hemisphere processing mechanisms, changes with age. Therefore, the present study examines the activation of event knowledge during real-time language comprehension in younger and older adults using the study design of Metusalem et al. (2012).

We expect patterns in the young adult sample to replicate Metusalem et al. (2012), with facilitated (less negative) N400 responses to contextually expected targets, large N400 responses to anomalous words that are unrelated to the event being described (event-unrelated targets), and

responses of intermediate amplitude to anomalous words that are related to the event being described (event-related targets). Critically, such differences between the two anomalous conditions attest to the broad activation of knowledge associated with the event being described, which then has an immediate effect on semantic access even for target words that are incongruent with the unfolding sentence.

Of primary interest are patterns within our healthy older adult sample. Given that older adults have more real-world knowledge and experience, it is possible that they will exhibit the same N400 effect pattern as the young adults, with not only the (well-attested) effect of contextual fit, but additional facilitation for anomalous but event-related words. This pattern would indicate that language processes involving event knowledge activation are largely preserved across the lifespan. Such an outcome would provide an interesting contrast with the *lack* of a related anomaly effect observed in other work for words that share semantic features with predicted targets (e.g., Federmeier et al., 2002). Event-knowledge-based related anomaly effects may be more likely for older adults because there is less time pressure, given that information about the event being described is available early – well in advance of the target word. Thus, age-related changes in processing speed, which could impact other aspects of context use, may not play as much of a role in event-knowledge use. Moreover, as previous work has focused mainly on aging effects that have been attributed to the left hemisphere, it is possible that event knowledge use — an ability associated with the right hemisphere (Metusalem et al., 2016) — may be differentially affected by age.

On the other hand, similar to patterns in other related anomaly studies using older adults, we may observe a pattern in which N400 effects in older adults are limited to contextually expected targets, with no additional differentiation among the anomalous targets as a function of their

event-relatedness. This pattern could arise if older adults' event-knowledge activation is more sensitive to familiarity, as observed by Pitts et al. (2022). Given that our materials cover a wide range of event types, if older adults are unfamiliar with some of the situations described in the contexts (e.g., they have never gone surfing), then access to experiential knowledge may limit their ability to activate the correct event knowledge structures often enough to show a reliable effect. Alternatively, it may be that decreases in working memory capacity prevent older adults from activating as much information as young adults or maintaining it in working memory for as long. Indeed, it may even be strategic for older adults to narrow the scope of their event knowledge activation to better cope with age-related processing changes.

Finally, it is possible that effects of event-relatedness could be observed in a later time window, such as on the Late Positive Complex (LPC). In Metusalem et al. (2012), there was limited analysis of patterns following the N400. In language research, posteriorly-distributed late positive potentials (often referred to as late positive components, or LPCs) have been viewed as resulting from explicit processes of semantic integration (Brouwer et al., 2012) and working memory updating (Van Petten & Luka, 2012). Previous research has suggested that late posterior positivities in response to unpredicted input could be a result of attempts to reevaluate and repair interpretations of discourse (Kuperberg et al., 2020). Given our stimuli and these possible explanations for late window effects, we will here examine patterns on the LPC for both the younger and older adult groups.

CHAPTER 2: METHODS

2.1 PARTICIPANTS

2.1.1 Older adults

Forty-three adults over the age of 50 from the local community participated and were compensated with a cash payment. All participants were right-handed, as assessed by the Edinburgh Inventory (Oldfield, 1971). Participants self-reported as being native English speakers with normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. All participants provided written informed consent prior to participation. Six participants were removed from the final analysis due to a loss of more than 34% of trials in one or more conditions due to artifacts. From the remaining 37 participants, ten participants from each of the three counter-balanced lists with the lowest numbers of trials rejected across conditions were selected for a final total of 30 participants (23 self-identifying as female; age range: 53-80; mean age: 65.7). Average education level was 17.1 years (some post-graduate study). The average Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) score was 28.1 out of 30 possible points (range: 25-30), indicating no evidence of cognitive impairment in any participants. All participants answered at least 90% of comprehension questions correctly, indicating that they were attentive in their reading for comprehension.

2.1.2 Younger adults

Thirty-two adults between the ages of 18-30 from the University of Illinois community participated for course credit. All participants were right-handed, as assessed by the Edinburgh

Inventory (Oldfield, 1971). Participants self-reported as being native English speakers with normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. All participants provided written informed consent prior to participation. Three participants were removed from the final analysis due to a loss of more than 34% of trials in one or more conditions due to artifacts. From the remaining 29 participants, eight participants from each of the three counter-balanced lists with the lowest numbers of trials rejected across conditions were selected for a total of 24 participants (15 self-identifying as female; age range: 18-22; mean age: 19.3). Average education level was 12.4 years (high school diploma). All participants answered at least 88% (mean: 0.96; range: 0.88-0.99) of comprehension questions correctly, indicating that they were reading attentively.

