Neurophysiological mechanisms of reading processes: Aging and context effects

by

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Abstract

Background. Context use in sentence comprehension is fairly resistant to age-related cognitive decline; however, event-related potentials (ERPs) studies have shown age effects in neural activity associated with sentence comprehension, specifically when contextual information is manipulated. One well-documented ERP component, N400, may reflect the use of context to predict upcoming words. Older adults have smaller and later N400 responses than younger adults for unexpected sentence-endings (Federmeier et al., 2002), suggesting age-related differences in how adults use context. As well, there is the post-N400 positivity (PNP) – both at the frontal and parietal regions - that may index attempted re-analysis of incongruent sentences, or reflect predictive processing, which is also influenced by age (Van Petten & Luka, 2012). The purpose of the present study is to determine whether there are age-related differences in reading comprehension of sentences with varying semantic anomalies, using electroencephalography methods.

Methods. Experiment 1 was designed as a pilot study, to investigate whether a passive reading paradigm would elicit the anticipated ERP responses. In Experiment 1, neurologically healthy young adults (n = 34; age range 18 – 30 years, M = 23.8, SD = 3.05) passively read pairs of sentences while wearing an electroencephalography cap. In Experiment 2, EEG was recorded while young (n = 22; age range 18 – 27 years, M = 21.1, SD = 2.62) and older (n = 21; age range 50 to 84 years, M = 62.0, SD = 8.98) adults read the same pairs of sentences as in Experiment 1, followed by a recognition memory task where they had to identify the presented sentence-ending word in order to elicit active processing of the stimuli. In both experiments, the reading task consisted of the presentation of two sentences. The first sentence established the context. The second sentence ended with a target word that was either 1) expected, 2) unexpected but

semantically related, or 3) unexpected and unrelated to the context. The amplitude and latency of the N400 and PNP were measured using electroencephalography for the final target word, in each experiment. Reading time and recognition memory accuracy (Experiment 2) was also measured.

Results. In Experiment 1, there was no significant N400 effect for the three sentence ending conditions. However, we detected a parietal PNP response in terms of mean amplitude. In Experiment 2, there were no significant differences in the behavioural measures between young and older adults (reading time and memory performance), as anticipated. Younger and older adults demonstrated maximal N400 responses for unexpected-unrelated words and minimal N400 responses for expected words. The latency of the N400 response was different between the groups, in which older adults had delayed processing in the earlier time window. Both groups of adults also demonstrated parietal post-N400 positivity (PNP) responses, contrary to previous literature.

Discussion. Younger and older adults performed similarly on behavioural measures and the N400 results indicated that older adults are able to use their semantic memory to assess the stimuli features similar to young adults. However, there was evidence for age-related differences in the N400 latency. The parietal PNP responses also showed differences in the processing of the stimuli between young and older adults. Overall, our findings are important for understanding the neural correlates underlying age effects on context use in sentence comprehension. As reading plays a vital role in our society, understanding how aging affects this ability will provide new insights into the corresponding neural mechanisms, with possible implications for clinical populations with reading impairments.

Keywords: aging, sentence context, reading, event-related potentials, N400, PNP

Preface

This thesis is an original work by Shrida Suha Sahadevan. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Neurophysiological mechanisms of reading in aphasia", Pro00041261, August 13, 2013.

This thesis may be modified for publication in a peer-reviewed journal. My role in this project was data collection, data analysis and interpretation, and I will be involved in the writing of the manuscript along with J. Cummine and E. Kim. As well, A. Kwan, A. Johns, and K. Wilson assisted with data collection for Experiment 1, and A. Kwan assisted with data analysis for Experiment 1. J. Cummine provided assistance for the statistical analyses. J. Cummine and E. Kim were the supervising authors, as they developed the idea for the project and edited the manuscript.

Dedication

This thesis is dedicated to my parents and my sisters, who have been my backbone, support and inspiration throughout my academic and research journey.

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List of Abbreviations

EEG: Electroencephalography

ERP(s): Event-related potential(s)

PNP: Post-N400 Positivity

Glossary of Terms

The following terms are used throughout the thesis document. To illustrate their meanings, a sample stimulus where context is established in the first sentence is presented.

Example: *She wanted to make her eyelashes look really black and thick. So she asked to borrow her older friend's…(mascara/lipstick/necklace).*

Predicted: when a specific lexical item is anticipated (e.g. *mascara*); related to cloze probability

Expected: when a semantic concept is anticipated (e.g. *makeup*) in a given context; related to constraint

Plausible: when a word logically fits in a given context; related to expectation and constraint

Semantically Related: Belonging to the same semantic category (e.g. *mascara* and *lipstick*)

Semantically Unrelated: Belonging to a different semantic category (e.g. *mascara* and *necklace*)

Constraint: the degree to which a context can produce a consistent expectation for a specific, forthcoming word and limits on the possible semantic concepts that can plausibly complete a sentence; related to expectation and plausibility

Cloze Probability: the probability of a specific target word completing a particular sentence frame; related to prediction

Neurophysiological mechanisms of reading processes: Aging and context effects.

Introduction

In 2015, 1 in 6 Canadians were over the age of 65 by Statistics Canada (2015); a proportion that is projected to increase substantially within the next few decades. As we age, we experience a general slowing of certain sensory, perceptual and cognitive abilities (Glisky, 2007). Therefore, as our aging population increases, our society is faced with the need to understand and address older adults' experiences. One area of interest is older adults' ability to read and comprehend. Modern society relies heavily on the ability to read in order to access and comprehend information. We also rely on contextual information to interpret the intended meaning of words and sentences in text (Van Berkum, 2008). Although declines in other cognitive processes are reported to occur with normal aging, language processes are thought to resist this decline (Glisky, 2007; Thornton & Light, 2006). Specifically, reading comprehension of sentences and the use of semantic context to facilitate processing seem to remain stable throughout the aging process (Henderson & Wright, 2016). Despite this evidence of reading comprehension remaining stable in terms of behavioural performance, neurophysiological evidence suggests there are age-related differences underlying reading comprehension (Federmeier & Kutas, 2005; Federmeier, McLennan, De Ochoa, & Kutas, 2002). The purpose of this study is to use a neuroimaging technique, electroencephalography (EEG), to explore the neurophysiological mechanisms underlying how young and older adults use semantic context during sentence comprehension.

Aging effects on sentence use in sentence comprehension

We often use context cues to interpret the semantics or intended meaning of words in spoken and written sentences to facilitate our language comprehension (Van Berkum, 2008).

Contextual information refers to the manner in which the processing of words embedded in sentences may be facilitated by semantic constraints (Mitchum, Haendiges & Berndt, 2005). For example, the phrase "*The paint turned out to be the wrong ...*" it is likely to be completed with "*color*." The semantic context allowed for the prediction of the upcoming word, based on our world knowledge and previous experience with language (Henderson & Wright, 2016).

Researchers have used a variety of operational terms to investigate how adults use contextual information during sentence comprehension. Although these terms are similar, there are subtle differences. For example, *prediction* refers to when a specific lexical item is anticipated, which is also similar to the term *cloze probability*: the probability of a specific target word completing a particular sentence frame. *Expectation*, on the other hand, is when a semantic concept is anticipated given a certain context, similar to *plausibility*, which refers to the logical fit of a word in a given context. *Constraint* is also similar, which refers to the degree to which a context can produce a consistent expectation for a specific, upcoming word. Operational definitions are also provided in the Glossary of Terms to further clarify the differences.

Although older adults may be slower in their response or reading times (Howard, 1983; Laver & Burke, 1993), their use of contextual information in sentence reading appears to be unaffected by aging. Several investigators have shown that older adults appear to retain the ability to use contextual information to facilitate on-line processing of words (Balota & Duchek, 1991; Burke & Harrold, 1993; Hopkins, Kellas, & Paul, 1995; Wingfield, Alexander, & Cavigelli, 1994). For example, older adults are able to use contextual information to draw inferences regarding exemplars that would match particular semantic categories; e.g. "bee" from "The insect in the clover stung the professor" (Light, Valencia-Laver & Davis, 1991). In part, this may be due to the notion that semantic information is important for on-line language

processing, and world-related knowledge (e.g. semantic memory) is retained, and even perhaps augmented with age (Salthouse, 1993). Thus, older adults may rely more heavily on their ability to use semantic context during sentence processing.

The stability of how information stored in semantic memory is organized and used in aging has been demonstrated in several behavioural studies. Older adults have been shown to perform as well as, or better than, education-matched young adults on standard vocabulary measures (Salthouse, 1993). Howard (1980) also demonstrated the stability of semantic memory organization by reporting that young and older adults generated similar exemplars when presented with taxonomic category labels. Semantic priming experiments have also been used to show that older adults' performance is facilitated by related word information; and in certain cases, greater priming effects may be observed due to their slower responses (Laver & Burke, 1993). The evidence shows that the use and organization of semantic memory does not change with age, potentially contributing to older adults' ability to use contextual information during sentence comprehension.

Despite evidence that older adults perform similarly to younger adults in terms of their use of context to process sentences they are reading, finer measurement tools such as eye-tracking methods reveal subtle differences in reading performance between young and older adults. Researchers have manipulated predictability in sentences (i.e., semantic context primes a specific lexical target) to investigate how readers use context. Previous studies that employed this technique show that both younger and older adults read highly predictable words more quickly than less predictable words (Balota, Pollatsek, & Rayner, 1985; Kliegl, Grabner, Rolfs, & Engbert 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006). However, the nature in which this occurs seems to differ as a function of age. In a study by Kliegl et al. (2004), young

adults skipped highly predictable words more often, but the older adults made fewer fixations on the highly predictable words and more on the unpredictable words. This suggests that though older adults retain the ability to use word predictability to facilitate sentence comprehension, the nature of their reading strategies may be different from younger adults.

Although the ability to use context in sentence comprehension remains stable as we age, perhaps due to stable semantic memory organization, the manner in which older adults use context may differ from young adults, especially in terms of linguistic prediction. Uncovering the neural correlates associated with sentence comprehension (e.g., use of contextual information) in younger and older adults would provide further insight into this language stability due to semantic memory and the differing nature of these context and predictability effects. Exploring the neural correlates of sentence comprehension, particularly for simpler tasks in which no age-related behavioural performance differences are expected may assist in the interpretation of why behavioural differences might emerge for more complex or difficult tasks (e.g. complex syntax).

Evidence from event-related potentials (ERPs)

Neuroimaging techniques have been used to investigate neural correlates of language processing, including *electroencephalography (EEG)*. In this technique, electrodes are placed along the surface of the scalp to measure voltage fluctuations and electrical activity within groups of neurons close to the scalp (Luck, 2005; Niedermeyer & Silva, 2005). Capitalizing on high temporal resolution of EEG, researchers have used measures of electrical brain activity known as event-related potentials (ERPs) to investigate the time in which stimuli are processed and the general topography of the processing. ERPs refer to the recording of the changes in brain activity that are time-locked to complex processing of stimuli (Luck, 2005); for example, the

electrophysiological responses to specific words can be measured. Certain ERP patterns have been linked to various cognitive functions, dependent on the timing and direction of the ERP component (Luck, 2005). These ERP patterns are often determined by averaging the EEG signals from the electrical activity across the scalp, across all the trials in one experimental condition and then interpreted by comparing them against the averaged ERPs of other experimental conditions, reducing the variability seen in these patterns for each individuals for the data analysis (Luck, 2005). Specifically, ERPs have been used to determine younger and older adults' usage of contextual information during sentence comprehension (Federmeier & Kutas, 2005; Federmeier et al., 2002; Rugg & Coles, 1995, Van Berkum, 2008). Two notable ERP components that are involved in semantic processing and integration of context include the *N400* and *Post-N400 Positivity (PNP)*.

N400. The N400 is a well-documented language-related ERP component that has been linked to semantic processing and integration of meaningful stimuli in both visual and auditory domains (Kutas & Federmeier, 2011). The N400 peaks in the negative direction around 400 milliseconds post-stimulus, but has been documented between the 300ms to 500ms time window. Reflected in the frontal, central and parietal areas, the N400 is slightly larger on the left hemisphere for visually presented words (Kutas & Federmeier, 2011) and anatomically most prominent in the medial parietal region (Federmeier & Kutas, 1999; Kutas & Van Petten, 1994).

First reported by Kutas and Hillyard (1980), the N400 was thought to index semantic integration. In a series of experiments including presentation of sentences with varying degrees of semantic incongruity (e.g., strong incongruity: *He took a sip from the transmitter*; moderate incongruity: *He took a sip from the waterfall*), Kutas and Hillyard (1980) demonstrated that individuals showed negative-deflecting ERPs in response to the semantically incongruent word.

The amplitude of the N400 was influenced by the degree of semantic incongruity of the final word. That is, the N400's amplitude was inversely correlated with the predictability of the stimulus in a particular context (Kutas & Hillyard, 1984). Therefore, "transmitter" elicited a greater negative deflection than "waterfall". They speculated that individuals were utilizing the sentence context to make predictions about upcoming words and the presence of a semantically incongruent word interfered with that language processing, resulting in a greater N400 amplitude.

Following Kutas and Hillyard (1980), several investigators have examined the extent to which the N400 reflects the use of contextual information to facilitate the prediction of the final word in a sentence (Cameli & Phillips, 2000; Debruille, 2007; Federmeier et al., 2002; Debruille, 2007; Kutas & Federmeier, 2000; Kutas & Federmeier, 2011; Van Petten & Luka, 2012). In these studies, predictability of the stimuli in sentence context is established by two factors: cloze probability and contextual constraint. Cloze probability refers to the probability of the target word completing that particular sentence. Therefore, the higher cloze probabilities would elicit a reduced N400, while the lower cloze probabilities (words that are incongruent with a context) would elicit the increased N400 (Federmeier & Kutas, 2005). Contextual constraint refers to the strength of a context to produce a consistent expectation for a specific, forthcoming word. For example, "The paint turned out to be the wrong …" is strongly constraining for the word "color", while "He was soothed by a gentle…" is weakly constraining and people can generate a wide range of sentence completions, such as "voice," "touch," and "hug". Specifically, highly constrained contexts can increase the predictability of an upcoming word as the sentence is processed (Henderson & Wright, 2016). Most studies investigating the N400 have an orienting task, such as a judgment task or memory task; however, passive reading of sentences, in which

the participants' attention is not actively engaged to ensure later performance on a behavioural task, have also been shown to elicit a N400 (Kutas & Federmeier, 2011).

Researchers have furthered explored how sentential context can facilitate word processing through predictive processing mechanisms. For instance, Federmeier and Kutas (1999) examined the effect of contextually induced expectation on the N400 response during sentence comprehension in young adults (18 to 24 years of age). They also assessed the impact of semantic memory organization on sentence context processing by creating different semantic categories. Context was established with the first sentence (e.g. She wanted to make her eyelashes look really black and thick). The subsequent sentence (e.g. So she asked to borrow her older friend's...) then ended with a final word that was either: expected (e.g. … mascara), unexpected, but from the same semantic category, (e.g. … lipstick) or unexpected, and from a different semantic category, (e.g. … necklace) to the context (Federmeier & Kutas, 1999). Participants showed reduced N400 amplitudes for the unexpected but semantically related final words (e.g. lipstick) when compared to the unexpected and semantically unrelated final word condition (e.g. necklace). Federmeier and Kutas (1999) postulated that the processing of the unrelated but semantically related words did not disrupt the on-line language processing as much as the unexpected, semantically unrelated sentence endings. Thus, establishing that sentence context facilitates the activation of semantic features of likely upcoming words, including the expected word as well as related ones (Federmeier & Kutas, 1999).

Aging effects on the N400. Despite previous studies suggesting a resistance to age-related cognitive decline for language comprehension (Thornton & Light, 2006; Wingfield & Grossman, 2006), subsequent studies using paradigms similar to the one outlined in Federmeier and Kutas (1999) have reported differences in older adults' ability to use sentence context

information (Cameli & Phillips, 2000; Federmeier et al., 2002; Wlotko, Federmeier, & Kutas, 2012). In these studies, certain N400 characteristics have reliably been reported to be affected by aging. For instance, the latency of the N400 (delay between the stimulus onset and the N400 response) has been shown to occur later in older adults for both auditory and visual modalities (Kutas & Iragui, 1998; Federmeier & Kutas, 2005; Woodward, Ford, & Hammett, 1993). This difference in latency may reflect a decline in processing speed for older adults that can possibly influence the impact of the context information on word processing (Federmeier & Kutas, 2005). The amplitude of the N400 also has been shown to become smaller with age (Kutas & Federmeier, 2011; Wlotko, Lee & Federmeier, 2010), but the nature of this difference is not clear (Wlotko et al., 2010).

Age-related declines may affect the way older adults effectively use contextual information to predict the upcoming word (Federmeier et al., 2002). For example, in a study by Federmeier and colleagues (2002), the N400 effect was examined in younger and older adults using the same paradigm as in Federmeier and Kutas (1999), except the stimuli were presented aurally. They expected both groups would use context predictively in a similar manner to previous literature (i.e., larger N400 amplitude for unexpected and semantically unrelated sentence endings) by relying on their semantic memory organization, in terms of category structure. They found that both groups showed similar N400 responses, suggesting that semantic memory organization remains intact with age. However, they found that in older adults, semantically related words elicited reduced N400 effects relative to semantically unrelated words only in the low constraint context. On the other hand, younger adults demonstrated similar N400 effects (reduced N400 effect for semantically related words) in the high, but not low constraint contexts (Federmeier et al., 2002). When collapsing across all conditions, they also found that

older adults had smaller N400 amplitudes than young adults. Thus, older and younger adults seem to be processing sentences differently based on how constrained the context is. Wlotko and colleagues (2010) have suggested that older adults may be less effective at engaging predictive processing mechanisms and may be using plausibility instead. Because of their stable semantic memory, older adults may tend to use plausibility to interpret meaning of sentences (Yoon et al., 2015). This is contrary to behavioural studies that found that older adults are able to predict during context use, albeit differently than young adults. The study by Federmeier et al. (2002) provided neural evidence that although semantic memory remains stable with age, older adults may become less effective at using context to predict upcoming words with aurally presented stimuli. However, it is unclear whether these effects would be also seen in a reading paradigm with similar stimuli that manipulated the semantic memory categorization and related context information.

Age-related differences in the N400 and predictive processing may also be attributed to increased difficulties in the usage of semantics, rather than the storage and organization, while processing incoming information (Federmeier & Kutas, 2005). Federmeier and Kutas (2005) investigated these differences by having young and older adults read sentences that were either strongly constraining with predictable endings or weakly constraining with an unpredictable ending. Both groups demonstrated smaller N400 responses to target words in the strong than in the weakly constraining contexts, but older adults demonstrated a later and smaller N400 response relative to the young adults. This suggests they were less successful than their younger counterparts in capitalizing on the information available to facilitate word processing in predictive contexts. To further explore this constraint effect, Wlotko and colleagues (2012) assessed young and older adults' responses to strongly and weakly constraining sentences with

the expected endings or unexpected but plausible endings. Similar to Federmeier and Kutas (2005), older adults demonstrated small and delayed N400 responses to the strongly constrained expected endings. As well, the weakly constraining sentences did not produce reliable N400 effects. These studies provide further evidence that aging affects the ability to use strong sentential context information, and weak sentential context may not facilitate word processing (Wlotko et al., 2010). Though these studies have provided some evidence towards differences in predictive processing in young and older adults, these studies manipulated the cloze probabilities of the target words to match the characteristics of each contextual constraint (strong constraint suggesting higher cloze probability). As cloze probability is a general indicator of predictability, focusing more on the cloze probability as opposed to the constraint would be optimal to truly decipher the effects of aging on predictive context use.