2.2 MATERIALS

We used the 72 three-sentence scenarios from Metusalem et al. (2012). The first two sentences established the context of a specific event. The third sentence was then constrained toward a particular (expected) noun, which had a mean cloze probability of 0.81 (range = 0.37-1.00; SD = 0.17; details of cloze probability norming in Metusalem et al., 2012). In the position of that target noun in the third sentence, three types of words were used: the expected target (highest cloze probability) word, an anomalous word (cloze probability = 0) that was related to the event described in the context sentences (event-related target), or an anomalous word (cloze probability = 0) that was unrelated to the event described in the context sentences (event-unrelated target). Target words were always in a mid-sentence position and all three conditions then continued identically (for examples, see Table 1).

The event-related targets for each scenario were selected from a task in which participants were shown the three-sentence scenarios and asked to "paint a mental picture" of the event described, then list up to five words associated with the described scenario (for more details about this norming task, see Metusalem et al., 2012). Words were scored based on the order listed, and the highest scoring, semantically anomalous word for each scenario that was never provided in the cloze task was chosen for the event-related condition.

The 72 scenarios were divided into three groups of 24 scenarios, with three lists being constructed by rotating each group through the three experimental conditions. Every scenario appeared once in each list and once in each condition across all three lists. The three rotation groups were matched for mean cloze probability (mean = 0.81), log frequency (mean = 6.95), and orthographic length (mean = 5.68) for expected targets and mean event–relatedness score (mean = 92.36 out of a possible 225 points), log frequency (mean = 6.86), and orthographic length (mean = 5.87) for event-related targets. To control for lexical factors across the two types of anomalous words, the event-unrelated targets were created by shuffling the list of event-related targets and pairing each with a scenario wherein the cloze probability for that word was zero, the event-relatedness score was zero (for all but two scenarios), and the word was matched in animacy and concreteness with the event-related target.

An additional 24 filler scenarios, containing no anomalous target words, were added to all three lists to maintain an even number of anomalous and non-anomalous trials. Participants were assigned one of these lists at the start of the experiment starting with List 1 and the order of items in each list was randomized for each participant.

Each scenario had a corresponding yes/no comprehension question to ensure attentiveness of the participant. The questions were designed so that the answer was obtainable regardless of the

condition of the third sentence. A complete appendix of stimuli can be found in Metusalem et al., 2012.

Table 1: Examples of Context Sentences, Third Experimental Sentences, Target Words, and Comprehension Questions

Context Sentences	**Final Sentence**	**Target**	**Comprehension Question**
My Aunt Bettie was very popular in our family. When she died, lots of people gathered to pay their respects.	Her three brothers and three sisters all gave very moving _____ during the service.	Expected: **speeches** Event-related: **coffins** Event-unrelated: **drinks**	Was Aunt Bettie liked by the rest of the family? Answer: Yes
For several months, there had been burglaries in the neighborhood. Many people thought they knew who the crook was.	Finally, he was caught when he set off somebody's _____ one night.	Expected: **alarm** Event-related: **police** Event-unrelated: **doctor**	Was the crook eventually caught? Answer: Yes
My friend Julie spends all her time exercising. The machine she likes the most is the treadmill.	By the time she's done, she's drenched in _____ and breathing very heavily.	Expected: **sweat** Event-related: **towel** Event-unrelated: **couch**	Does Julie exercise frequently? Answer: Yes

2.3 PROCEDURE

Prior to EEG setup and recording, participants completed an updated version of the Author Recognition Test and a Magazine Recognition Test (ART/MRT; Acheson et al., 2008). These assessments consist of 130 names or titles, 65 real and 65 fake; participants are asked to select only the names or titles that they are certain are names of authors or titles of magazines. These tests have been shown to correlate with measures of analytic intelligence, vocabulary, verbal fluency, reading comprehension, and history and literature knowledge (Acheson et al., 2008; Stanovich & West, 1989). For younger adults, the average ART score was 10 (range: 3-24) and the average MRT score was 4.4 (range: -1-21). For older adults, the average ART score was 36.7 (range: 11-61) and the average MRT score was 23.4 (range: 11-36). Thus, the older adults showed evidence of an overall higher level of exposure to (traditional forms of) written text. Participants also completed a verbal fluency task, in which they were given one minute to name as many words as they could that either began with a particular letter ("F," "A,", and "S") or belonged to a particular category (animals, fruits and vegetables, and first names). For younger adults (scores only available for 19 of the 24 participants), the average letter total was 38.6 (range: 24-48) and the average category total was 69.6 (range: 46-87). For older adults (scores only available for 29 of the 30 participants), the average letter total was 49.9 (range: 23-74) and the average category total was 77.6 (range: 53-110). For both groups, FAS totals were within one standard deviation of normative mean for age and education (Tombaugh et al., 1999).

During EEG recording, participants were seated in a quiet room approximately 100 centimeters from a 21-inch CRT computer monitor. A white noise machine was placed outside the room to muffle external noise. Participants were instructed to read each scenario for comprehension. Stimuli were presented in white Arial font on a black background. Each trial began with both

context sentences appearing on the screen in paragraph format. The participant then pressed a key to proceed to the final sentence. A red crosshair appeared at the center of the screen, cueing the participant to avoid blinking or moving their eyes during the presentation of the third sentence. After 1000 ms, the third sentence was presented above the crosshair, one word at a time (rapid serial visual presentation, RSVP) with a 500 ms stimulus onset asynchrony (SOA) divided into a 200 ms stimulus duration and a 300 ms inter-stimulus interval (ISI). A comprehension question appeared 2000 ms after the final word of the third sentence was presented, and participants indicated their answer by pressing the corresponding key (the "F" for "yes" and "J" key for "no").

Participants completed a practice block of four, non-anomalous trials prior to starting the actual experiment. The 96 total trials were divided into six blocks of 16 trials, and participants were offered a break between blocks. Participants were debriefed about the purpose of the study after the experiment was completed.

2.4 EEG RECORDING AND PROCESSING

EEG was recorded from 26 evenly spaced silver-silver chloride electrodes attached to an elastic cap in an equidistant arrangement (see Figure 1). These electrodes were referenced online to the left mastoid and re-referenced offline to the average of the left and right mastoids. Additional electrodes were placed on the left and right infraorbital ridges to monitor for blinks and on the outer canthus of both eyes to monitor horizontal eye movements. Impedances of all electrodes were kept below 5 KΩ. Signals were amplified by a BrainVision BrainAmp DC with a 16-bit A/D converter, bandpass filter of 0.016-250 Hz, and a sampling rate of 1000 Hz. The continuous

EEG was high pass filtered offline through a 0.1 high pass Hz filter (two-pass Butterworth with a 12 dB/oct roll-off).

To obtain ERPs for target words, each participants' EEG was time-locked to the onset of the target word across a 1000 ms post-stimulus epoch with a 200 ms prestimulus baseline. Before averaging, trials contaminated by blinks, muscle activity, channel drift, or amplifier blocking were discarded. Thresholds for artifact rejection were set for individual subjects, determined by condition-blind visual inspection of raw waveforms. For older adults, a mean of 8.8% of target word epochs were rejected due to artifacts (9.2% in unrelated condition, 9% in related condition, 8.1% in expected condition). For younger adults, a mean of 5.6% of target word epochs were rejected due to artifacts (7.5% in unrelated condition, 3.5% in related condition, 5.7% in expected condition). The 24 filler trials were not included in analyses. ERPs were formed by averaging in the time domain for each participant and each condition.

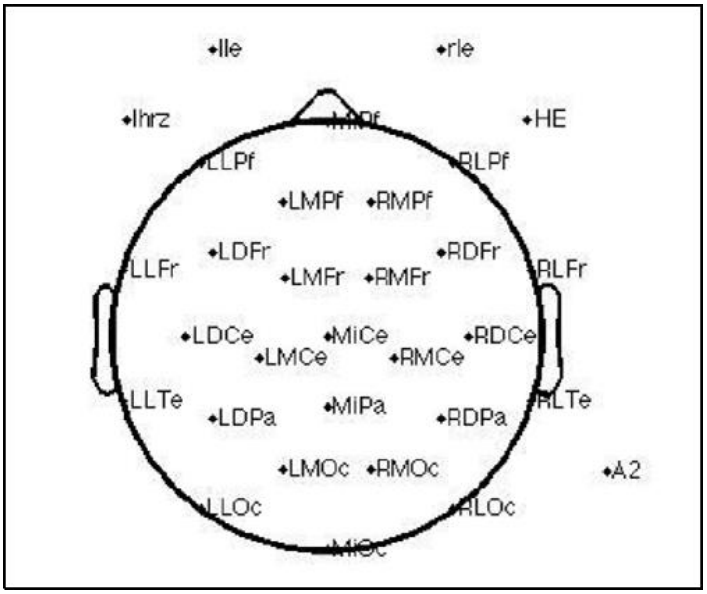

Figure 1: labeled schematic of electrode montage.

CHAPTER 3: RESULTS

Figure 2 displays the grand average ERPs of both participant groups for target word at each of the 26 scalp electrodes from 200 ms pre-stimulus to 1000 ms post-stimulus, arranged according to the distribution of electrodes across the scalp presented in Figure 1. To quantify the N400, mean amplitude measures were taken in a 300-500 ms window, averaged across a set of electrodes where N400 amplitude is usually maximal (following Wlotko et al., 2012), including LMCe, RMCe, MiCe, MiPa, LDPa, and RDPa channels. Figure 3 shows a larger version of the effect pattern at a representative electrode, MiPa. To quantify the late time window effects, mean amplitude measures were taken in a 700-900 ms window, averaged across a set of electrodes where LPC amplitude is maximal and N400 contamination is limited (Delogu et al., 2021), including LLOc, RLOc, LMOc, RMOc, and MiOc channels.