Summary of N400 effects. Overall, the N400 appears to be sensitive to age-related declines in sentence comprehension. Specifically, the N400 may provide insights into how predictive processing mechanisms and semantic memory organization during sentential context usage are impacted by age-related declines. Although the findings are mixed with respect to the characteristics of the N400 that are particularly sensitive to age related changes in cognitive processing (e.g., latency, amplitude), such variability is likely a result of paradigm choice (e.g. aural vs visual) and manipulated factors (e.g., cloze probability vs. contextual constraint). Further clarity about the nature of age-related changes during sentence comprehension can be sought through utilizing a reading paradigm, manipulation of cloze probability and examining additional ERP components.

Post-N400 Positivity. The Post-N400 Positivity (PNP) is less well-documented ERP component, but has been linked to semantic integration (Juottonen, Revonsuo & Lang, 1996),

confidence in the integration of a word within its context (Finnigan, Humphreys, Dennis & Geffen, 2002), and re-analysis of problematic sentences associated with predictive processing (Van Petten & Luka, 2012). The PNP is thought to begin approximately 600ms post-stimulus onset until about 900ms (Van Petten & Luka, 2012). Previous studies have reported two sources of the PNP: frontal and parietal (DeLong, Quante, & Kutas, 2014; Van Petten & Luka, 2012). As well, the PNP has been shown in a few studies to have left-hemisphere lateralization (Coulson & Van Petten, 2007; Kutas, 1993), which may reflect Federmeier (2007)'s postulation that predictive processing mechanisms originate in the left hemisphere.

Initially, the PNP was seen in studies as a biphasic response, along with the N400, in conventional manipulations of semantic predictability (see review by Van Petten & Luka, 2012). When comparing studies that contrasted congruent and incongruent sentence completions, Van Petten and Luka (2012) determined that the parietal PNP source was linked to incongruent words whereas the frontal PNP source was connected to congruent words. Incongruent words, including unexpected sentence completions, generally elicit the PNP with parietal topography (Van Petten & Luka, 2012), but the PNP is elicited by a wide variety of incongruent stimuli. The parietal PNP is thought to reflect attempted semantic reanalysis of the incongruent sentences after engaging in predictive processing (Van Petten & Luka, 2012). Recent studies have shown that semantic anomalies elicited this parietal positivity response (Kuperberg, 2007; van Herten, Chwilla & Kolk, 2006). On the other hand, congruent stimuli have been shown to elicit a frontal PNP, but the characteristics of this component remain unclear. Some researchers have shown that PNPs in this area are elicited during the interpretation of plausible sentence endings that are low in predictability (Van Petten & Luka, 2012). However, Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (2007) found a frontal positivity for unexpected items in strongly

constraining contexts, seeming to reflect a "revision" process when a prediction is not fulfilled. A frontal positivity is also elicited for lexically predicted expected words (Thornhill & Van Petten, 2012). As seen by the many findings for the frontal PNP, the understanding behind the functional difference of the frontal PNP from the parietal PNP remains unclear.

Subsequent studies have assessed the PNP response in sentential paradigms, by manipulating predictability and plausibility of a word completing a sentence (Wlotko et al., 2010). DeLong and colleagues (2014) aimed to further establish the difference between the two topographically distinct PNP ERPs. They included three sets of sentence completions: expected and highly plausible (high cloze), unexpected but plausible (low cloze), and unexpected and anomalous (low cloze). They found functional distinctions between the frontal and parietal PNPs with the frontal component associated with plausible, but not anomalous, words and the parietal PNP associated with the anomalous sentence completion. These studies reflect a possible distinction in the sentential predictability and plausibility processing. Specifically, the frontal positivity may reflect processing of both the cloze probability and contextual plausibility, in which lexically unexpected words, but also contextually plausible, elicit the response (DeLong et al., 2014). Further studies have to be conducted to further establish the presence of late positive components during sentence processing paradigms (Van Petten & Luka, 2012).

Aging effects on the PNP. The underlying mechanisms associated with an individual's ability to predict upcoming information is of interest for sentential context studies, especially for older adults. As seen in N400 studies (Federmeier & Kutas, 2005; Federmeier et al., 2002), older adults are less likely to predict upcoming information while reading sentences, but instead seem to rely on plausibility (Federmeier, 2007; Wlotko et al., 2010). If the PNP is associated with revising or reattempted analysis when a prediction is not fulfilled, then older adults may be less

affected by the processing consequences of revising incorrect predictions (Wlotko et al., 2010). For example, Federmeier and colleagues (2007) tested high and low sentence constraint with expected and unexpected endings in young adults and found that young adults showed increased ERP frontal positivity for the unexpected words in the high constraint contexts. In contrast, Wlotko, Federmeier and Kutas (2007) tested high and low sentence constraint with expected and unexpected endings in older adults and found that these individuals did not elicit a frontal PNP. This finding fits with the notion that prediction is not part of the sentential strategies older adults use in sentence comprehension (Wlotko et al., 2010). In another study by Federmeier, Kutas and Schul (2010), younger adults elicited a prefrontal positivity, which was not elicited by older adults. The young adults' PNP response likely reflected their processing of disconfirmed predictions (Federmeier et al., 2010). Thus, older adults are less likely to elicit a frontal PNP because of their decreased ability to predict effectively during context use. However, limited research exists on aging effects of the parietal PNP in sentential context processing. As the parietal PNP is linked to predictive processing, it is likely to be affected by aging.

Summary of PNP effects. The PNP is a late ERP component, implicated in a variety of functions including semantic integration using context or later processing associated with predictive processing. The two functionally distinct PNPs at the parietal and frontal areas may be affected by aging, as older adults are less likely to engage in predictive processing during sentence context use. However, further work is warranted to establish the impact of age on the PNPs, particularly in the parietal region.

Summary

Overall, the effects of aging on sentence processing and the use of sentential context have been explored in previous behavioural and electrophysiological studies (e.g. Federmeier &

Kutas, 2005; Federmeier et al., 2002; Wlotko et al., 2010). Behavioural studies show that older adults are able to use contextual information, most likely due to stability in their semantic memory. They are also able to predict upcoming information/words using semantic context during reading comprehension; however, the nature of their predictability is different from younger adults. The neurophysiological studies show that differences in the N400, and the less well-established PNP, have been found between young and older adult populations in sentential processing. Semantic memory organization appears to remains stable in these studies; however, predictability processing is less effective in older adults as shown by N400 and PNP findings, contrary to behavioural findings. As well, many studies manipulate the cloze probability as a function of contextual constraint, which lead to results not clearly elucidating the predictive processing mechanisms. To resolve these differences, a reading paradigm with semantic category stimuli similar to Federmeier et al. (2002) that instead focuses on manipulating cloze probability (e.g., predictability), as opposed to contextual constraint, may be optimal.

Research Questions and Hypothesis

Experiment 1. The purpose of this study is to function as a pilot experiment, to determine whether young adults demonstrate the N400 and PNP effects when passively reading sentences containing sentence context anomalies as opposed to actively engaging their attention during the reading to ensure later performance on a behavioural task.

Research Question 1. Do young adults demonstrate the N400 and PNP responses when passively reading sentences containing sentence context anomalies?

Hypothesis 1. Young adults should demonstrate the N400 effects; amplitude will be related to the degree of semantic context anomalies. For example, the most negativity during the N400 time window should occur for the unexpected, unrelated stimuli and the least negativity for

the expected stimuli. In terms of the PNP, young adults will elicit the PNP, with functional distinction between the unexpected-related (most positive at the frontal region) and unexpected-unrelated conditions, (most positive at the parietal region).

Experiment 2. The purpose of this study is to determine whether younger and older individuals differ when actively reading sentences presented visually that contain sentence context anomalies (i.e., with their attention engaged on the stimuli for the purposes of performing a behavioural task). Specifically, the purpose of Experiment 2 is to elucidate age-related differences in behavioural results and ERP (N400 and PNP) effects.

Research Question 1. Do young and older adults differ on behavioral measures when reading sentences that contain semantic context anomalies?

Hypothesis 1. Young and older adults will perform similarly with respect to task accuracy, but older adults will be slower in their reading time.

Research Question 2a. Do adults demonstrate the N400 and PNP responses when actively reading sentences containing semantic context anomalies?

Hypothesis 2a. All participants will demonstrate N400 responses, which will be influenced by the degree of semantic context anomalies. Both groups should elicit the most negativity during the N400 time window for the unexpected, unrelated stimuli and the least negativity for the expected stimuli. As well, young adults will elicit the PNP, with a functional distinction between the unexpected-related (most positive at the frontal region) and unexpected-unrelated conditions (most positive at the parietal region), while the older adults will not elicit a differentiated PNP response between the unexpected-related and unexpected-unrelated conditions.

Research Question 2b. Do the N400 and PNP responses (e.g., mean amplitude and latency) differ between young and older adults when reading sentences containing different degrees of semantic context anomalies?

Hypothesis 2b. Younger participants will elicit an N400 response where amplitude will be related to the degree of semantic context anomaly (e.g., minimal for the expected stimuli, large for the unexpected, semantically unrelated stimuli). The older participants will demonstrate a similar pattern of N400 responses, but with a smaller amplitude and longer latency relative to the younger participants.

Younger adults will demonstrate the frontal and parietal PNP, where amplitude will be related to the degree of semantic context anomaly (e.g. frontal - most positive for unexpected-related, minimal for unexpected-unrelated; parietal - most positive for unexpected-unrelated, minimal for unexpected-related). Older adults should not have a difference in the amplitude or latency between the unexpected-related and unexpected-unrelated conditions at the frontal and parietal region. Therefore, the responses will differ for the PNP between both groups.

Method

Participants

Experiment 1. Thirty-nine young adults (6 male, 33 female) were recruited through convenience sampling from the population of the University of Alberta (Edmonton, Alberta) students, with an age range of 18 to 30 years (M = 23.4, SD = 3.42). 36 younger adults were right-handed, 2 were left-handed and 1 was ambidextrous, as assessed by the Edinburgh Inventory (Oldfield, 1971). Participants with English as their first language, normal or corrected-to-normal vision, no neurological deficits nor learning or reading disabilities were included in the

final sample. Participants were offered a $10 gift card, and participants from the Department of Linguistics participant pool received partial course credit.

Five participants were excluded from the analysis because of technical issues during the EEG recording (n = 2) and too many artifacts in the recording (n = 3). Therefore, thirty-four participants (4 male, 30 female) were included in the final analysis, with an age range of 18 to 30 years (M = 23.8, SD = 3.05). Of these participants, 31 were right-handed, 2 left handed and 1 ambidextrous, as assessed by the Edinburgh Inventory (Oldfield, 1971).

Experiment 2. Twenty-two young adults (4 male, 18 female; age range of 18 to 27 years M = 21.1, SD = 2.62) were recruited through convenience sampling from the population of the University of Alberta (Edmonton, Alberta) and local Edmonton community through online advertisements and posters. Younger adults were offered a $10 gift card and parking/transit expenses were reimbursed. Twenty-one younger adults were right handed and one was left handed, as assessed by the Edinburgh Inventory (Oldfield, 1971).

Twenty-one older adults (5 male, 16 female; age range of 50 to 84 years; M = 62.0, SD = 8.98) were recruited from the local Edmonton population, through online advertisements, newsletter postings and presentations at senior activity centres. Older adults were offered a $10 gift card and parking/transit expenses were reimbursed. Seventeen older adults were right handed, 2 were ambidextrous and 2 were left handed, as assessed by the Edinburgh Inventory (Oldfield, 1971).

Overall, older adults (M =16.4 years, SD = 3.60 years) were significantly more educated than the younger adults (M =14.0 years, SD =2.15 years) when comparing years of schooling completed; $t(41) = -2.70$, $p = .010$. Participants were included if they had English as their first language, normal or corrected-to-normal vision, no neurological deficits, learning or reading

disabilities. All participants scored within normal range on the Raven's Coloured Progressive Matrices (Raven, 1976), which was used as a screening process to ensure normal nonverbal intelligence.

Materials

The stimuli used in this study were 160 pairs of sentences. Of these 40 were from Federmeier and Kutas (1999), and the remaining 120 pairs of sentences were developed based on procedures outlined by Federmeier and Kutas (1999) in Donnelly and Kinsman (2014). The first sentence established the context. The second sentence ended with a target word that was either 1) expected, 2) unexpected but semantically related, 3) unexpected and unrelated to the context. There were 40 pairs of sentences in each condition. An additional 40 pairs with expected endings were used as 'filler' sentences, to ensure an even number of expected and unexpected sentences. Stimuli are provided in the Appendix.

To create the target word stimuli, forty pairs of target words were chosen with an average Thorndike-Lorge written frequency of 655.56 (range 12 - 5786), average concreteness rating of 577.16 (range 381 - 640), and average imageability rating of 588.22 (range 402 - 642) (Thorndike & Lorge, 1944). These pairs of words represented 40 different categories (e.g. medical professionals, law professionals) and then, each category was grouped with another related category to create an overarching category (e.g. medical + law professionals → professionals).

The expected and semantically related words were chosen from the category (e.g. medical professionals), and the semantically unrelated word came from the overarching category (e.g. professionals). For example, the word "nurse" would be the unexpected and semantically

related target to sentence expected ending of "doctor," while "judge" would be the unexpected and semantically unrelated target.

The pairs of words were then used to create the 120 pairs of sentences. The first sentence established the semantic context and prediction for the target word in the second sentence ending (e.g. Tim had been having abdominal pain for three days, so he finally went to the hospital). The second sentence was manipulated to create three conditions of sentence ending target words (e.g. He thought he should be seen by a …).

1) expected (e.g. … *doctor*) - the most likely to complete the sentence based on the context sentence. These expected target words were chosen based on a cloze probability greater than or equal to 0.5 (Donnelly & Kinsman, 2014), to limit the amount of variability and to ensure the facilitation provided by context sentence. The expected target words were also required to be the word with the highest mean cloze probability from the sample. The mean cloze probability for all the expected target words was 0.86, excluding the filler sentences.

2) unexpected but semantically related (e.g. … *nurse*) - not likely to complete sentence but semantically related to the expected target word. The mean cloze probability of these words was 0.0016, with a range of 0 to 0.041.

3) unexpected and semantically unrelated (e.g. … *lawyer*). - not likely to complete the sentence nor semantically related to the expected word. The mean cloze probability of these words was 0.014, with a range of 0 to 0.24.

In addition to the three categories of sentences, forty pairs of filler sentences (80 sentences) were included as the control stimuli. The final word of the filler sentences was the semantically expected word. Therefore, there were an equal number of expected (expected +

filler) and unexpected (semantically related + unrelated) sentence final target words randomly presented to the participants.

Procedure

Experiment 1. Participants began the session by completing the informed consent form and completing the Edinburgh Handedness Inventory (Oldfield, 1971). This questionnaire assessed the laterality of the participant's hand in everyday activities or the dominance of their right or left hand, with a more positive result indicating right-hand laterality (Oldfield, 1971). The remainder of the testing session took place in a sound-attenuated testing room, with the lights turned off and the door closed. The participant wore an electroencephalography 64-channel Geodesic Hydrocel Sensor Net cap during the task.

Seated in front of a monitor screen in the testing room, participants were instructed to silently read the stimulus sentences to reflect passive processing of the stimuli. As seen in Figure 1, the stimuli were presented on a black screen with white font. Participants were prompted to press a button to move on to the next set of stimuli. A fixation cross was presented for 500 ms to orient the participant, which preceded the two sentences. All the words in the first sentence, which established the context, were presented simultaneously on the screen for an unlimited time, and the participants pressed the button to move to the next sentence. A 250 ms fixation cross separated the first sentence from the second sentence. The second sentence was presented one word at a time, with 500ms word-to-word onset time. The last word presented of the second sentence was the target word. The last word was randomized for each participant. The participants were prompted to press the button to read the next set of sentences. A total of 320 sentences (160 sets of paired sentences) were presented randomly, with 40 pairs of sentences in each condition (expected, unexpected-related, unexpected-unrelated or filler).

Experiment 2. The procedures for Experiment 2 were identical to Experiment 1 with the following changes: participants were administered the Raven's Coloured Progressive Matrices (Raven, 1976), and were instructed to remember the sentences that were presented, as they would receive a recognition memory task following the reading paradigm. This was to promote the active reading processing, in which their attention would be engaged for later performance on the recognition memory task as opposed to Experiment 1's instruction of passive reading. The paper-based recognition memory task included forty sentences that were randomly chosen from the experiment. The context sentence and part of the second sentence were written in the first column. In the second column, three choices for the sentence ending were given; each choice was one of the three potential sentence endings for that sentence. For example, if the stimuli presented was "Tim had been having abdominal pain for three days, so he finally went to the hospital. He thought he should be seen by a doctor," the participant would have to choose "doctor" from the options that would be "doctor/nurse/lawyer." Participants were instructed to circle the word they saw presented to them in the reading experiment from the three choices.

Data Collection

For both experiments, the participants read the sentences, presented in sequential fashion using E-Prime software on a desktop computer while the EEG signals were recorded from a high density 64 channel Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR). The electrode impedance was kept below 50 kΩ. The ERP data was sampled at 1000Hz and was initially referenced at the vertex electrode Cz. Behavioural data from the reading experiment was recorded by E-Prime. The EEG data was recorded by Net Station (version 4.5.6, Electrical Geodesic, Inc. [EGI], 2009), which was running concurrently on another desktop computer. The

EEG data was exported for analysis with the EEGLAB (Delorme & Makeig, 2004) toolbox in the MATLAB (MathWorks, Inc., 2013).

Design and Analysis

In Experiment 1, a within-subject one-way ANOVA design was used with Sentence Ending as the factor of interest with 3 levels (Expected, Unexpected-related, Unexpected-unrelated). The dependent measures of interest included mean amplitude and peak latency of N400. Mean amplitude was determined for the time windows of interest as the average of the responses in the corresponding time window in microvolts (μV). Peak latency was determined for the time windows of interest as the time in milliseconds for the peak of the grand averaged responses to reach maximum amplitude.

In Experiment 2, a 2 x 3 (Sentence Ending [Expected, Unexpected-related, Unexpected-unrelated]) x Age [Younger, Older]) mixed ANOVA design was used. For the behavioural analysis, the dependent measures of interest included the response time for the context establishing sentence and accuracy of the recognition memory test. For the ERP analyses, the dependent measures of interest included mean amplitude and peak latency. Because years of education completed differed significantly between the two groups, education was initially included as a covariate in the analyses. However, the years of education did not correlate with the dependent measures data (behaviour: accuracy, ERP: mean amplitude and peak latency). Therefore, we conducted the analysis without using education as a covariate.

A series of ANOVAs were run to test the outlined hypotheses. In cases where Mauchly's Test of Sphericity was violated, the Greenhouse-Geisser's correction was reported. Significant main effects and interactions were followed up with Bonferroni corrected *t*-tests ($p = 0.016$).

Behavioural analysis. Response time was a measurement of the time spent reading the context-establishing sentence and was determined as the time from the onset of the context sentence to the time the participant pressed the button to move on to the second sentence. Performance on the recognition memory task was determined as the number of correctly identified sentence endings in each category (expected, unexpected-related, unexpected-unrelated) as well as overall accuracy.

EEG analysis. Data collected from both experiments was analyzed with the EEGLAB toolbox (Delorme & Makeig, 2004) in MATLAB (MathWorks, Inc., 2013) along with a custom script in the program. Preprocessing of the EEG data included the signal from EEG recordings being band-pass filtered between 0.1 to 30 Hz. Then, the bad channel components were detected by visual inspection and removed before the signal was average re-referenced. The artifacts in the data were then corrected in the EEGLAB toolbox in MATLAB, by independent component analysis (Delorme & Makeig, 2004). Then, the data was interpolated with electrodes that were removed prior to independent component analysis. Thirty-six ms were added to each trial's latency, in response to Electrical Geodesic Inc.'s warning about a delay of the EEG data in the anti-aliasing filters of the EGI Net Amps 400. Single participant ERP averages were determined for each condition (expected, unexpected-related, and unexpected-unrelated) and were then grand averaged over the time window of 100ms before stimulus onset to 1000 ms after the stimulus onset. There was a 100ms baseline.

For Experiment 1 and 2, the electrodes of interest were the vertex (central) electrode, Cz, frontal electrode, Fz, and parietal electrode, Pz for the N400 effect. For the PNP effect in Experiment 1, electrode Fz and Pz were included in the analyses. For Experiment 2, electrode Fz was included as well as the left parietal electrode, P3. These electrodes were chosen based on the

findings from previous studies (see reviews Kutas & Federmeier, 2011; Van Petten & Luka, 2012). For Experiment 1, the grand averaged responses for each condition can be seen in Figure 2 for electrode Fz, Figure 3 for Cz, Figure 4 for Pz. For Experiment 2, refer to Figure 5 for Fz, Figure 6 for Cz, Figure 7 for Pz and Figure 8 for P3.

Based on previous studies, the N400 ERP component may appear from 300 - 500 ms post-stimulus (Federmeier & Kutas, 1999; Federmeier & Kutas, 2005; Federmeier et al., 2002; Kutas & Federmeier, 2011). Therefore, the time windows of 300-400ms and 400-500ms were chosen to encapsulate the N400 effect. In a review conducted by Van Petten & Luka (2012), the PNP was found to originate approximately 600 ms post-stimulus and up until 900ms, so the time window chosen was 600 – 900 ms post-stimulus. Peak latency and mean amplitude was determined for each time window and electrode. Also, topographical plots were determined for each time window. These plots were derived by subtracting the grand averaged responses between two conditions (unexpected-unrelated vs expected; unexpected-unrelated vs unexpected-related) and show the general scalp distribution of the ERP responses.

Results

Experiment 1

Behavioural results. Participants silently read the context sentence for a mean duration of 3885 ms (*SD* = 921 ms) prior to being presented the second sentence.

ERP Time Window 300 – 500 ms.

Topographical plot. The difference between the two conditions (expected and unexpected-unrelated) demonstrated a positivity that spreads over the anterior to the posterior regions (see Figure 9).

Mean amplitude. The mean amplitudes and standard deviations are reported in Table 1. The main effect of sentence ending was not significant at electrode Fz, $F(2,66) = 1.03$, $MSE = 0.60$, $p = .36$, electrode Cz, $F(2,66) = 0.58$, $MSE = 0.26$, $p = .57$, or electrode Pz, $F(1.70,56.1) = 0.053$, $MSE = 0.43$, $p = .93$.

Peak latency. Refer to Table 2 for the peak latencies and standard deviations for electrode Fz, Cz, and Pz. The main effect of sentence ending was not significant for electrode Fz, $F(2,66) = 0.049$, MSE=2938, $p = .95$; Cz, $F(2,66) = 0.59$, $MSE = 2258$, $p = .56$; or Pz, $F(1.70,56.0) = 1.05$, $MSE = 3808$, $p = .35$.

ERP Time Window 600 – 900 ms.

Topographical plot. As seen in Figure 10, the difference in activation between the two conditions elicits a strong frontal positivity and strong posterior negativity.

Mean amplitude. The mean amplitudes and standard deviations are reported in Table 3 for electrode Fz and Pz. At electrode Fz, the main effect of sentence ending was not significant, $F(2,66) = 2.07$, $MSE = 1.05$, $p = .14$. However, at electrode Pz, the main effect of sentence ending did reach significance, $F(2,66) = 4.47$, $MSE = 0.70$, $p = .015$. Paired sample t-tests were conducted to determine the nature of this effect. The expected ($M = 0.032$ μV, $SD = 1.51$ μV) condition was significantly different from the unexpected-unrelated ($M = 0.64$, μV, $SD = 1.16$ μV) condition, $t(30) = -2.82$, $p = .008$. The expected condition did not differ significantly from the unexpected-related ($M = 0.35$ μV, $SD = 1.18$ μV) condition, $t(30) = -1.22$, $p = .23$. The difference between unexpected-related and unexpected-unrelated conditions approached significance, $t(30) = -1.96$, $p = .059$.

Peak latency. Peak latencies and standard deviations are reported for the two electrodes of interest (Fz, Pz) in Table 4. The main effect of sentence ending was not significant at

electrode Fz, $F(2,66) = 0.048$, $MSE = 6827$, $p = .95$, or at electrode Pz, $F(2,66) = 1.20$, $MSE = 6543$, $p = .31$.

Interim Summary of Experiment 1 Results. A summary of the ERP results can be seen in Table 5. No significant main effect of sentence ending (Expected, Unexpected-related, Unexpected-unrelated) on the N400 was found in the 300 – 500 ms time window, for either of the characteristics of the ERP (peak amplitude, peak latency). However, in the PNP time window, there was a significant main effect of sentence ending at electrode Pz, with the unexpected-unrelated responses eliciting the most positivity. Together, these effects show that the passive reading paradigm in this experiment did not elicit the hypothesized N400 effect, but a strong parietal PNP was found.

Experiment 2

Context sentence reading time. Younger participants silently read the context sentence for a mean duration of 4149 ms ($SD = 1526$ ms). In comparison to the young adults, older adult participants read for a mean duration of 4864 ms ($SD = 996$ ms). The difference in the time spent reading the context sentence between both groups approached significance; $t(41) = 1.81$, $p = .078$.

An independent samples *t*-test was conducted with the reading time from Experiment 1. The difference between the two young adult groups in Experiment 1 and Experiment 2 was not significant; $t(54) = -0.809$, $p = .42$.

Recognition memory task accuracy. A 2 x 3 (sentence ending [Expected, Unexpected-related, Unexpected-unrelated]) x (Age [Young, Older]) mixed ANOVA was used to compare performance on the recognition memory task. The mean accuracy and standard deviation was calculated for the correct identification of the presented sentence endings (Table 7). There was

no significant main effect of sentence ending, $F(2,82) = 1.18$, $MSE = 0.020$, $p = .31$ or age, $F(1,41) = 1.32$, $MSE = 0.047$, $p = .26$. There was no significant interaction between age and sentence ending, $F(2,82) = 2.26$, $MSE = 0.018$, $p = .11$.

ERP Time Window 300-500ms.

Topographical plots. There was centroparietal activation for the difference between expected and unexpected-unrelated conditions in both groups (see Figure 11).

Mean amplitude. The mean amplitudes and standard deviations are reported for electrode Fz , Cz, and Pz in Table 8. At electrode Fz, neither the main effect of sentence ending, $F(1.73,70.9) = 0.42$, $MSE = 0.26$, $p = .63$, nor main effect of age $F(1,41) = 0.12$, $MSE = 0.36$, $p = .74$, reached significance. There was no significant interaction between age and sentence ending, $F(1.73,70.9) = 1.06$, $MSE = 0.26$, $p = .34$. At electrode Cz, the main effect of sentence ending was significant, $F(1.71,70.1) = 5.33$, $MSE = 0.29$, $p = .010$. The expected ($M = 0.42$ μV, $SD = 0.91$ μV) condition was significantly different from the unexpected-unrelated ($M = 0.065$ μV, $SD = 0.56$ μV) condition, $t(42) = 2.80$, $p = .008$. The expected condition did not differ significantly from the unexpected-related ($M = 0.25$ μV, $SD = 0.64$ μV) condition, $t(42) = 1.59$, $p = .12$. There was no significant difference between unexpected-related and unexpected-unrelated conditions, $t(42) = 2.05$, $p = .046$.

There was no significant main effect of age, $F(1,41) = 0.060$, $MSE = 1.07$, $p = .81$. There was no evidence of an interaction between age and sentence ending, $F(1.71,70.1) = 1.01$, $MSE = 0.29$, $p = .36$. At electrode Pz, there were no significant main effects of sentence ending, $F(1.69,69.2) = 1.77$, $MSE = 0.36$, $p = .18$, or age, $F(1,41) = 0.79$, $MSE = 1.10$, $p = .38$. Also, there was no evidence of an interaction between age and sentence ending, $F(1.69,69.2) = 0.07$, $MSE = 0.36$, $p = .90$.

Peak latency. Refer to Table 9 for the peak latencies and standard deviations for the electrodes Fz, Cz, and Pz. At electrode Fz, the main effect of sentence ending was not significant, $F(1.66,67.9) = 0.030$, $MSE = 3004$, $p = .95$, or age, $F(1,41) = 0.65$, $MSE = 6303$, $p = .42$. There was no evidence of a significant interaction between age and sentence ending, $F(1.66,67.9) = 1.52$, $MSE = 3004$, $p = .23$. At electrode Cz, the main effect of sentence ending was not significant, $F(2,82) = 1.40$, $MSE = 3059$, $p = .25$. However, the main effect of age approached significance, $F(1,41) = 3.22$, $MSE = 7683$, $p = .080$. There was no significant interaction between age and sentence ending, $F(2,82) = 0.009$, $MSE = 3059$, $p = .99$. At electrode Pz, no significant main effect of sentence ending was found, $F(1.72,70.5) = 1.80$, $MSE = 2431$, $p = .18$, or age, $F(1,41) = 7.90$, $MSE = 10517$, $p = .52$. There was no evidence of an interaction between age and sentence ending, $F(1.72,70.5) = 0.46$, $MSE = 2431$, $p = .60$.

ERP Time Window 300-400ms. Because significant effects were found in the larger 300-500ms time window for at least one variable (i.e., sentence ending type) at one electrode (i.e., Cz), analyses were conducted for all electrode sites using a smaller time window (300 – 400 ms, 400 – 500 ms).

Topographical plots. The difference between the two conditions (expected and unexpected-unrelated) demonstrates a centroparietal activation in both groups (see Figure 12).

Mean amplitude. The mean amplitudes and standard deviations are reported for electrode Fz, Cz, and Pz in Table 8. At electrode Fz, neither the main effect of sentence ending, $F(2,82) = 0.41$, $MSE = 0.20$, $p = .67$, or main effect of age $F(1,41) = 0.42$, $MSE = 0.43$, $p = .52$, reached significance. There was no significant interaction between age and sentence ending, $F(2,82) = 1.14$, $MSE = 0.20$, $p = .33$. At electrode Cz, the main effect of sentence ending was significant, $F(2,82) = 3.50$, $MSE = 0.23$, $p = .035$. The expected ($M = 0.43$ μV, $SD = 0.88$ μV)

condition trended to be significantly different from the unexpected-unrelated (M = 0.16 μV, SD = 0.69 μV) condition, $t(42) = 2.36$, $p = .023$. The expected condition did not differ significantly from the unexpected-related (M = 0.28 μV, SD = 0.69 μV) condition, $t(42) = 1.51$, $p = .14$. There was no significant difference between unexpected-related and unexpected-unrelated conditions, $t(42) = 1.30$, $p = .20$.

There was no significant main effect of age, $F(1,41) = 0.12$, $MSE = 1.29$, $p = .74$. There was no evidence of an interaction between age and sentence ending, $F(2,82) = 0.86$, $MSE = 0.23$, $p = .43$. There were no significant main effects of sentence ending, $F(1.67,68.7) = 1.20$, $MSE = 0.32$, $p = .30$, or age, $F(1,41) = 0.91$, $MSE = 1.21$, $p = .35$. Also, there was no evidence of an interaction between age and sentence ending, $F(1.67,68.6)=0.14$, $MSE = 0.32$, $p = .84$.

Peak latency. Refer to Table 9 for the peak latencies and standard deviations at electrodes Fz, Cz and Pz. At electrode Fz, the significant main effects of sentence ending, $F(2,82) = 0.96$, $MSE = 971$, $p = .39$, and age, $F(1,41) = 0.94$, $MSE = 1814$, $p = .34$, did not reach significance. There was no evidence of a significant interaction between age and sentence ending, $F(2,82) = 1.14$, $MSE = 971$, $p = .33$. At electrode Cz, neither the main effects of sentence ending, $F(2,82) = 1.45$, $MSE = 874$, $p = .24$, nor main effect of age, $F(1,41) = 0.007$, $MSE = 2173$, $p = .94$, were significant. Similarly, there was no significant interaction between age and sentence ending, $F(2,82) = 0.86$, $MSE = 874$, $p = .24$. At electrode Pz, no significant main effect of sentence ending was found, $F(1.75,71.8) = 1.67$, $MSE = 886$, $p = .20$. There was a significant main effect of age, $F(1,41) = 7.90$, $MSE = 2085$, $p = .008$, in which younger adults (M = 332ms, SE = 5.62ms) had a faster peak latency than older adults (M = 355ms, SE = 5.75ms). There was no evidence of an interaction between age and sentence ending, $F(1.75,71.8) = 1.63$, $MSE = 886$, $p = .21$.

ERP Time Window 400-500ms.

Topographical plots. As seen in Figure 13, there was still centroparietal activation as a result of the difference between expected and unexpected-unrelated conditions in both groups that is carried into this time window.

Mean amplitude. The mean amplitudes and standard deviations are reported in Table 8 for electrodes Fz, Cz, and Pz. At electrode Fz, the main effects of sentence ending, $F(1.66,67.9) = 0.42$, $MSE = 0.13$, $p = .62$, and age, $F(1,41) = 0.0003$, $MSE = 0.0001$, $p = .99$, did not reach significance. There was no evidence of an interaction between age and sentence ending, $F(1.66,67.9) = 1.01$, $MSE = 0.32$, $p = .36$. At electrode Cz, the main effect of sentence ending reached significance, $F(1.60,65.5) = 6.90$, $MSE = 0.36$, $p = .004$. The expected ($M = 0.40$ μV, $SD = 0.98$ μV) condition was significantly different from the unexpected-unrelated ($M = -0.028$ μV, $SD = 0.50$ μV) condition, $t(42) = 3.11$, $p = .003$. There was also a significant difference between unexpected-related ($M = 0.22$ μV, $SD = 0.65$ μV) and unexpected-unrelated conditions, $t(42) = 2.72$ $p = .010$. The expected condition did not differ significantly from the unexpected-related, $t(42) = 1.59$, $p = .12$.

The main effect of age was not significant, $F(1,41) = 0.014$, $MSE = 1.08$, $p = .91$. There was no significant interaction between age and sentence ending, $F(1.60,65.5) = 1.11$, $MSE = 0.36$, $p = .324$. For electrode Pz, there was no main effect of sentence ending, $F(1.65,67.6)=2.21$, $MSE = 0.45$, $p = .13$, nor age, $F(1,41) = 0.47$, $MSE = 1.43$, $p = .50$. Finally, there was no significant interaction between age and sentence ending, $F(1.65,67.6)=0.048$, $MSE = 0.45$, $p = .93$.

Peak latency. The peak latencies and standard deviations are reported for the three electrodes of interest, Fz, Cz, and Pz, in Table 9. At electrode Fz, neither the main effect of

sentence ending reached significance, $F(1.73,70.8) = 0.31$, $MSE = 313$, $p = .70$, nor age, $F(1,41) = 0.18$, $MSE = 320$, $p = .67$. However, the interaction between age and sentence ending, $F(1.73,670.8) = 2.83$, $MSE = 2823$, $p = .073$, approached significance. As seen in Figure 14, there was a greater effect of sentence ending in younger adults (expected: $M = 453$ ms, $SD = 32.5$ ms; unexpected-related: $M = 443$ ms, $SD = 31.7$ ms; unexpected-unrelated: $M = 433$ ms, $SD = 35.6$ ms) than in older adults (expected: $M = 441$ ms, $SD = 36.6$ ms; unexpected-related: $M = 446$ ms, $SD = 33.8$ ms; unexpected-unrelated: $M = 452$ ms, $SD = 34.0$ ms). At electrode Cz, the main effect of sentence ending was significant, $F(2,82) = 4.93$, $MSE = 925$, $p = .009$. The expected ($M = 442$ ms, $SD = 34.9$ ms) condition was significantly different from the unexpected-unrelated ($M = 463$ ms, $SD = 31.3$ ms) condition, $t(42) = -2.99$, $p = .005$. The expected condition did not differ significantly from the unexpected-related ($M = 452.4$ ms, $SD = 32.8$ ms) condition, $t(42) = -1.57$, $p = .12$. The difference between unexpected-related and unexpected-unrelated conditions was not significant, $t(42) = -1.73$, $p = .091$.

There was no significant main effect of age, $F(1,41) = 0.20$, $MSE = 1476$, $p = .66$, and no significant interaction between age and sentence ending, $F(2,82) = 0.45$, $MSE = 925$, $p = .64$. For electrode Pz, the main effect of sentence ending was not significant, $F(2,82) = 1.66$, $MSE = 836$, $p = .20$. There was a significant main effect of age, $F(1,41) = 6.08$, $MSE = 1555$, $p = .018$, in which the younger adults ($M = 459$ ms, $SE = 4.86$ms) had a more delayed peak latency than older adults ($M = 441$ms, $SE = 4.97$ms). There was no evidence of an interaction between age and sentence ending, $F(2,82) = 0.62$, $MSE = 836$, $p = .54$.

ERP Time Window 600 - 900 ms.

Topographical plots. Younger adults elicit a left lateralized parietal negativity for the difference between expected and unexpected-unrelated conditions, whereas the older adults elicit

some left lateralized parietal negativity. Both groups also elicit central positivity. The difference between the unexpected-related responses and the unexpected-unrelated responses was also plotted (Figure 15). Both groups elicit a weak frontal positivity. Younger adults also elicit a left lateralized negativity in the parietal area, whereas older adults elicit a more positive response in the left parietal region.

Mean amplitude. The mean amplitudes and standard deviations are reported in Table 10 for electrodes Fz and P3. At electrode Fz, neither the main effect of sentence ending, $F(2,82) = 1.39$, $MSE = 0.34$, $p = .25$, nor age, $F(1,41) = 0.063$, $MSE = 1.04$, $p = .80$, reached significance. There was no evidence of an interaction between sentence ending and age, $F(2,82) = 1.04$, $MSE = 0.34$, $p = .36$. At electrode P3, the main effect of sentence ending was significant, $F(2,82) = 4.25$, $MSE = 0.41$, $p = .017$. The expected ($M = -0.12$ μV, $SD = 0.12$ μV) condition trended to be significantly different from the unexpected-unrelated ($M = 0.21$ μV, $SD = 0.12$ μV) condition, $t(42) = -2.37$, $p = .022$. The unexpected-related ($M = 0.24$ μV, $SD = 0.69$ μV) condition also approached being significantly different from the expected, $t(42) = -2.43$, $p = .019$. There was no significant difference between unexpected-related and unexpected-unrelated conditions, $t(42) = 0.21$, $p = .83$.