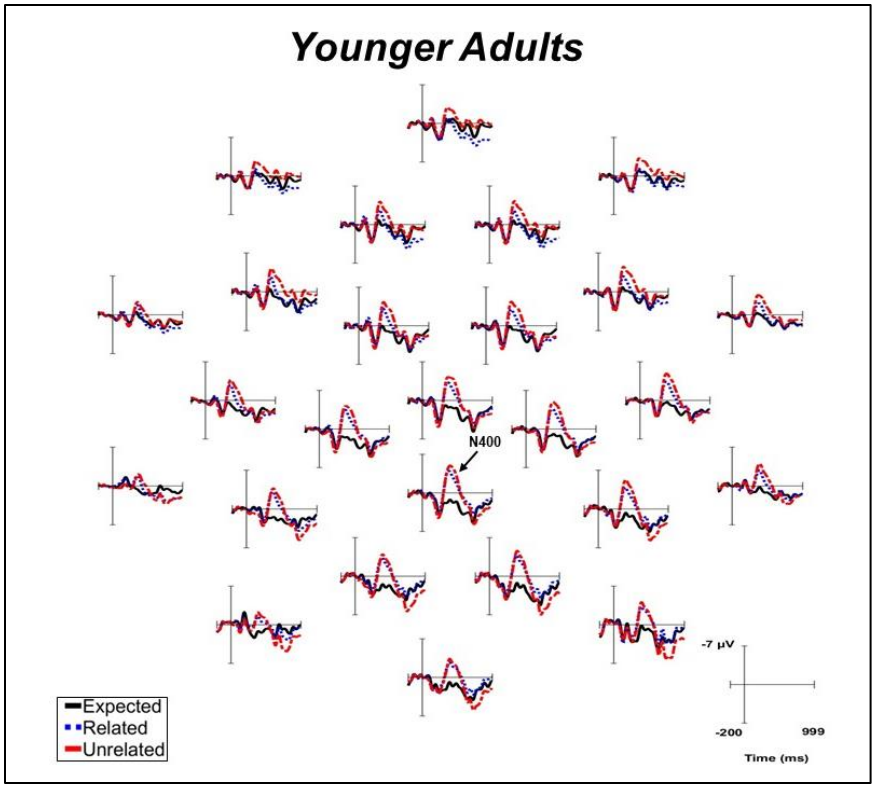

Figure 2: Grand average ERPs time-locked to presentation of target words at all scalp electrodes. Negative is plotted up

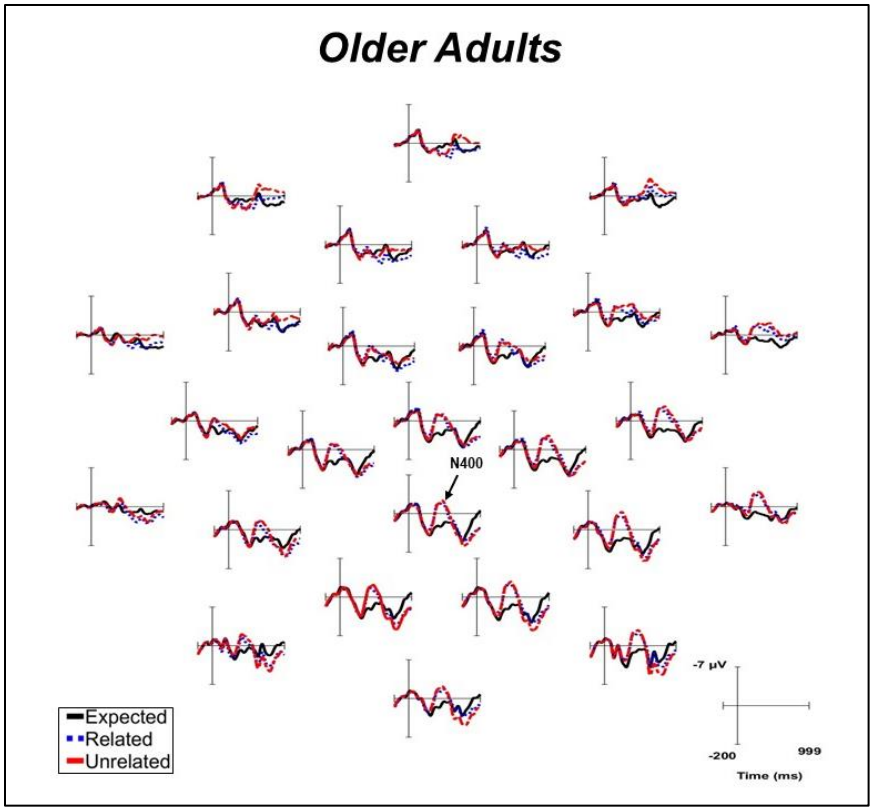

Figure 2 (cont.): Grand average ERPs time-locked to presentation of target words at all scalp electrodes. Negative is plotted up.