No significant main effect of age, $F(1,41) = 1.61$, $MSE = 0.83$, $p = .21$, was found. The interaction between sentence ending and age approached significance, $F(2,82)=2.671$, $MSE=0.408$, $p=0.075$. As seen in Figure 16, there is a greater effect of sentence ending in younger adults (expected: $M = -0.35$ μV, $SD = 0.81$ μV; unexpected-related: $M = 0.076$ μV, $SD = 0.84$ μV; unexpected-unrelated: $M = 0.29$ μV, $SD = 0.49$ μV) than older adults (expected: $M = 0.10$ μV, $SD = 0.82$ μV; unexpected-related: $M = 0.40$ μV, $SD = 0.75$ μV; unexpected-unrelated: $M = 0.19$ μV, $SD = 0.67$ μV).

Peak latency. See Table 11 for the peak latencies and standard deviations for electrodes Fz and P3. At electrode Fz, neither the main effect of sentence ending, $F(2,82) = 0.19$, $MSE = 7105$, $p = .83$, or age, $F(1,41) = 0.63$, $MSE = 10598$, $p = .43$, reached significance. There was no evidence of an interaction between sentence ending and age, $F(2,82) = 0.061$, $MSE = 7105$, $p = .94$. At electrode P3, the main effect of sentence ending was not significant, $F(2,82) = 0.54$, $MSE = 6391$, $p = .59$, and the main effect of age, $F(1,41) = 0.084$, $MSE = 12942$, $p = .77$, was not significant. Finally, the interaction between sentence ending and age, $F(2,82) = 0.075$, $MSE = 6391$, $p = .93$, did not reach significance.

Interim Summary of Experiment 2 ERP Results. Both younger and older adults demonstrated the N400 effect, with different effects in corresponding time windows. Both young and older adults had minimal N400 amplitude for the expected condition, more negative amplitude for the unexpected-related condition and the most negative response for the unexpected-unrelated condition. Significant ERP results are summarized in Table 12 for mean amplitude and Table 13 for peak latency across the corresponding electrodes. In the 300 – 500 ms time window, there was a significant main effect of sentence ending at electrode Cz. As well, the main effect of age approached significance at electrode Cz. No effects were seen in electrode Fz and Pz. To further elucidate these effects, finer time windows were used for analysis. In the 300 – 400 ms time window, there was a significant main effect of sentence ending at electrode Cz for mean amplitude, but not at the other electrodes Fz and Pz. The main effect of age for peak latency reached significance at electrode Pz. However, no interactions were significant. In the time window of 400 – 500 ms, the significant main effect of sentence ending was also observed at Cz for both mean amplitude and peak latency, but not Fz and Pz. At electrode Pz, there was a significant main effect of age for peak latency, similar to the previous time window. No

interactions were found to be significant, though at electrode Fz, the interaction between age and sentence ending approached significance. For the PNP effect, both the younger and older adults elicited an effect at electrode P3, not at electrode Fz. Specifically, in the 600 – 900 ms time window, the main effect of sentence ending was significant at electrode P3 for mean amplitude and the interaction between age and sentence ending for mean amplitude approached significance for this electrode. Therefore, both younger and older adults do elicit the N400 effect, as hypothesized, and the parietal PNP response, which fits with our hypothesized role of the PNP in sentence comprehension.

Comparisons of Recognition Accuracy and ERP Measures

Exploratory analyses were conducted to determine the relationship between recognition accuracy and the ERP measures. Pearson's product-moment correlation coefficient was computed. The mean amplitude and peak latency of the time windows 400-500ms at electrode Fz and 600-900ms at electrode P3 were chosen to investigate this relationship. Electrode Fz and P3 are often used to assess the encoding stage in recognition memory tasks (Chen et al., 2014). Though the time window of 400-500ms in this study is used to reflect the N400 effect, at electrode Fz this time window may reflect the semantic processing of the sentences for the memory task (Voss and Federmeier, 2011). The time window of 600-900ms at electrode P3 in this study was chosen to reflect the post N400 positivity; however, this time window has also been implicated in deeper levels of processing and contextually rich memory that are thought to be indexed by the late parietal complex (Chen et al., 2014). Together, these two time windows of interest may provide insights into the relationship of the recognition accuracy and ERP measures.

ERP measures were averaged across the three sentence endings: expected, unexpected-unrelated, and unexpected-unrelated. The recognition accuracy was determined by the

participants' performance on the memory test in which they had to identify the presented sentence ending.

No significant correlations were found for mean amplitude at electrode Fz or P3. At electrode Fz, there were no significant correlations in mean amplitude for younger adults, r = -.30, n = 22, p = .17 or older adults, r = -.16, n = 21, p = .48. Neither at electrode P3 for younger adults, r = .32, n = 22, p = .14, nor older adults, r = -.056, n = 21, p = .81. At electrode Fz, there was a significant negative correlation between peak latency and recognition accuracy in older adults, r = -.47, n = 21, p = .035, but not in younger adults, r = 0.001, n = 22, p = .99 (Figure 17). At electrode P3, there were no significant correlations between peak latency and recognition accuracy in younger adults, r = .33, n = 22, p = .14, or older adults, r = -.048, n = 21, p = .86.

Discussion

The present study examined whether there were age-related effects in the use of semantic context during sentence processing. Findings from behavioral measures and electrophysiological data explored these effects in younger and older adults. As expected, the groups did not perform differently on behavioural measures, such as reading time and recognition accuracy. Differences in recognition accuracy are in line with previous experiments manipulating semantic information; however, contrary to previous studies, both groups in our study demonstrated similar reading times.. In Experiment 1, young adults did not elicit the N400 effect while passively reading, but they elicited a parietal PNP effect (most positive for the unexpected-unrelated condition). In Experiment 2, both groups of adults elicited the N400 effect while actively reading the sentences, which was modulated by the degree of semantic context anomaly. Both groups showed the most negativity for the unexpected-unrelated condition and the least negativity for the expected condition. There was an age-related difference in peak latency, but

not in the mean amplitude of the N400. For the PNP effect, neither group showed a frontal PNP, contrary to our predictions. Instead, a parietal PNP was found for both groups. While the young adults showed the most parietal PNP for the unexpected-unrelated, the older adults showed the most parietal positivity for the unexpected-related condition. Exploratory analyses that compared the behavioural results with the ERP measures found a relationship between frontal N400 peak latency and memory performance in older adults. The results from these experiments are further discussed below in reference to the implications for age-related effects on semantic memory and predictive processing mechanisms.

Sentence Context: Behavioural Results

Young adults in Experiment 1 and Experiment 2 did not differ in their reading times. In Experiment 2, the younger and older adults were able to recognize the presented sentence ending with similar high accuracy, indicating that they were attending to and comprehending the experimental stimuli. This is in line with previous research testing semantic manipulations, in which both groups of adults perform similarly on certain behavioural measures (Balota & Duchek, 1991; Burke & Harrold, 1993; Henderson & Wright, 2016; Wingfield et al., 1994). However, older adults trended to have slightly longer reading time than young adults. Though many studies have found no difference in the reading time for older adults, other studies have found that older adults may be slower in reading due to manipulated sentence characteristics (Dennis & Cabeza, 2008; Thornton & Light, 2006). The slower reading time may be linked to declines in processing speed, which has been suggested to decrease with aging. Salthouse (1996) proposed the process-speed theory of aging where he postulates that an increase in age leads to a decrease in the time available and thus allocated for elementary or lower order cognition. This decrease would ultimately effect higher order functions such as reading.

Sentence Context: N400 and PNP ERP Results

Our study determined that the N400 was only present when participants are actively engaging in the reading task (Experiment 2) and that the N400 was sensitive to aging. The PNP, on the other hand, was present regardless of whether participants are actively engaged (Experiment 2) or passively reading (Experiment 1). These findings are discussed in further detail below.

N400. One goal of the current work was to determine whether adults elicit the N400 while reading sentences with varying degrees of semantic context anomalies. In Experiment 1, a significant N400 effect among the three conditions was not elicited by the young adults though the ERP responses in the 300 - 500 ms time window were in the predicted direction (i.e., most positive response for expected condition and most negative response for unexpected-unrelated condition). We suspect this null effect was driven by the passive reading task. While some previous studies have shown N400 effects during passive viewing of stimuli, the N400 response is more robust when participants are required to make overt responses, such as answering a comprehension question, making a judgment about a specific feature of the stimuli, or responding to a memory probe (Kutas & Federmeier, 2011). As such, we modified our procedure to make Experiment 2 an active reading task. Specifically, participants were required to make overt responses on a recognition memory task after viewing the sentences. The instructions were intended to ensure that their attention was engaged during sentence reading. The significant N400 effects observed in both younger and older adults in Experiment 2 suggest we were successful in our approach. Therefore, in a sentence reading task it is optimal to devise an active paradigm to elicit the intended N400 effect.

With respect to Experiment 2, we found that younger and older adults show differences in their N400 response as a function of sentence context. Similar to Federmeier et al. (2002), there was a difference between the unexpected-related and unexpected-unrelated conditions for both groups. As seen in Figure 8, at electrode Cz, young adults elicited a more positive response for the expected than the unexpected-related and unexpected-unrelated responses. In older adults, the expected condition was also the most positive, and unexpected-related and unexpected-unrelated conditions were both more negative. However, the older adults had a more reduced N400 mean amplitude to the unexpected-related condition than the younger adults, which may indicate that older adults are less able to engage in predictive processing mechanisms (Federmeier et al., 2002).

There were age-related differences in the peak latency of the N400 at electrode Pz and the difference approached significance at electrode Cz (300- 500 ms), whereby older adults had a slower N400 response around 300-400 ms and a faster response around 400-500 ms. The delayed N400 response, in the first time window, may reflect their difficulty in rapidly using the sentence context information to facilitate effective prediction (Federmeier & Kutas, 2005), as a result of a decrease in speed of processing. Alternatively, the delayed N400 may reflect a difference in the underlying processes recruited by older adults when compared to younger adults (Wlotko et al., 2010). For example, if older adults are having difficulties in the use of semantic information while processing information (Federmeier & Kutas, 2005), they may utilize alternative reading strategies to complete the task. On the other hand, in the later N400 time window of 400 – 500 ms, the older adults had an earlier peak latency than the younger adults. An earlier peak latency for the older adults in the later time window may reflect the older adults' slowed processing and integration of context. Therefore, N400 peak latency in the earlier time window (300 - 400 ms)

may best reflect the age-related declines in processing; however, more work is needed to determine the exact nature of how the N400 unfolds over time for older adults.

Contrary to the latency findings, the mean amplitude of the N400 did not differ significantly between younger and older adults. While not in line with previous work (Federmeier & Kutas, 2005; Federmeier et al., 2002), we suspect this may reflect stability in semantic memory organization in aging adults. Specifically, the three sentence ending conditions were determined by creating category structures with semantic features. Established by both behavioural and electrophysiological studies, older adults retain their ability to maintain and store their semantic information and world related knowledge (e.g., Federmeier et al., 2002; Howard, 1980; Laver & Burke, 1993; Salthouse, 1993). It is possible that both the younger and older adults processed the three sentence ending conditions with respect to semantic features of the stimuli, which was subsequently reflected in similar N400 amplitudes. In addition, our study did not explicitly manipulate contextual constraint, which has been reported to have differential impacts on the N400 mean amplitude in younger and older adults (Federmeier & Kutas, 2005; Federmeier et al., 2002). Ultimately, future work that manipulates semantic categories within differentiated contextual constraints is needed to further establish the role of semantic memory during sentence comprehension in aging adults. Overall, we replicate previous work that shows the N400 amplitude is sensitive to semantic context when individuals are actively engaged in the task. Further, we provide evidence that the latency of the N400 is sensitive to age related changes in sentence comprehension.

PNP. Contrary to previous work, we did not find that the frontal PNP was sensitive to age, nor did we find it was sensitive to differences among the three sentence ending conditions. Previous studies have established differences in the PNP at the frontal topography between

younger and older adults (Wlotko et al., 2010). The frontal PNP is thought to reflect a revision process when a prediction is not fulfilled or may be modulated by semantic plausibility with low predictability (Federmeier et al., 2007; Thornhill & Van Petten, 2012). In these previous studies that manipulated predictive processing, older adults did not produce a frontal PNP, whereas younger adults did in tasks, consistent with the theory that older adults are less efficient at predicting during sentence comprehension (Wlotko et al., 2010). Our contrasting findings may reflect a third uncontrolled variable our study, namely contextual constraint. While we created stimuli based on semantic categories with manipulated cloze probabilities, we did not control explicitly for contextual constraint, which has been noted in previous work as contributing to the PNP frontal positivity (DeLong et al., 2014). Future work that carefully controls for, and manipulates, semantic context, cloze probability and contextual constraint are needed to fully elucidate the frontal PNP effects.

We did provide evidence that the parietal PNP is sensitive to sentence context effects. In Experiment 1 and 2, younger participants showed a parietal PNP, where the unexpected-unrelated condition elicited the most positivity, which is consistent with previous studies (DeLong et al., 2014; Van Petten & Luka, 2012). Previous research has suggested the parietal PNP reflects attempted semantic re-analysis of the incongruent sentences during predictive processing and may be modulated by the stimuli's semantic implausibility (DeLong et al., 2014; Van Petten & Luka, 2012). Despite the nature of the paradigm (passive reading in Experiment 1 and engaged reading in Experiment 2), the younger participants produced the parietal PNP response indicating that they are able to integrate the semantic context to facilitate the subsequent analysis of the incongruent sentences as a result of their intact predictive processing.

Interestingly, while both younger and older individuals elicited left PNP activation, there was a trend for an interaction between age and sentence ending. As mentioned, the younger adults elicited the hypothesized effect, in which the unexpected-unrelated (anomalous) condition was the most positive (Federmeier, 2007); however, the older adults elicited a PNP, in which their responses to the unexpected-related conditions was the most positive. This difference in sentence ending positivity between younger and older adults may reflect a difference in underlying processing, for example, the older adults may not use prediction but perhaps rely on plausibility, then the pattern of attempted semantic re-analysis would likely differ. The unexpected but plausible condition may reflect processing that depends on the individual's world knowledge to update their contextual information. On the other hand, the unexpected-unrelated sentences have sentence-endings that are illogical, and low in predictability based on the preceding context. This would lead to the disambiguation of the stimuli and an attempt to reanalyze the anomaly (DeLong et al., 2014).

Another possible explanation for this increased positivity for the unexpected but plausible condition would be that older adults experience an increased linguistic and cognitive processing load when they view semantically implausible conditions such as the unexpected-unrelated sentence ending condition (Joon et al., 2015). In a study by Joon et al., (2015), they found that older adults were slower and performed worse for the semantically implausible conditions as opposed to the plausible conditions. If the posterior PNP is modulated by semantic implausibility, the older adults would have an increased difficulty processing this information and may thus process the semantically plausible information in the parietal area, to lighten the cognitive load as a compensatory mechanism. This would thus be reflected in the more positive response in the older adults for the semantically plausible condition. A future study that also

manipulated the plausibility ratings of the stimuli may further highlight the effects of aging in the parietal PNP responses. Nevertheless, both groups of adults do show a parietal PNP response, with different conditions eliciting the most positivity.

Comparisons of Behavioural and ERP Measures

In our work, we found a significant negative correlation between a frontal N400 peak latency and recognition accuracy in only older adults, whereby a delayed peak latency was associated with better recognition accuracy on the memory task. Younger adults do not show this relationship. This relationship between latency and recognition accuracy in the frontal area may reflect age-related changes often seen in this region. Certain factors that contribute to language processing are affected by normal aging, such as a reduction in working memory capacity, which is mainly processed in the frontal regions (Wingfield, Peelle & Grossman, 2003). Areas such as the frontal cortex that are involved in language comprehension are the most vulnerable to age-related brain volume reduction (Tyler et al, 2010). Therefore, the processing and encoding of semantic information would be affected by age-related atrophy (Meunier, Stamatakis, & Tyler, 2014). As a result of this age-related atrophy, Caplan and Waters (2005) argue that the initial interpretive semantic processing of sentences should be resistant to aging. On the other hand, post-interpretative processes that involve retaining the memory after it is initially encoded and involve sentence processing may be affected by age (Caplan & Waters, 2005). Despite that the delay in processing may be indicative of the frontal region atrophy seen in aging, older adults who had the most delayed N400 peak latency performed the best on the recognition task. This may suggest underlying compensatory mechanisms may be involved to sustain the stable recognition memory performance. Therefore, older adults who perform as well as younger adults might have a delayed processing time of the stimuli.

Limitations

There are limitations with respect to equipment, dependent measures, and experimental design that are worth noting. First, with respect to equipment, the EEG recordings may have been subject to environmental noise, as data collection was not conducted in an electrically shielded room. The impact of environmental noise, and potential increased variability in EEG signal, on the resulting null effects reported in the current study are uncertain. Thus, caution must be taken when interpreting any non-significant findings, as these may be a function of low power resulting from increased noise.

Even though peak latency is a well-established ERP measure, recent studies have cautioned researchers in their interpretation of this measure (Luck, 2005). Specifically, this ERP measure is most susceptible to extraneous influences. For example, peak latency is sensitive to increases in noise, especially high-frequency noise such as light. The measurement time window for peak latency can also be problematic. We attempted to address the limitations of peak latency by also analyzing mean amplitude. This ERP measure is not subject to the aforementioned limitations associated with peak latency. Regardless, cautious interpretations must be made about the significant peak latency results determined in this study.

Age-related effects on cognition are undoubtedly impacted by many life experiences and contextual factors, both personal and environmental. Therefore, an aging population will have more variance than a population of typical young adults. The optimal design for an aging study would be longitudinal, but ours was a cross-sectional study. We attempted to control for cognitive ability, by pre-screening all the participants with the Raven's Progressive Colored Matrices. However, the variance seen in aging populations does introduce limitations in studies investigating age-related cognitive decline, such as the present experiment.

Finally, the lower end of the age range (e.g., 50 years old) of the older adult participants in this study was younger than other studies reported in literature (e.g., Federmeier & Kutas, 2005; Federmeier et al., 2002). While previously reported literature does vary in the age range of the older participants, a majority of the papers in this field included participants above the age of 60, and less so often above the age of 55 years. Even though the mean of the present sample was 62.0 years old and the upper end of the age range was 84 years, many of the included participants were below 60. Therefore, caution must be taken when generalizing the interpretations and findings of the older adult sample to other findings reported in literature.

Future Directions

While our results are important for understanding sentence processing in younger and older adults, employing a similar paradigm in a clinical population who suffer from reading impairments would provide further insights into reading processes. For example, aphasia is an acquired disorder affecting a person's ability to communicate, and majority of these affected individuals also suffer from alexia, an acquired reading impairment (Webb & Love, 1983). They often employ strategies that increase their ability to read, such as using context to effectively read sentences (Beeson & Insalaco, 1998). In previous studies, individuals with alexia derived more benefit when reading high context sentences as opposed to low context sentences and reading words in a list format (Rayner, 1998). Current clinicians capitalize on these context-effects by administering text-based reading treatments to individuals with alexia (Beeson & Insalaco, 1998; Cherney, 2004). However, the neurophysiological mechanisms behind these context-effects in individuals with alexia are relatively unknown. Event-related potentials (ERPs) may be used to represent the neural mechanisms behind the sentence context effects, specifically the N400 as it is shown to be influenced by semantic context (Kutas & Hillyard, 1980). The

characteristics of N400 have shown to be altered (lateralized to the language dominant hemisphere) by intensive treatment in individuals with aphasia (Wilson et al., 2012). As the cognitive and neural correlates underlying the sentence context-effects in individuals with aphasia and alexia remain relatively unclear, future directions may provide further insight in these effects and language processing in these individuals as well as further establish these effects in healthy older adults.