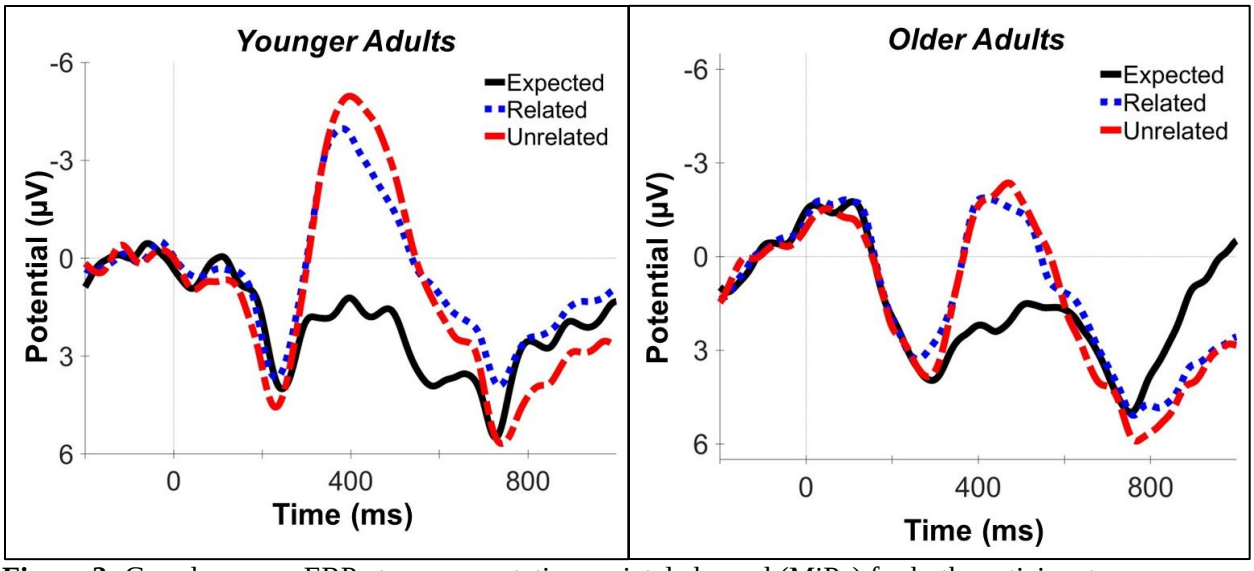

Figure 3: Grand average ERP at a representative parietal channel (MiPa) for both participant groups time-locked to presentation of target words for younger adults (left) and older adults (right). Negative is plotted up.

3.1 N400

3.1.1 Younger adults

To compare N400 amplitude differences across the three conditions, the mean amplitudes from 300-500 ms for each condition (Expected: mean = 1.43 μV, SE= 0.39 μV, Event-related: mean = -2.35 μV, SE = 0.33 μV, Event-unrelated: mean = -3.39 μV, SE = 0.56 μV; see Figure 4, left) were entered into a repeated measures ANOVA, with three levels of Condition, revealing a statistically significant difference between at least 2 conditions ($F(2,46) = 37.54$, $p < 0.01$). Follow-up analyses used paired t-tests. As expected, mean N400 amplitudes were smaller (less negative) for expected targets compared to event-unrelated anomalous targets ($t(23) = 2.22$, $p < 0.01$). Additionally, mean N400 amplitudes were smaller for expected targets compared to anomalous but event-related targets ($t(23) = 7.04$, $p < 0.01$). Finally, the mean N400 amplitude in the event-related condition was also significantly reduced compared to the event-unrelated condition ($t(23) = 0.92$, $p < 0.01$). In summary, we observe the same three-way effect of condition seen in younger adults in Metusalem et al. (2012).

3.1.2 Older Adults

Mean amplitudes from 300-500 ms for each condition (Expected: mean = 2.24 μV, SE = 0.35 μV, Event-related: mean = -0.50 μV, SE = 0.45 μV, Event-unrelated: mean = -0.60 μV, SE = 0.48 μV; see Figure 4, right) were entered into a repeated measures ANOVA, with three levels of Condition, revealing a statistically significant difference between at least 2 conditions ($F(2,58) = 29.18$, $p < 0.01$).

Follow-up paired t-tests showed that, as expected, mean N400 amplitudes to expected targets were smaller (less negative) than to either event-unrelated ($t(29) = 5.95$, $p < 0.01$) or event-related ($t(29) = 6.80$, $p < 0.01$) anomalous targets. However, the mean N400 amplitude in the event-related condition was not significantly reduced compared to the event-unrelated condition ($t(29) = 0.26$, $p = 0.79$). In summary, we do not observe the same three-way effect of condition seen in younger adults; instead we see a two-way difference between anomalous and expected conditions.

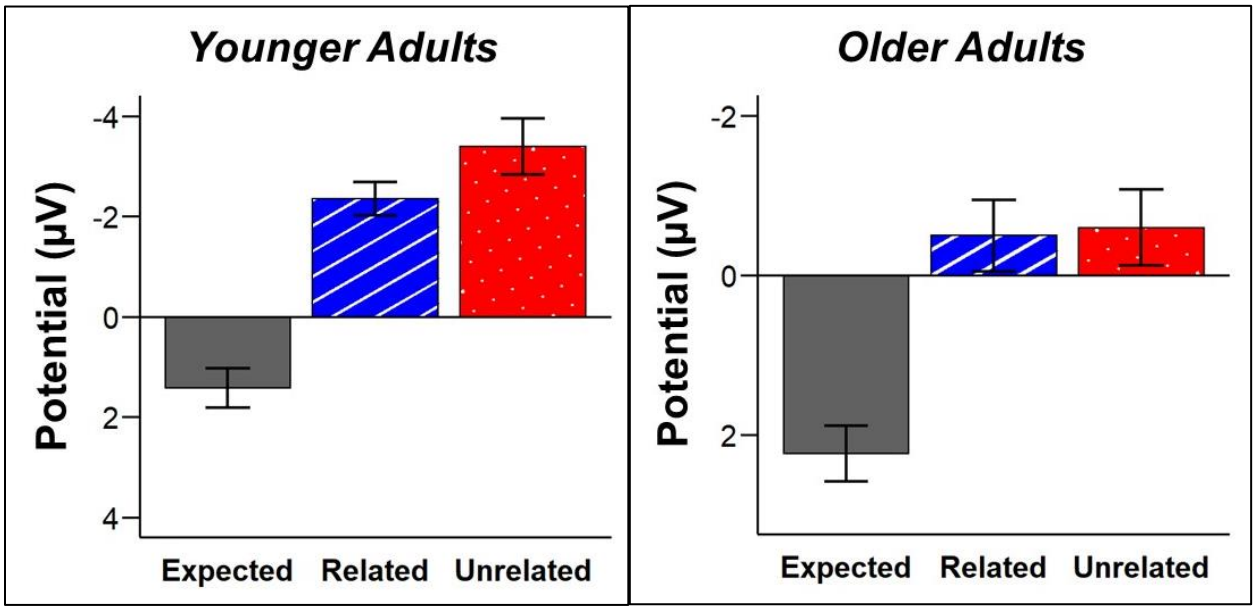

Figure 4: Mean N400 amplitude and standard error for each condition for younger adults (left) and older adults (right). Note there is a difference in scale of the y-axes. Negative is plotted up.

3.2 LATE POSITIVE COMPLEX (LPC)

3.2.1 Younger Adults

To compare LPC amplitude differences across the three conditions, the mean amplitudes from 700-900 ms for each condition (Expected: mean = 2.50 μV, SE = 0.49 μV, Event-related: mean = 2.43 μV, SE = 0.35 μV, Event-unrelated: mean = 4.95 μV, SE (μV) = 0.72 μV; see Figure 5,

left) were entered into a repeated measures ANOVA, with three levels of Condition, revealing a statistically significant difference between at least 2 conditions ($F(2,46) = 7.90$, $p < 0.01$).

Follow-up comparisons with paired t-tests showed that mean LPC amplitude in the event-unrelated condition was significantly greater (more positive) than in the expected condition ($t(23) = -2.93$, $p = .0076$) and than in the event-related condition ($t(23) = -3.35$, $p < 0.01$). However, there was no significant difference between the mean LPC amplitudes of the event-related condition and expected conditions ($t(23) = 0.14$, $p = 0.89$). In summary, we observe a two-way effect of condition, with the event-unrelated mean LPC amplitude being significantly greater than the expected or event-related conditions.

3.2.2 Older Adults

To compare LPC amplitude differences across the three conditions, the mean amplitudes from 700-900 ms for each condition (Expected: mean = 2.07 μV, SE = 0.36 μV, Event-related: mean = 3.29 μV, SE = 0.44 μV, Event-unrelated: mean = 4.26 μV, SE = 0.63 μV; see Figure 5, right) were entered into a repeated measures ANOVA, with three levels of Condition, revealing a statistically significant difference between at least 2 conditions ($F(2,58) = 10.27$, $p < 0.01$).

Follow-up comparisons with paired t-tests showed that mean LPC amplitude in the event-unrelated condition was significantly greater than in the expected condition ($t(29) = -3.71$, $p < 0.01$) and than in the event-related condition ($t(29) = -2.91$, $p < 0.01$). LPC amplitudes were also reliably larger for the event-related than the expected condition ($t(29) = -2.28$, $p < 0.05$). In summary, different from the pattern observed in younger adults, we find a three-way effect of condition on LPC amplitudes in older adults.