Conclusion

In summary, semantic context use during sentence comprehension is fairly resistant to age-related decline, most likely due to stable semantic memory. However, evidence from event-related potentials show there is a difference in how older adults process sentence reading and engage in predictive processing, specifically with manipulated semantic context. This is also supported by the findings of the present experiments, in which there is no significant difference in the behavioural measures. However, the ERP data provide evidence of an effect of age on the processing of these sentences, specifically in the N400 and PNP effects. Findings show that older adults are able to maintain their sentence comprehension, but potentially through different mechanisms than their younger counterparts. However, they are less effective at engaging in predictive processing as seen in their different N400 and PNP results. As well, the N400 was elicited by an engaged reading paradigm, as opposed to the PNP elicited regardless of the passive or engaged reading paradigm. Finally, exploratory analyses showed that there is a potential relationship between N400 latency and memory performance in older adults. In view of other related cognitive declines, the findings show that older adults are able to maintain their sentence comprehension. As a result, this study provides further evidence for age-related differences in

neural processing of semantic context in sentence reading, and adds to current views of age-related effects on semantic memory and predictive processing mechanisms.

References

Balota, D. A., & Duchek, J. M. (1991). Semantic priming effects, lexical repetition effects, and contextual disambiguation effects in healthy aged individuals and individuals with senile dementia of the Alzheimer type. *Brain and Language*, *40*(2), 181-201. doi:10.1016/0093-934X(91)90124-J

Balota, D. A., Pollatsek, A., & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive psychology*, *17*(3), 364-390. doi: 10.1016/0010-0285(85)90013-1

Beeson, P. M. & Insalaco, D. (1998). Acquired alexia: Lessons from successful treatment. *Journal of the International Neuropsychological Society,* 4, 621-635. doi:10.1017/s1355617798466116

Borovsky, A., Kutas, M., & Elman, J. (2010). Learning to use words: Event-related potentials index single-shot contextual word learning. *Cognition*, *116*(2), 289-296. doi:10.1016/j.cognition.2010.05.004

Buckner, R. L. (2004). Memory and executive function in aging and AD: multiple factors that cause decline and reserve factors that compensate. *Neuron*, *44*(1), 195-208. doi:10.1016/j.neuron.2004.09.006

Burke, D. M., & Harrold, R. M. (1993). Automatic and effortful semantic processes in old age Experimental and naturalistic approaches. In L. L. Light & D. M. Burke (Eds.), *Language, memory, and aging* (pp. 100–116). New York: Cambridge University Press.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology and aging*, *17*(1), 85. doi:10.1037/0882-7974.17.1.85

Cameli, L., & Phillips, N. A. (1999). Age-related differences in semantic priming: evidence from

event-related brain potentials. *Brain and Cognition*, *43*(1-3), 69-73. doi:10.1037/0882-7974.17.1.85

Caplan, D., & Waters, G. (2005). The relationship between age, processing speed, working memory capacity, and language comprehension. *Memory*,*13*(3-4), 403-413. doi:10.1080/09658210344000459

Cherney, L. R. (2004). Aphasia, alexia, and oral reading. *Topics in Stroke Rehabilitation, 11(1),* 22-36. doi:10.1310/VUPX-WDX7-J1EU-00TB

Chen, Y. Y., Lithgow, K., Hemmerich, J. A., & Caplan, J. B. (2014). Is what goes in what comes out? Encoding and retrieval event-related potentials together determine memory outcome. *Experimental brain research*, *232*(10), 3175-3190. doi:10.1007/s00221-014-4002-1

Cooke, A., Grossman, M., DeVita, C., Gonzalez-Atavales, J., Moore, P., Chen, W., ... & Detre, J. (2006). Large-scale neural network for sentence processing. *Brain and language*, *96*(1), 14-36. doi:10.1016/j.bandl.2005.07.072

Coulson, S., & Van Petten, C. (2007). A special role for the right hemisphere in metaphor comprehension?: ERP evidence from hemifield presentation.*Brain Research*, *1146*, 128-145. doi:10.1016/j.brainres.2007.03.008

Debruille, J. B. (2007). The N400 potential could index a semantic inhibition. *Brain Research Reviews*, *56*(2), 472-477. doi:10.1016/j.brainresrev.2007.10.001

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, *134*(1), 9-21. doi:10.1016/j.jneumeth.2003.10.009

DeLong, K. A., Quante, L., & Kutas, M. (2014). Predictability, plausibility, and two late

ERP positivities during written sentence comprehension.*Neuropsychologia*, *61*, 150-162. doi:10.1016/j.neuropsychologia.2014.06.016

Dennis, N. A., & Cabeza, R. (2008). Neuroimaging of healthy cognitive aging. *The handbook of aging and cognition*, *3*, 1-54.

Federmeier, K. D. (2007). Thinking ahead: The role and roots of prediction in language comprehension. *Psychophysiology*, *44*(4), 491-505. doi: 10.1111/j.1469-8986.2007.00531.x

Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of memory and Language*, *41*(4), 469-495. doi:10.1006/jmla.1999.2660

Federmeier, K. D., & Kutas, M. (2005). Aging in context: Age-related changes in context use during language comprehension. *Psychophysiology*, *42*(2), 133-141. doi:10.1111/j.1469-8986.2005.00274.x

Federmeier, K. D., Kutas, M., & Schul, R. (2010). Age-related and individual differences in the use of prediction during language comprehension. *Brain and language*, *115*(3), 149-161. doi:10.1016/j.bandl.2010.07.006

Federmeier, K. D., McLennan, D. B., Ochoa, E., & Kutas, M. (2002). The impact of semantic memory organization and sentence context information on spoken language processing by younger and older adults: An ERP study.*Psychophysiology*, *39*(2), 133-146. doi:10.1111/1469-8986.3920133

Federmeier, K. D., Wlotko, E. W., De Ochoa-Dewald, E., & Kutas, M. (2007). Multiple effects of sentential constraint on word processing. *Brain research*,*1146*, 75-84. doi:10.1016/j.brainres.2006.06.101

Finnigan, S., Humphreys, M. S., Dennis, S., & Geffen, G. (2002). ERP 'old/new' effects: memory strength and decisional factor (s).*Neuropsychologia*, *40*(13), 2288-2304. doi:10.1016/S0028-3932(02)00113-6

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, *68*(1), 1-76. doi:10.1016/S0010-0277(98)00034-1

Glisky, E. L. (2007). Changes in cognitive function in human aging. *Brain aging: models, methods, and mechanisms*, 3-20. doi:10.1201/9781420005523.sec1

Hopkins, K. A., Kellas, G., & Paul, S. T. (1995). Scope of word meaning activation during sentence processing by young and older adults. *Experimental Aging Research*, *21*(2), 123-142. doi:10.1080/03610739508254273

Howard, D. V. (1980). Category norms: A comparison of the Battig and Montague (1969) norms with the responses of adults between the ages of 20 and 80. *Journal of Gerontology*, *35*(2), 225-231. doi: 10.1093/geronj/35.2.225

Howard, D. V. (1983). The effects of aging and degree of association on the semantic priming of lexical decisions. *Experimental aging research*, *9*(3), 145-151. doi: 10.1080/03610738308258443

Henderson, A., & Wright, H. H. (2016). Cognition, language, and aging.*Cognition, Language and Aging*, *1*. 108-111.

Juottonen, K., Revonsuo, A., & Lang, H. (1996). Dissimilar age influences on two ERP waveforms (LPC and N400) reflecting semantic context effect.*Cognitive Brain Research*, *4*(2), 99-107. doi:10.1016/0926-6410(96)00022-5

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology*, *16*(1-2), 262-284. doi: 10.1080/09541440340000213

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension: Challenges to syntax. *Brain research*, *1146*, 23-49. doi: 10.1016/j.brainres.2006.12.063

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in cognitive sciences*, *4*(12), 463-470. doi:10.1016/S1364-6613(00)01560-6

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual review of psychology*, *62*, 621. doi: 10.1146/annurev.psych.093008.131123

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*(4427), 203-205. doi:10.1126/science.7350657

Kutas, M., & Iragui, V. (1998). The N400 in a semantic categorization task across 6 decades. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *108*(5), 456-471. doi:10.1016/S0168-5597(98)00023-9

Kutas, M., & Van Petten, C. (1994). Psycholinguistics electrified: Event-related brain potential investigations. In M.A. Gernsbacher (Ed.), *Handbook of Psycholinguistics* (pp. 83-143). San Diego: Academic Press.

Landi, N., Frost, S. J., Mencl, W. E., Sandak, R., & Pugh, K. R. (2013). Neurobiological bases of reading comprehension: Insights from neuroimaging studies of word-level and text-level processing in skilled and impaired readers. *Reading & Writing Quarterly*, *29*(2), 145-167. doi:10.1080/10573569.2013.758566

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging*, *8*(1), 34. doi:10.1037/0882-7974.8.1.34

Light, L. L., Valencia-Laver, D., & Zavis, D. (1991). Instantiation of general terms in young and older adults. *Psychology and aging*, *6*(3), 337. doi: 10.1037/0882-7974.6.3.337

Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-recruitment and nonselective recruitment: dissociable neural mechanisms associated with aging. *Neuron*, *33*(5), 827-840. doi:10.1016/S0896-6273(02)00612-8

Luck S.J. (2005). An introduction to the event-related potential technique. MIT Press, Cambridge.

MathWorks, Inc. (2013). MATLAB (Version 8.1.0.604) [Computer software]. Natick, MA: MathWorks.

Meunier, D., Stamatakis, E. A., & Tyler, L. K. (2014). Age-related functional reorganization, structural changes, and preserved cognition. *Neurobiology of Aging*, *35*(1), 42-54. doi:10.1016/j.neurobiolaging.2013.07.003

Mitchum, C., Haendiges, A., & Berndt, R. S. (2005). Oral reading of words and sentences: Investigating the source of context effects. *Aphasiology*, *19*(7), 615-631. doi:10.1080/02687030544000281

Niedermeyer, E., & da Silva, F. L. (Eds.). (2005). *Electroencephalography: basic principles, clinical applications, and related fields*. Lippincott Williams & Wilkins.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsycholollgia*, 9, 97-113. doi:10.1016/0028-3932(71)90067-4

Raven, J. C. (1976). Coloured progressive matrices: Sets A, A_B, B [test booklet]. San Antonio, TX: Pearson.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422. doi:10.1037/0033-2909.124.3.372

Rayner, K., Reichle, E. D., Stroud, M. J., Williams, C. C., & Pollatsek, A. (2006). The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. *Psychology and aging*,*21*(3), 448. doi: 10.1037/0882-7974.21.3.448

Reuter-Lorenz, P. A., & Sylvester, C. Y. C. (2005). The cognitive neuroscience of working memory and aging. *Cognitive neuroscience of aging: Linking cognitive and cerebral aging*, 186-217.

Rugg, M. D., & Coles, M. G. (1995). *Electrophysiology of mind: Event-related brain potentials and cognition*. Oxford University Press.

Salthouse, T. A. (1993). Effects of aging on verbal abilities: Examination of the psychometric literature. In L. L. Light & D. M. Burke (Eds.), *Language, memory, and aging* (pp. 17–35). New York: Cambridge University Press.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological review*, *103*(3), 403. doi: 10.1037/0033-295X.103.3.403

Sheldon, S., Pichora-Fuller, M. K., & Schneider, B. A. (2008). Priming and sentence context support listening to noise-vocoded speech by younger and older adults. *The Journal of the Acoustical Society of America*, *123*(1), 489-499. doi: 10.1121/1.2783762

Statistics Canada. (n.d.). Canada's population estimates: Age and sex, July 1, 2015. Retrieved April 19, 2016, from http://www.statcan.gc.ca/daily-quotidien/150929/dq150929b-eng.htm

Thorndike, E.L. and Lorge, I. (1944). The Teacher's Word Book of 30,000 Words. New York: Teachers College, Columbia University.

Thornhill, D. E., & Van Petten, C. (2012). Lexical versus conceptual anticipation during sentence processing: Frontal positivity and N400 ERP components. *International Journal of Psychophysiology*, *83*(3), 382-392. doi:10.1016/j.ijpsycho.2011.12.007

Thornton, R., & Light, L. L. (2006). Language comprehension and production in normal aging. *Handbook of the psychology of aging*, *6*, 261-287. doi:10.1016/B9-78-012101-2/64950-015X

Tyler, L. K., Shafto, M. A., Randall, B., Wright, P., Marslen-Wilson, W. D., & Stamatakis, E. A. (2009). Preserving syntactic processing across the adult life span: the modulation of the frontotemporal language system in the context of age-related atrophy. *Cerebral Cortex*, bhp105. doi:10.1093/cercor/bhp105

Van Berkum, J. J. (2008). Understanding sentences in context what brain waves can tell us. *Current directions in psychological science*, *17*(6), 376-380. doi:10.1111/j.1467-8721.2008.00609.x

Van Herten, M., Chwilla, D. J., & Kolk, H. H. (2006). When heuristics clash with parsing routines: ERP evidence for conflict monitoring in sentence perception. *Journal of Cognitive Neuroscience*, *18*(7), 1181-1197. doi: 10.1162/jocn.2006.18.7.1181

Van Petten, C. & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology*, *83*, 176-190. doi:10.1016/j.ijpsycho.2011.09.015

Voss, J. L., & Federmeier, K. D. (2011). FN400 potentials are functionally identical to N400 potentials and reflect semantic processing during recognition testing. *Psychophysiology*, *48*(4), 532-546. doi:10.1111/j.1469-8986.2010.01085.x

Webb, W. G., & Love, R. J. (1983). Reading problems in chronic aphasia. *Journal of Speech and Hearing Disorders, 48,* 164-171. doi:10.1044/jshd.4802.164

Wilson, K. R., O'Rourke, H., Wozniak, L. A., Kostopoulos, E., Marchand, Y., & Newman, A. J. (2012). Changes in N400 topography following intensive speech language therapy for individuals with aphasia. *Brain and Language, 123*, 94-103. doi:10.1016/j.bandl.2012.06.005

Wingfield, A., Alexander, A. H., & Cavigelli, S. (1994). Does memory constrain utilization of top-down information in spoken word recognition? Evidence from normal aging. *Language and Speech*, *37*(3), 221-235. doi: 10.1177/002383099403700301

Wingfield, A., Peelle, J. E., & Grossman, M. (2003). Speech rate and syntactic complexity as multiplicative factors in speech comprehension by young and older adults. *Aging, Neuropsychology, and Cognition*, *10*(4), 310-322. doi:10.1076/anec.10.4.310.28974

Wlotko, E.W., Federmeier, K.D., Kutas, M. (2012). To Predict or Not to Predict: Age-Related Differences in the Use of Sentential Context, *Psychology and Aging*, *27*(4). 975-88. doi:10.1037/a0029206

Wingfield, A., & Grossman, M. (2006). Language and the aging brain: patterns of neural compensation revealed by functional brain imaging.*Journal of Neurophysiology*, *96*(6), 2830-2839. doi:10.1152/jn.00628.2006

Wlotko, E. W., Lee, C. L., & Federmeier, K. D. (2010). Language of the Aging Brain: Event-Related Potential Studies of Comprehension in Older Adults. Language and Linguistics Compass, 4(8), 623-638. doi:10.1111/j.1749-818X.2010.00224.x

Woodward, S. H., Ford, J. M., & Hammett, S. C. (1993). N4 to spoken sentences in young and older subjects. *Electroencephalography and Clinical Neurophysiology*, *87*(5), 306-320.

doi:10.1016/0013-4694(93)90184-W

Yoon, J., Campanelli, L., Goral, M., Marton, K., Eichorn, N., & Obler, L. K. (2015). The Effect of Plausibility on Sentence Comprehension Among Older Adults and its Relation to Cognitive Functions. *Experimental Aging Research*, *41*(3), 272–302. doi:10.1080/0361073X.2015.1021646

Table 1

Mean amplitude in microvolts for the 300 – 500 ms Time Window

	Electrode								
	Fz			Cz			Pz		
Sentence Ending	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Expected	34	0.13	0.71	34	0.44	0.78	34	0.14	0.95
Unexpected-related	34	0.30	1.12	34	0.41	0.68	34	0.10	0.90
Unexpected-unrelated	34	0.03	0.84	34	0.32	0.61	34	0.13	0.72

Table 2

Peak Latency in milliseconds for the 300 – 500 ms Time Window

	Electrode								
	Fz			Cz			Pz		
Sentence Ending	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Expected	34	422.91	68.45	34	400.09	65.18	34	376.41	71.92
Unexpected-related	34	422.91	70.07	34	408.03	68.05	34	395.94	66.10
Unexpected-unrelated	34	419.35	62.99	34	412.44	68.79	34	382.74	67.90

Table 3

Mean amplitude in microvolts for the 600 – 900 ms Time Window

	Electrode					
	Fz			Pz		
Sentence Ending	*n*	*M*	*SD*	*n*	*M*	*SD*
Expected	34	0.27	1.56	34	0.03	1.51
Unexpected-related	34	0.07	1.60	34	0.35	1.18
Unexpected-unrelated	34	-0.23	1.54	34	0.64	1.16

Table 4

Peak Latency in milliseconds for the 600 – 900 ms Time Window

	Electrode					
	Fz			Pz		
Sentence Ending	*n*	*M*	*SD*	*n*	*M*	*SD*
Expected	34	712.65	86.67	34	758.00	78.64
Unexpected-related	34	718.32	105.66	34	781.76	87.86
Unexpected-unrelated	34	717.68	97.30	34	753.56	100.57

Table 5

Summary Table of ERP Mean Amplitude Results

	Electrode					
	Fz		Cz		Pz	
Time Window	Effect	*p*	Effect	*p*	Effect	*p*
300 – 500 ms	No effects	.	No effects	.	No effects	.
600 – 900 ms	No effects	.	N/A		M.E. Sentence Ending	0.02

Note. M.E. = main effect, N/A = statistical tests were not conducted in this time window and electrode. Results that reached statistical significance ($p < 0.05$) and those that approached statistical significance are reported.

Table 6

Summary Table of ERP Peak Latency Results

	Electrode					
	Fz		Cz		Pz	
Time Window	Effect	*p*	Effect	*p*	Effect	*p*
300 – 500 ms	No effects	.	No effects	.	No effects	.
600 – 900 ms	No effects	.	N/A		No effects	

Note. M.E. = main effect. N/A = statistical tests were not conducted in this time window and electrode. Results that reached statistical significance ($p < 0.05$) and those that approached statistical significance are reported.