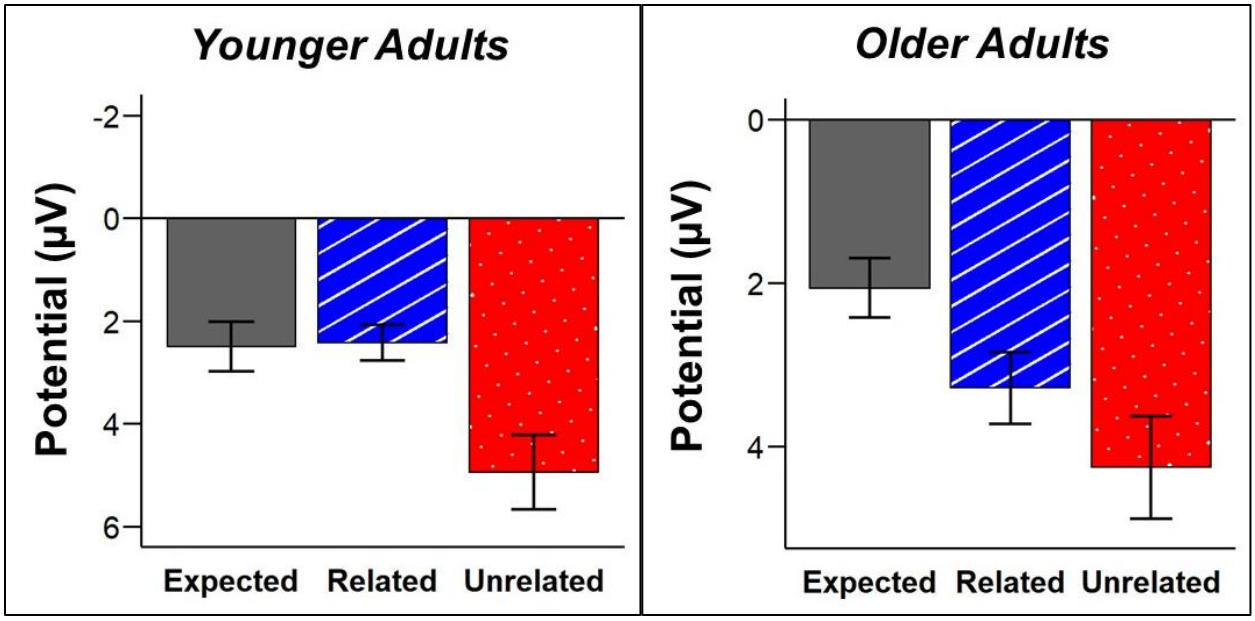

Figure 5: Mean LPC amplitude and standard error for each condition for younger adults (left) and older adults (right). Note there is a difference in scale of the y-axes. Negative is plotted up.

CHAPTER 4: DISCUSSION

The goal of this study was to examine real-time event knowledge use in older adults during language comprehension. By building up context in the first two sentences, we were able to measure ERP responses to expected and unexpected continuations in the third sentence and make inferences about whether older adults were activating event knowledge in real time. Replicating the study from Metusalem et al. (2012) with young adults using the same design and materials allowed for a direct comparison between patterns in young adults and older adults. In young adults, we observed a three-way effect on the N400 that was highly similar to the pattern observed by Metusalem et al. (2012), with anomalous words that were related to the described event eliciting a smaller N400 than a completely anomalous word. This suggests that young adults are activating general event knowledge while reading, including words that are relevant to the event but are not necessarily relevant to the specific sentence they are currently reading. Strikingly, we found a different effect pattern in healthy older adults.

In this study, we did not observe the same three-way effect in older adults that we observed in younger adults. Importantly, like young adults, older adults do differentiate between expected and unexpected continuations, with older adults showing significantly smaller N400 responses to expected continuations compared to anomalous continuations. This suggests that older adults are maintaining sensitivity to the contextual fit of words, particularly in strong contexts, in line with previous work (Wlotko & Federmeier, 2012). However, unlike young adults, older adults did not seem to reliably discriminate between event-related and event-unrelated anomalous words within the timeframe of the N400. Because older adult's semantic access of the target word was not facilitated by its event-relatedness, it seems that they either did not activate a broad event model

while comprehending or that they did not maintain activation of that event information long enough for it to impact semantic access when they encountered the target word in the third sentence.

In combination with previous work, some inferences can be made about how aging may affect brain networks. In young adults, Federmeier and Kutas (1999b) found evidence for left hemisphere bias for semantic context and Metusalem et al. (2016) found evidence for right hemisphere bias for event context. Together, these studies suggest that sequential prediction and event knowledge tap into different brain networks. Using visual half-field methods, Federmeier and Kutas (2019) showed that the left-hemisphere dominant networks that seem to be important for sequential prediction changed with age, such that older adults were less likely to show evidence of predictive processing. Although we did not directly probe hemispheric differences in the present study, the fact that we observed age-related differences in processing that, in young adults, has been associated with right-hemisphere networks, is suggestive that these networks, too, are undergoing age-related change. However, the specific cause of these changes is still unclear.

Interestingly, older adults did exhibit a graded effect in a 700-900 ms time window, during the time frame of the LPC, such that anomalous event-unrelated words elicited the largest positivity and expected words the smallest positivity, with event-related anomalous words eliciting an intermediate response. Although it is still unclear precisely which cognitive processes are reflected in the LPC, prior research suggests that late posterior positivities that late posterior positivities may be enhanced upon comprehending extended (compared to more minimal) linguistic context. Extended contexts likely motivates the construction of a situation model, and when information does not readily integrate into this model, readers may revisit the input and

attempt to make sense of it (Brothers et al., 2020). Our findings also align with claims that late posterior positivities reflect difficulty of reanalysis and integration of a given word into the provided context (Brouwer et al., 2017).

Unlike older adults, consistent with DeLong and Kutas (2020), younger adults exhibited a two-way effect in this time window, with anomalous words that were unrelated to the described event resulting in larger late positivities, and no significant difference in responses to expected and anomalous, event-related words. This is likely explained by the three-way effect observed in the N400 time window; event-relatedness is taken into account sooner in younger adults, and therefore does not require the same reevaluation efforts later on. The pattern shown in younger adults suggests a pre-activation of broad event knowledge structures; semantic information associated with the event-related words was already active when they were encountered, leaving little work for later explicit processing to do, unless the word is anomalous and unrelated to the event. In contrast, older adults are able to use event context to easily process the expected continuation and, when an unexpected word is presented, they are able to detect this anomaly and use more explicit processing to make sense of the anomalous word, with event-related words seeming to be more accessible during the updating process.

These results do not refute the claims made by behavioral studies that older adults can make use of event knowledge and situation models to shape their comprehension and memory, resulting in (in many cases) similar patterns of performance as those of young adults. However, these results contextualize those behavioral patterns by showing that older adults are not using event knowledge to shape semantic access during on-line processing in the same ways young adults do. Our findings indicate that young adults seem to maintain active knowledge about a broad array of event-related information, such that semantic access is facilitated for words that are

anomalous in the language sequence but that are related to the event being described. Older adults do not show a related anomaly pattern until later in processing, suggesting that their use of event-knowledge during reading differs in its timing and/or its breadth.

Because the N400 has been shown to reflect initial aspects of the contact between the incoming stimulus and long-term semantic memory (see review in Federmeier, 2022), one possible explanation is that older adults do activate broad event knowledge but, due to age-related changes in processing speed, cannot do so rapidly enough to impact the N400. However, the design of this study makes that an unlikely explanation. Event knowledge is not as time-sensitive as word-by-word prediction and can be activated as soon as context is provided. In this study, event context was established in the first two sentences, which participants were free to read at their own pace. This would seem to provide older adults with ample time to activate broader event knowledge structures prior to the third sentence. Since there was no effect of event-related words on the N400, it does not appear that these structures were activated, and it is less likely that time constraints offer a complete explanation for why this activation did not occur.

Indeed, although age-related changes are often framed as deficits, it is possible that the pattern in older adults, in which contextually irrelevant event-related knowledge is not actively maintained (resulting in the two-way effect on the N400) but can be readily accessed if needed (yielding the three-way effect on the LPC), is an adaptive use of event knowledge. Shake et al. (2009) argue that older adults rely more on event knowledge to lessen demands on working memory. It follows that older adults may not activate many event-related concepts and/or words, which could tax working memory, and instead limit their focus to a smaller range of related words. In the unlikely event that older adults are presented with an anomalous word, they are able to use more explicit processing to attempt to make sense of the unexpected word. Since younger adults

do not need to compensate for working memory deficits, they can afford to activate more event-related words as they form expectations about the upcoming word. In this case, the difference in patterns between younger and older adults would be the result of adaptation in response to limitations of working memory.

Inspection of individual participant data patterns revealed that there were some participants who appeared to show a clear three-way effect. As Metusalem et al. (2012) observed reliable individual differences across participants, it is possible that, with a larger sample size, there would be significant individual differences in N400 and LPC amplitudes. Indeed, Federmeier et al. (2002) found reliable individual differences in the category-prediction-based related anomaly effect, with older participants who had higher verbal fluency levels more likely to show the three-way pattern seen in young adults. Further work looking at event-knowledge use by older adults could therefore also examine how individual differences in verbal fluency or ART/MRT scores influence N400 and LPC amplitudes.

Together, these findings highlight the variation in event knowledge use during language comprehension across the lifespan. Our results align with proposals that older adults are able to use event knowledge to comprehend language and proposals that when and how knowledge is activated during online language comprehension is influenced by age. Importantly, although our results show that language comprehension processes are changing with age, they are consistent with claims that those changes are useful adaptations that may be part of the reason that language comprehension outcomes remain robust with advancing age, even in the face of underlying changes in factors such as processing speed and working memory.

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