Table 7

Accuracy of Sentence-Endings Identified in Recognition Memory Task

	Sentence Ending									Overall		
	Expected			Unexpected-related			Unexpected-unrelated					
Age Group	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Younger Adults	22	0.92	0.10	22	0.83	0.18	22	0.84	0.14	22	0.86	0.11
Older Adults	21	0.81	0.23	21	0.84	0.14	21	0.80	0.19	21	0.83	0.13

Table 8

Mean amplitude in microvolts for the N400 Time Windows

Time Window	Electrode	Sentence Ending	Age Group					
			Younger Adults			Older Adults		
			n	*M*	*SD*	*n*	*M*	*SD*
300 – 500 ms	Fz	Expected	22	0.04	0.73	21	0.04	0.46
		Unexpected-related	22	0.10	0.64	21	0.02	0.26
		Unexpected-unrelated	22	-0.13	0.38	21	0.07	0.48
	Cz	Expected	22	0.349	1.18	21	0.49	0.51
		Unexpected-related	22	0.315	0.79	21	0.18	0.45
		Unexpected-unrelated	22	0.003	0.67	21	0.13	0.64
	Pz	Expected	22	0.37	1.22	21	0.23	0.50
		Unexpected-related	22	0.27	0.90	21	0.14	0.39
		Unexpected-unrelated	22	0.19	0.52	21	-0.03	0.65
300 – 400 ms	Fz	Expected	22	0.07	0.68	21	0.06	0.42
		Unexpected-related	22	0.11	0.64	21	0.10	0.32
		Unexpected-unrelated	22	-0.11	0.37	21	0.14	0.61
	Cz	Expected	22	0.35	1.11	21	0.52	0.56
		Unexpected-related	22	0.32	0.83	21	0.24	0.50
		Unexpected-unrelated	22	0.10	0.80	21	0.22	0.57
	Pz	Expected	22	0.29	1.08	21	0.52	0.56
		Unexpected-related	22	0.25	0.87	21	0.24	0.50
		Unexpected-unrelated	22	0.17	0.53	21	0.22	0.57
400 – 500 ms	Fz	Expected	22	0.01	0.82	21	0.005	0.61
		Unexpected-related	22	0.10	0.68	21	-0.060	0.33
		Unexpected-unrelated	22	-0.15	0.49	21	0.006	0.49
	Cz	Expected	22	0.35	1.29	21	0.46	0.53
		Unexpected-related	22	0.31	0.79	21	0.13	0.47
		Unexpected-unrelated	22	-0.09	0.60	21	0.04	0.36
	Pz	Expected	22	0.46	1.37	21	0.31	0.57
		Unexpected-related	22	0.29	0.98	21	0.19	0.46
		Unexpected-unrelated	22	0.20	0.67	21	0.01	0.68

Table 9

Peak latency in milliseconds for the N400 Time Windows

Time Window	Electrode	Sentence Ending	Age Group					
			Younger Adults			Older Adults		
			n	*M*	*SD*	*n*	*M*	*SD*
300 – 500 ms	Fz	Expected	22	416.55	63.50	21	407.71	66.24
		Unexpected-related	22	398.55	60.81	21	426.86	54.05
		Unexpected-unrelated	22	403.00	58.95	21	417.38	63.63
	Cz	Expected	22	382.95	70.24	21	412.19	68.10
		Unexpected-related	22	389.95	67.91	21	416.05	63.83
		Unexpected-unrelated	22	403.09	74.52	21	430.81	61.06
	Pz	Expected	22	364.18	76.72	21	378.86	58.43
		Unexpected-related	22	380.23	75.65	21	399.48	65.89
		Unexpected-unrelated	22	383.45	77.66	21	384.48	62.07
300 – 400 ms	Fz	Expected	22	357.32	35.45	21	348.24	37.93
		Unexpected-related	22	359.55	32.10	21	358.86	36.31
		Unexpected-unrelated	22	367.86	35.45	21	355.76	34.97
	Cz	Expected	22	351.05	36.56	21	347.10	34.39
		Unexpected-related	22	356.91	38.02	21	356.14	40.28
		Unexpected-unrelated	22	356.27	29.91	21	363.00	36.98
	Pz	Expected	22	320.64	29.65	21	354.14	35.74
		Unexpected-related	22	340.86	34.79	21	352.67	37.50
		Unexpected-unrelated	22	335.77	34.64	21	358.29	36.30
400 – 500 ms	Fz	Expected	22	453.09	32.50	21	441.52	36.55
		Unexpected-related	22	443.27	31.72	21	445.76	33.84
		Unexpected-unrelated	22	433.05	35.64	21	451.57	34.03
	Cz	Expected	22	441.45	38.08	21	443.00	32.14
		Unexpected-related	22	452.68	36.88	21	452.14	28.85
		Unexpected-unrelated	22	467.91	32.48	21	457.76	29.92
	Pz	Expected	22	458.14	33.20	21	433.10	33.41
		Unexpected-related	22	462.45	31.11	21	450.29	34.44
		Unexpected-unrelated	22	454.91	34.37	21	440.76	30.01

Table 10

Mean amplitude in microvolts for the PNP Time Window

Time Window	Electrode	Sentence Ending	Age Group					
			Younger Adults			Older Adults		
			n	*M*	*SD*	*n*	*M*	*SD*
600 – 900 ms	Fz	Expected	22	0.11	0.88	21	0.14	0.67
		Unexpected-related	22	0.33	0.94	21	0.20	0.70
		Unexpected-unrelated	22	-0.06	0.50	21	0.17	0.77
	P3	Expected	22	-0.35	0.81	21	0.10	0.82
		Unexpected-related	22	0.08	0.84	21	0.40	0.75
		Unexpected-unrelated	22	0.29	0.49	21	0.19	0.67

Table 11

Peak latency in milliseconds for the PNP Time Window

Time Window	Electrode	Sentence Ending	Age Group					
			Younger Adults			Older Adults		
			n	*M*	*SD*	*n*	*M*	*SD*
600 – 900 ms	Fz	Expected	22	748.27	78.85	21	757.00	97.70
		Unexpected-related	22	766.09	94.42	21	764.24	99.97
		Unexpected-unrelated	22	764.68	100.91	21	775.24	81.33
	P3	Expected	22	458.14	33.20	21	433.10	33.41
		Unexpected-related	22	462.45	31.10	21	450.29	34.44
		Unexpected-unrelated	22	454.91	34.37	21	440.76	30.01

Table 12

Summary Table of ERP Mean Amplitude Results

	Electrode							
	Fz		Cz		Pz		P3	
Time Window	Effect	*p*	Effect	*p*	Effect	*p*	Effect	*p*
300 – 500 ms	No effects	.	M.E. Sentence Ending	0.010	No effects	.	N/A	
300 – 400 ms	No effects	.	M.E. Sentence Ending	0.035	No effects	.	N/A	
400 – 500 ms	No effects	.	M.E. Sentence Ending	0.004	No effects	.	N/A	
600 – 900 ms	No effects	.	N/A		N/A		M.E. Sentence Ending Age x Sentence Ending	0.017 0.075

Note. M.E. = main effect. N/A = statistical tests were not conducted in this time window and electrode. Results that reached statistical significance ($p < 0.05$) and those that approached statistical significance are reported.

Table 13

Summary Table of ERP Peak Latency Results

	Electrode							
	Fz		Cz		Pz		P3	
Time Window	Effect	*p*	Effect	*p*	Effect	*p*	Effect	*p*
300 – 500 ms	No effects	.	M.E. Age	0.080	No effects	.	N/A	
300 – 400 ms	No effects	.	No effects	.	M.E. Age	0.008	N/A	
400 – 500 ms	Age x Sentence Ending	0.073	M.E. Sentence Ending	0.009	M.E. Age	0.018	N/A	
600 – 900 ms	No effects	.	N/A		N/A		No effects	.

Note. M.E. = main effect. N/A = statistical tests were not conducted in this time window and electrode. Results that reached statistical significance ($p < 0.05$) and those that approached statistical significance are reported.

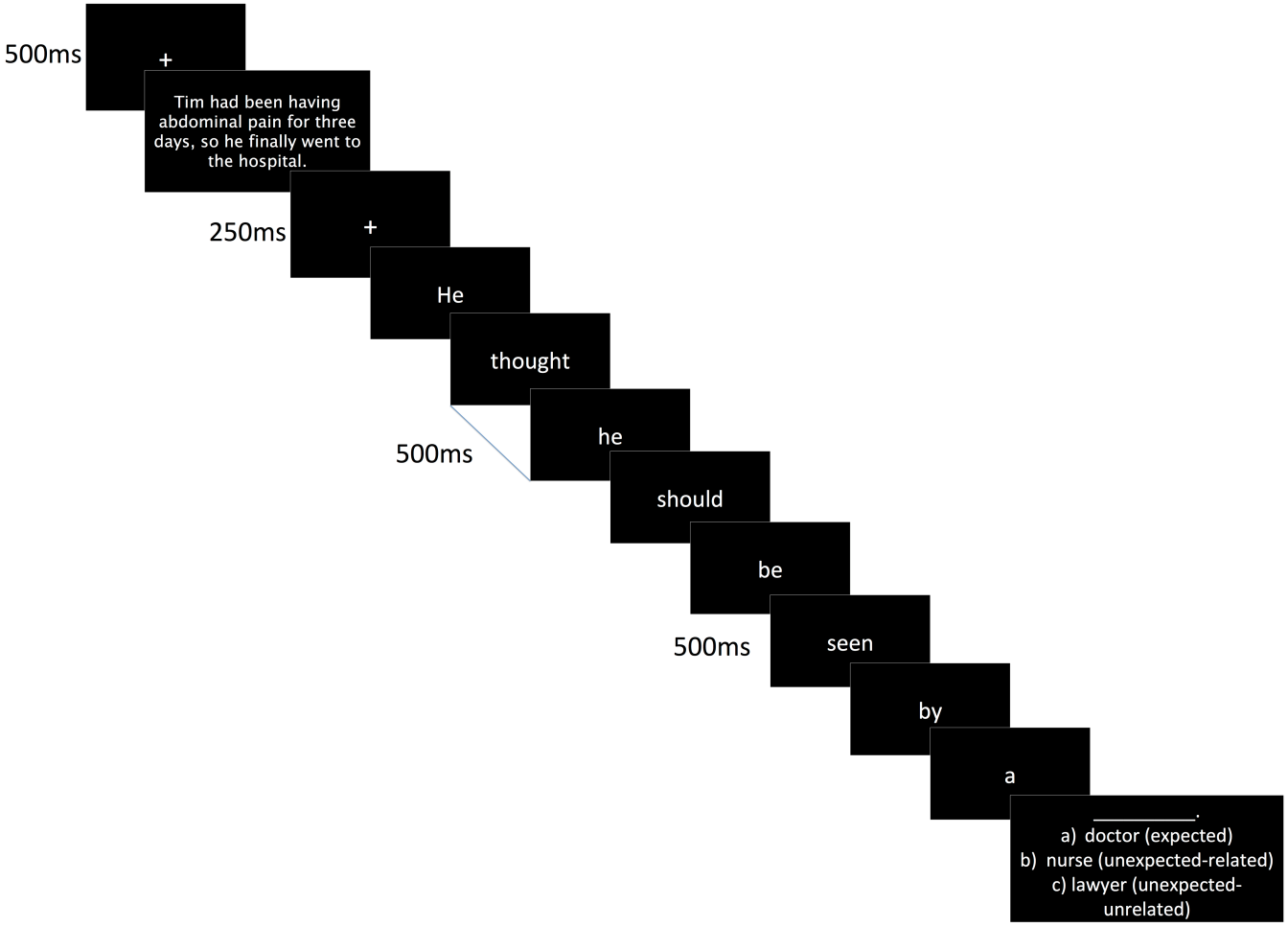

Figure 1. Experimental paradigm. Participants were first presented with a fixation cross for 500ms, which preceded two sentences. The first sentence which established the context was then presented with all the words presented simultaneously on the screen, until the participant pressed the button to move to the next sentence. A 250 ms fixation cross separated the first sentence from the second sentence. The second sentence was presented one word at a time, with 500ms word to word onset time. The last word presented of the second sentence was the target word, and was either be expected, unexpected but semantically related, unexpected and semantically unrelated or a filler word.

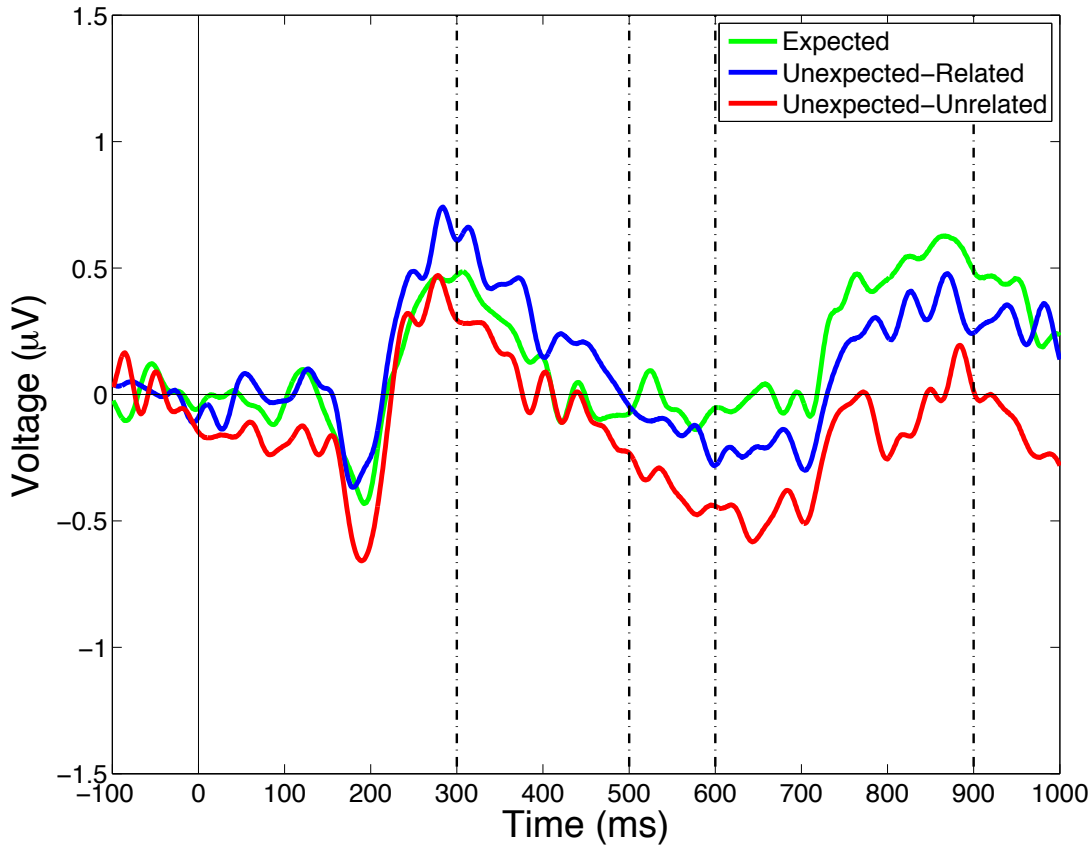

Figure 2. Grand averaged ERPs for electrode Fz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time windows for the N400 (300 – 500 ms) and PNP effects (600 – 900 ms) are highlighted. Neither a N400 nor PNP effect was not found at this electrode. Negative is plotted downward.

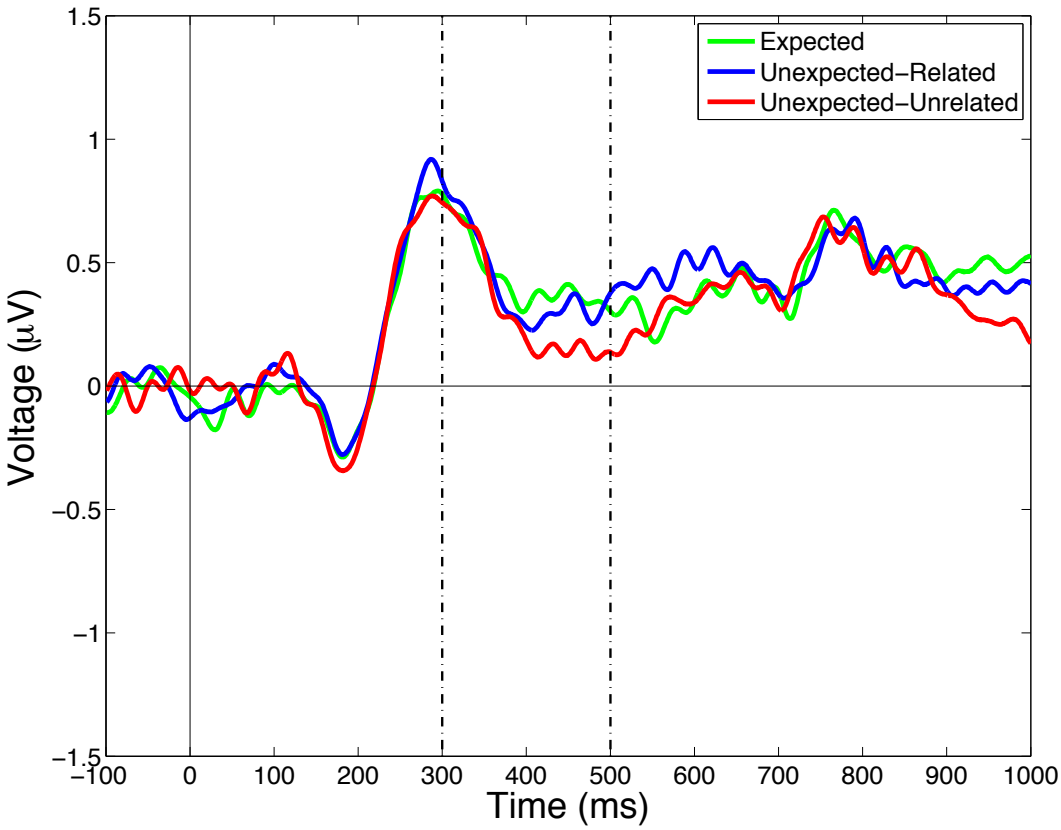

Figure 3. Grand averaged ERPs for electrode Cz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time window for the N400 (300 – 500 ms) is highlighted. A N400 effect was not found at this electrode.

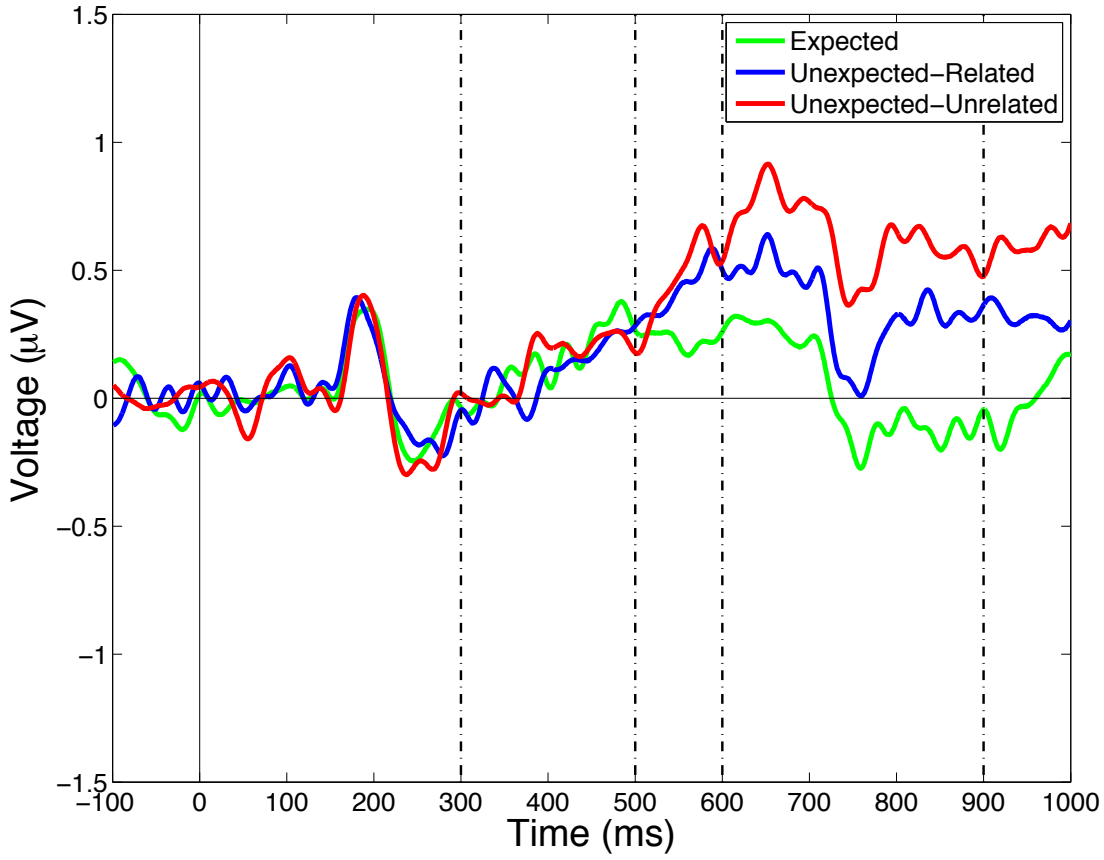

Figure 4. Grand averaged ERPs for electrode Pz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time windows for the N400 (300 – 500 ms) and the PNP (600 – 900 ms) are highlighted. A PNP effect is shown with the unexpected-unrelated response eliciting the most positivity.

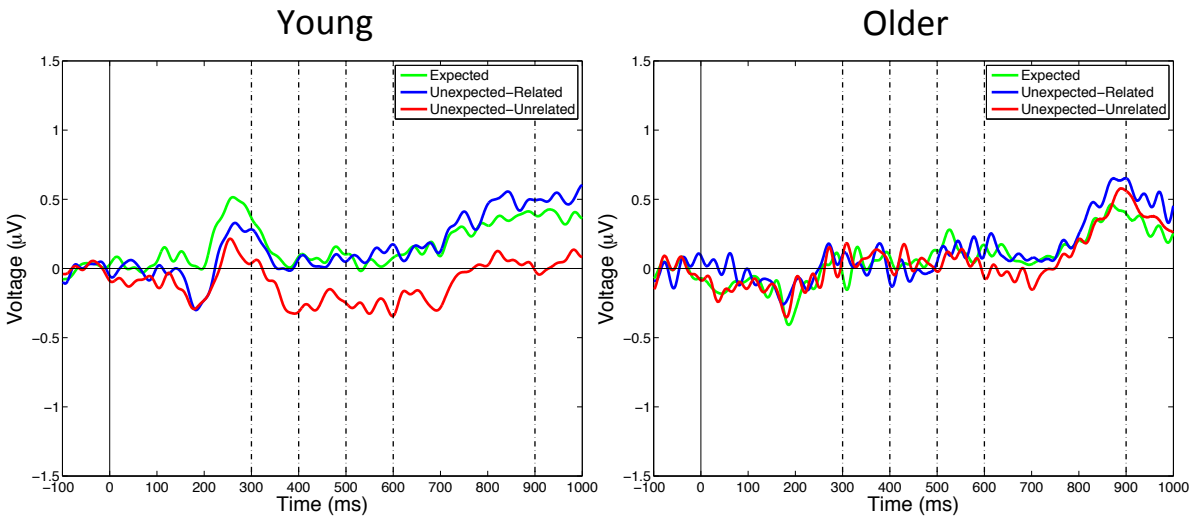

Figure 5. Grand averaged ERPs for electrode Fz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time windows of comparison for the N400 effect (300-500ms, 300-400ms, 400-500ms) and PNP (600 – 900 ms) are highlighted. Younger adults show a N400 effect, beginning at the 300 ms, whereas older adults do not show the N400 effect.

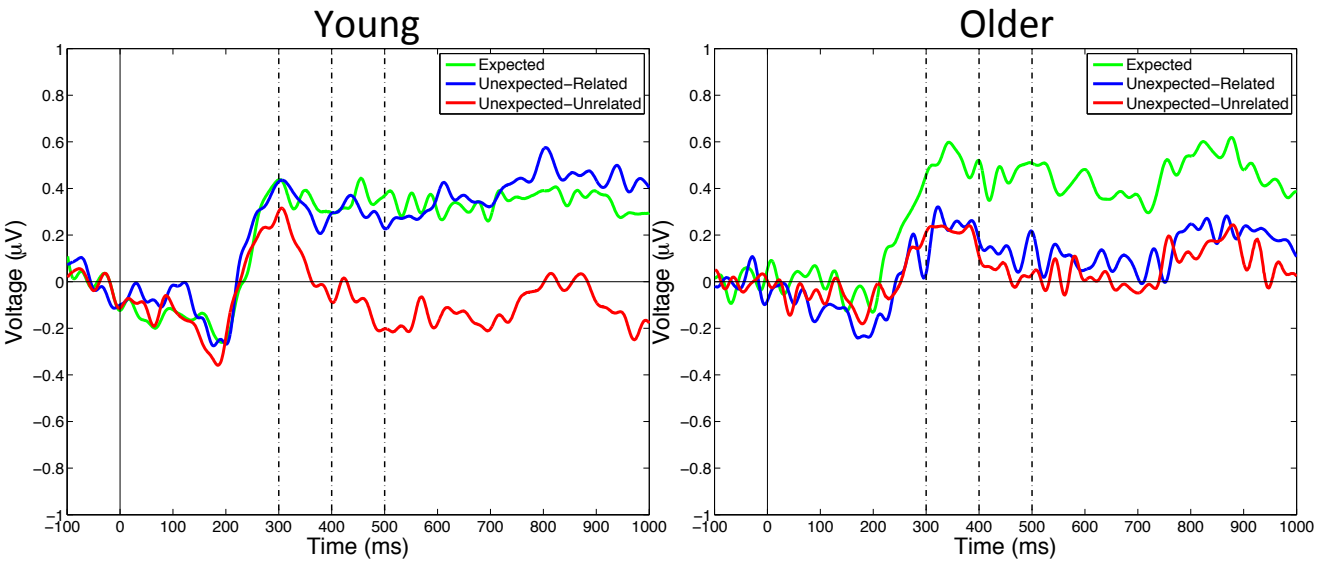

Figure 6. Grand averaged ERPs for electrode Cz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time windows of comparison for the N400 effect (300-500ms, 300-400ms, 400-500ms) are highlighted. Both young and older adults show a N400 effect, starting approximately at the 300 ms post-stimulus.

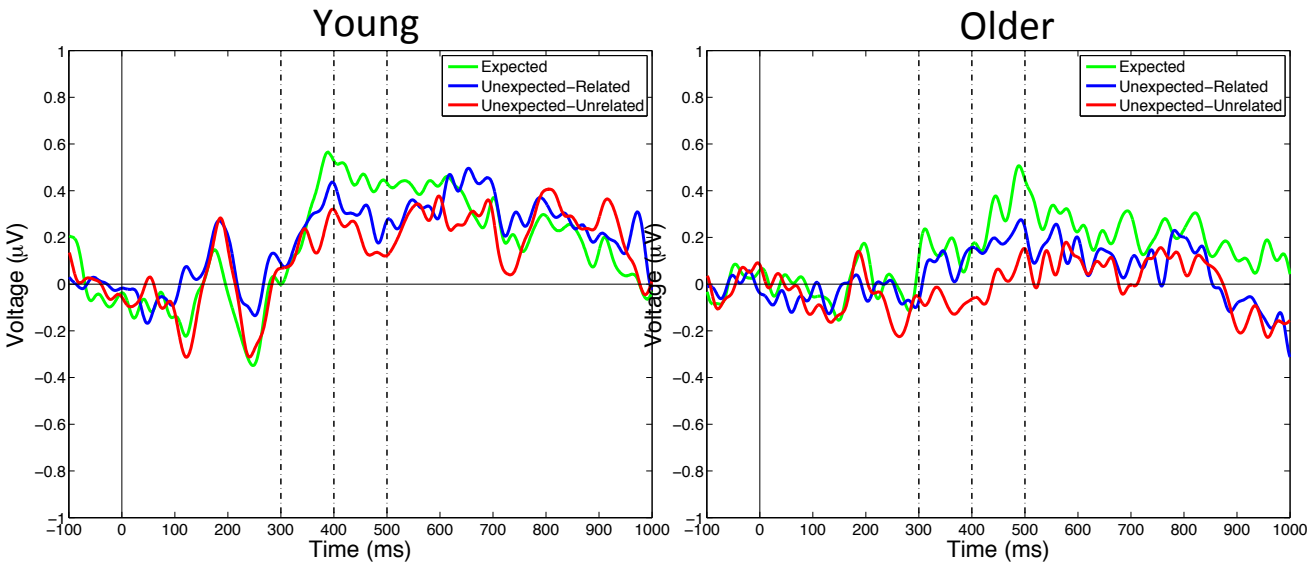

Figure 7. Grand averaged ERPs for electrode Pz for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time windows of comparison for the N400 effect (300-500ms, 300-400ms, 400-500ms) are highlighted. Both young and older adults show a N400 effect.

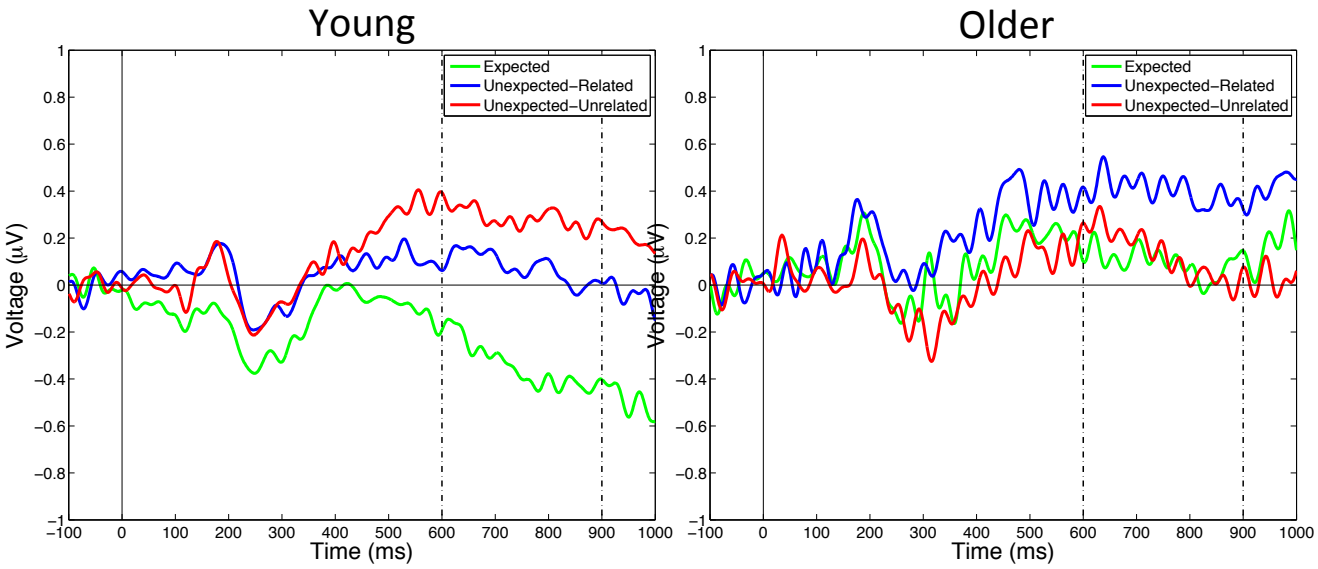

Figure 8. Grand averaged ERPs for electrode P3 for each of the semantic conditions (Expected, Unexpected-related, Unexpected-unrelated). The time window of comparison for the PNP effect (600-900ms) is highlighted. Both young and older adults elicit a PNP effect. Young adults elicit a more positive response for the unexpected-unrelated condition, whereas the older adults a more positive response for the unexpected-related condition.

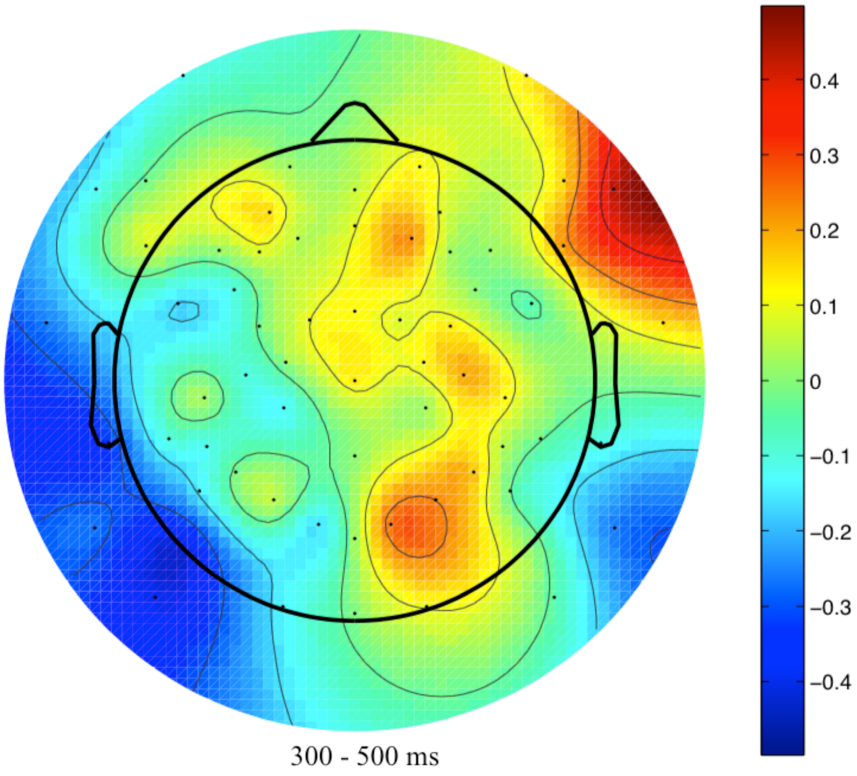

Figure 9. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions in the 300-500ms time window. This is a spline plot (color reflects the mean voltage difference over the time window of 300-500ms). The difference in the responses generated a positivity that spreads over the frontal to parietal areas.

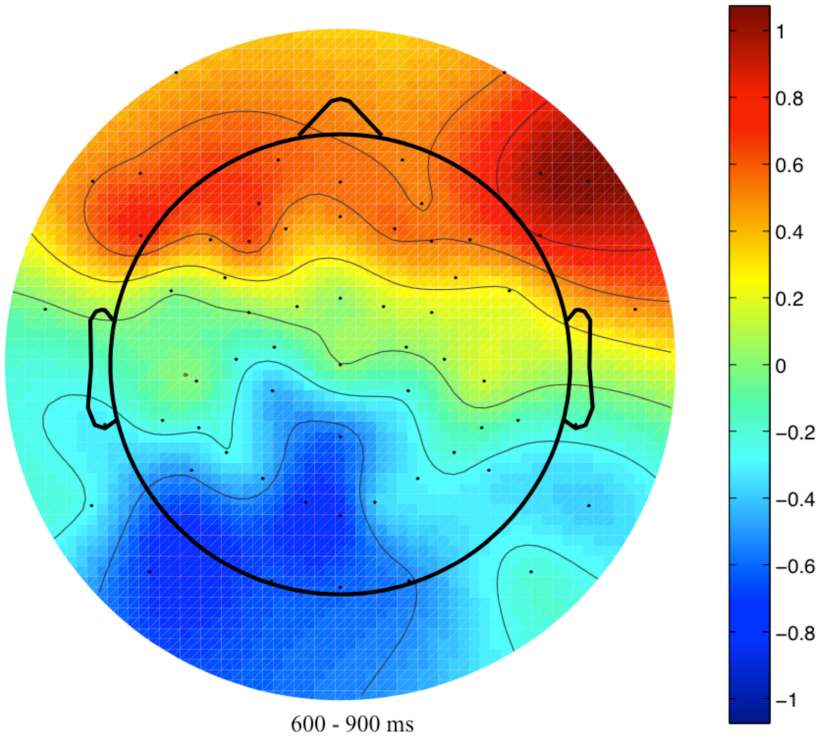

Figure 10. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions in the 600-900ms time window. This is a spline plot (color reflects the mean voltage difference over the time window of 600-900ms). There is strong frontal positivity and parietal negativity for the difference in responses.

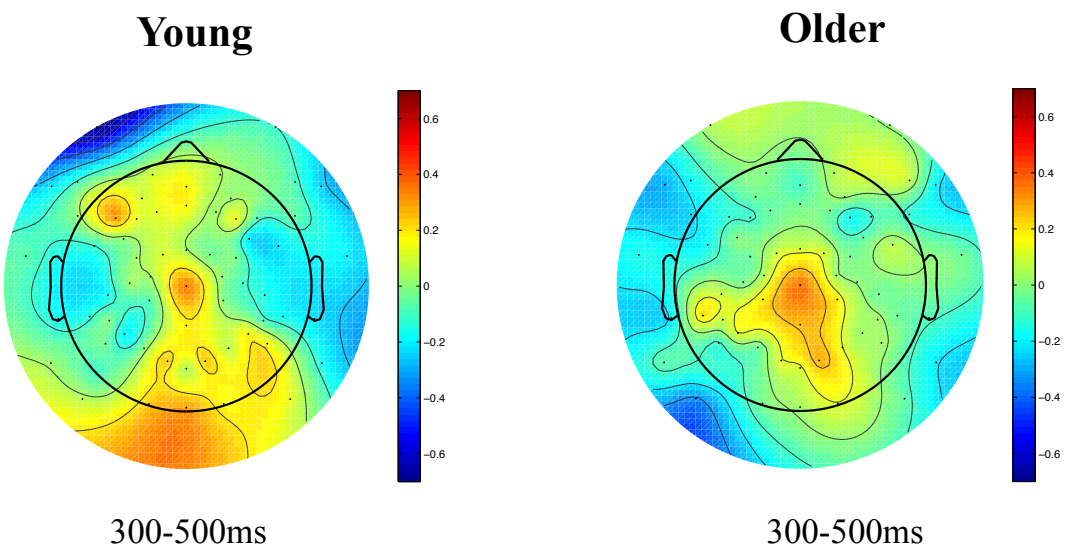

Figure 11. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions in the 300-500ms time window for young and older adults. This is a spline plot (color reflects the mean voltage difference over the time window of 300-500ms). Both groups of adults elicit a centroparietal positivity.

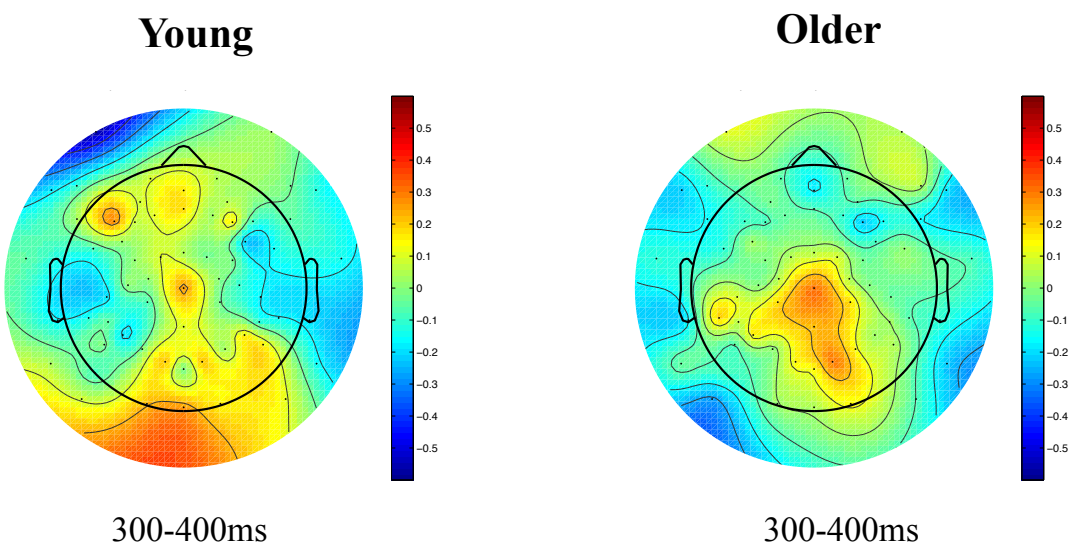

Figure 12. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions in the 300-400ms time window for young and older adults. This is a spline plot (color reflects the mean voltage difference over the time window of 300-400ms). Both groups of adults elicit a centroparietal positivity.

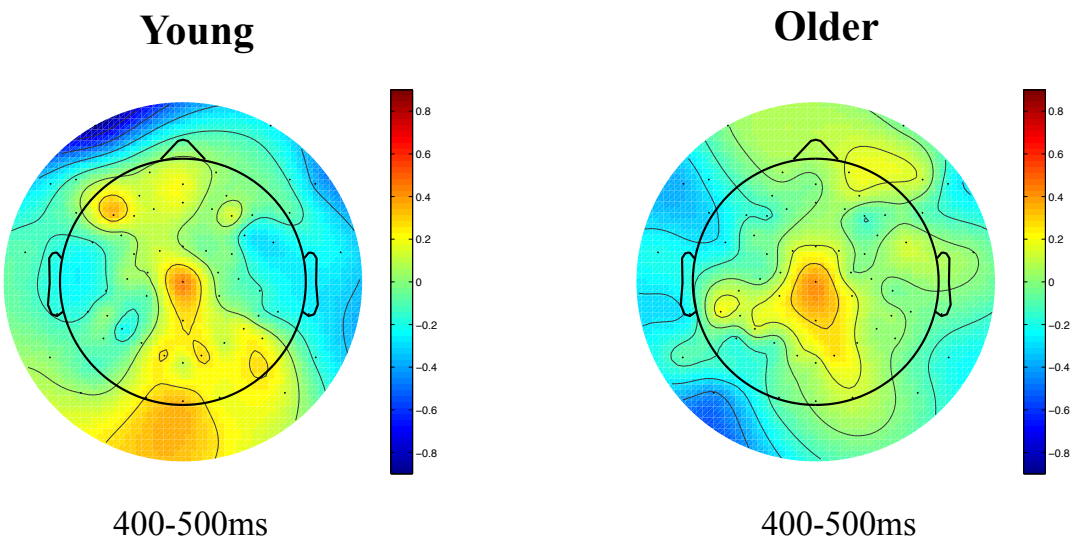

Figure 13. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions in the 400-500ms time window for young and older adults. This is a spline plot (color reflects the mean voltage difference over the time window of 400-500ms). Both groups of adults elicit the centroparietal positivity response in the difference that is carried from the previous time window.

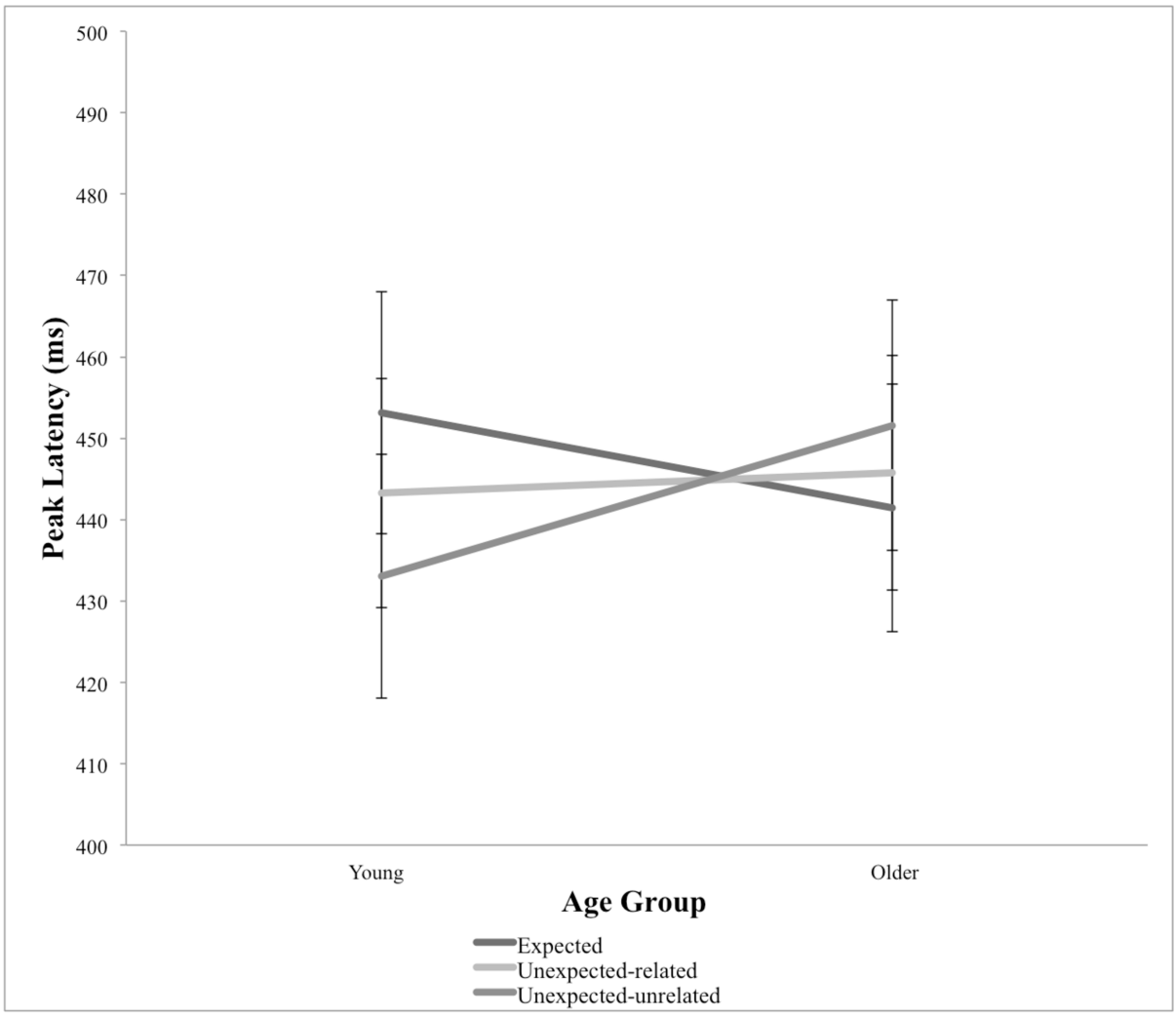

Figure 14. Peak latency (ms) representing the latency in processing the sentence ending (expected, unexpected-related, unexpected-unrelated) type as a function of age group in the 400 to 500 ms time window at electrode Fz. There was a greater effect of sentence ending in younger adults than in older adults.

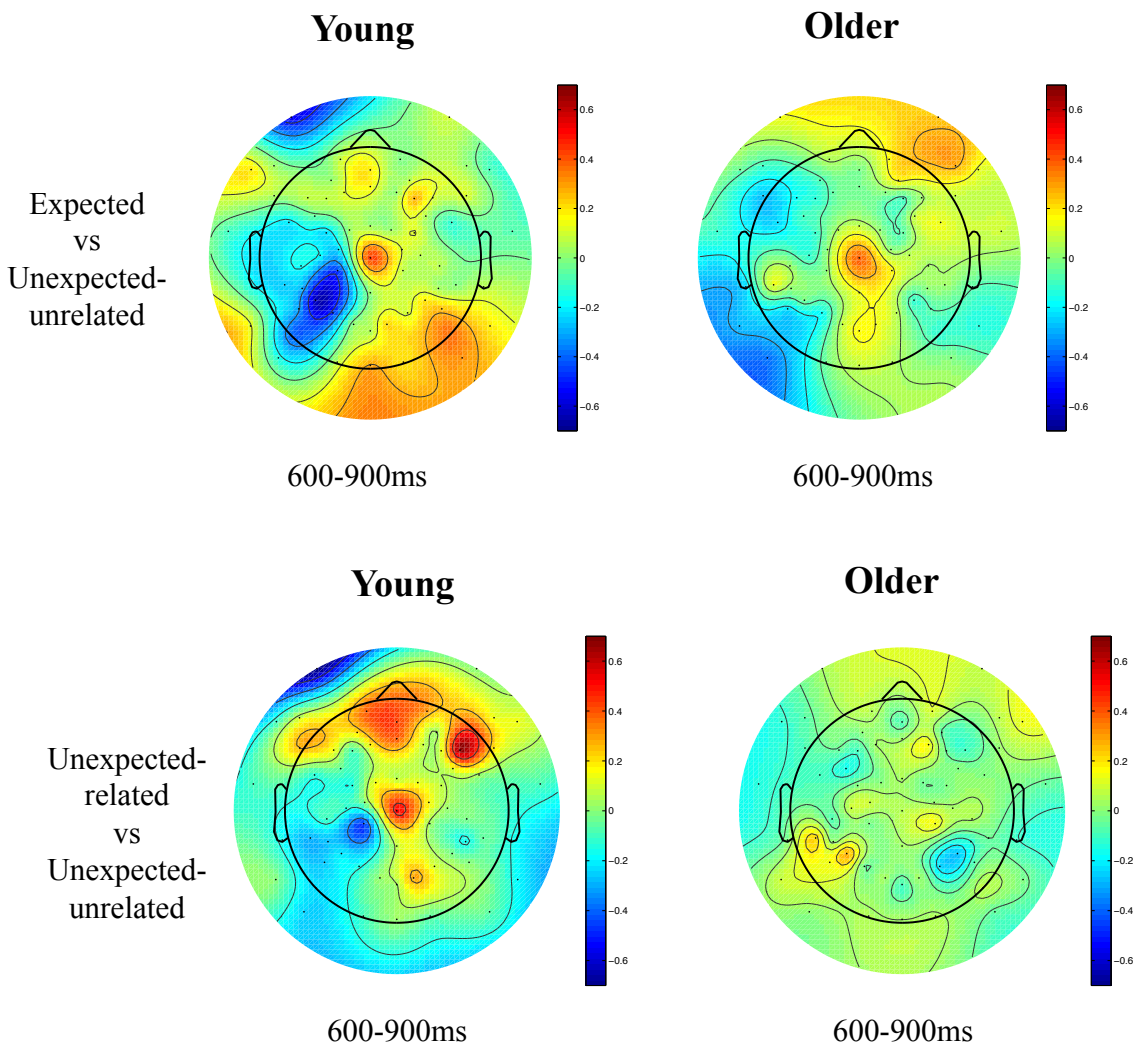

Figure 15. Topographic plot for the difference between the Expected and Unexpected-unrelated conditions and Unexpected-related and Unexpected-unrelated conditions in the 600-900ms time window for young and older adults. This is a spline plot (color reflects the mean voltage difference over the time window of 400-500ms). Both adults elicit a left parietal negativity for the difference in expected vs unexpected-unrelated responses. They also elicit a central positivity. For the difference in unexpected-related vs unexpected-unrelated responses, young adults elicit a left parietal negativity and older adults elicit a weak left parietal positivity.

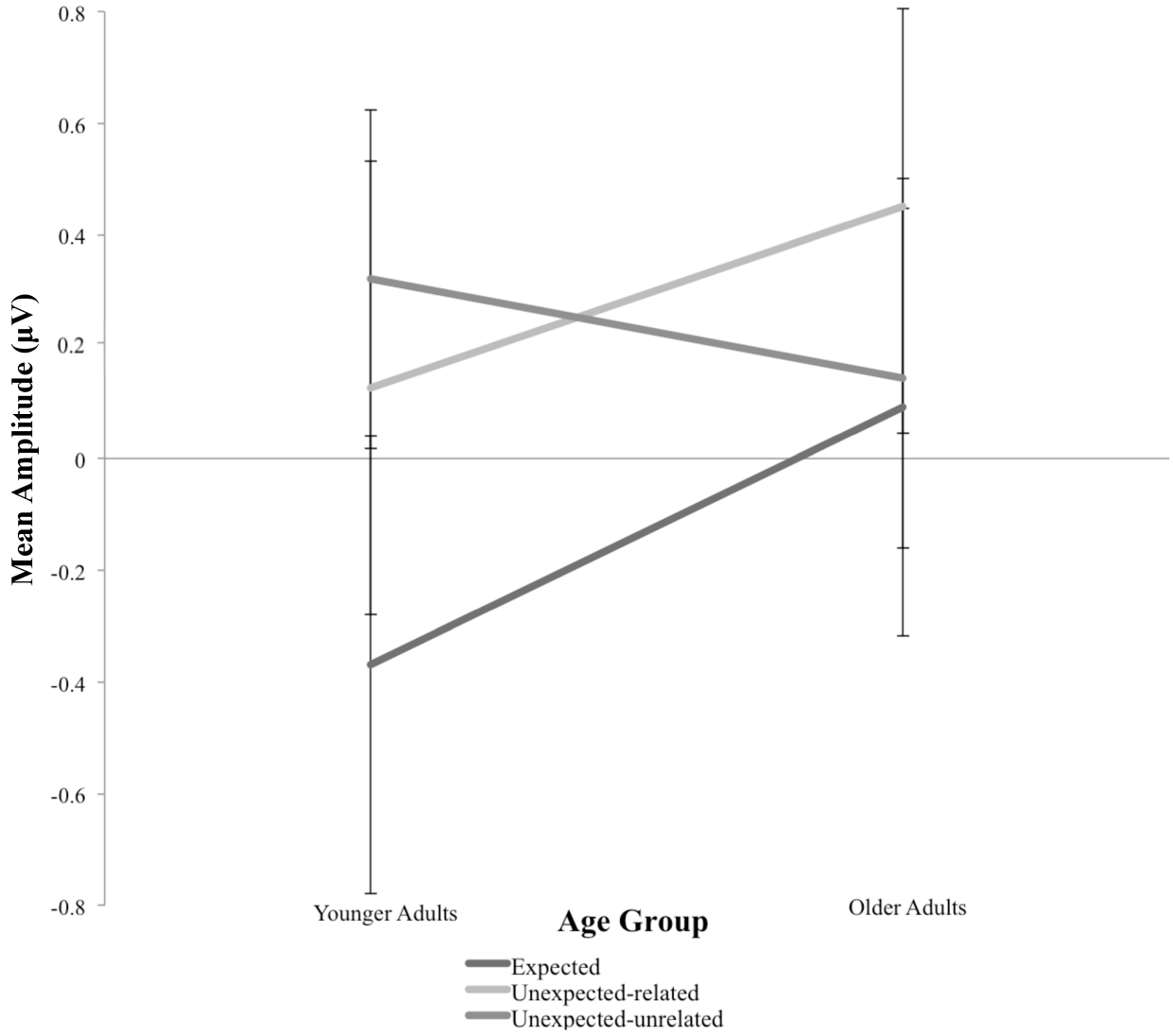

Figure 16. Mean amplitude (μV) representing the neurophysiological amplitude in processing the sentence ending (expected, unexpected-related, unexpected-unrelated) type as a function of age group in the 600 to 900 ms time window at electrode P3. There was a greater effect of sentence ending in younger adults than in older adults.

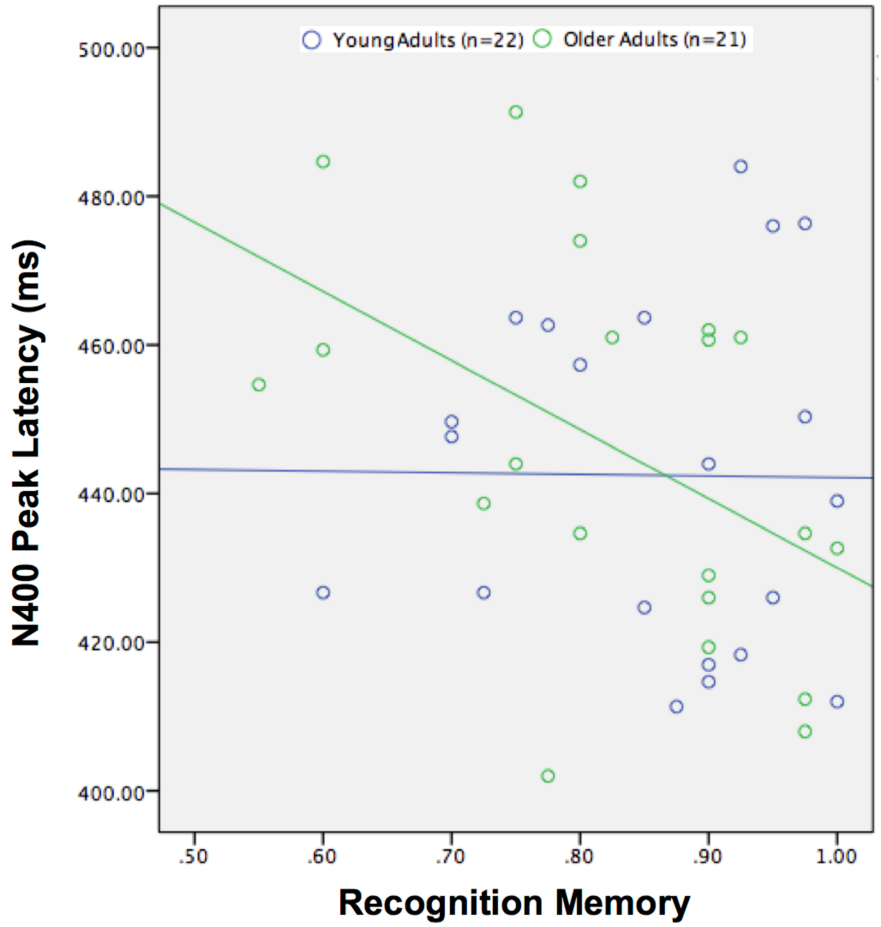

Figure 17. Scatterplot representing the relationship between peak latency of the averaged response across all conditions in the 400 to 500 ms time window at electrode Fz and overall recognition accuracy. There was no relationship between peak latency and recognition accuracy for young adults; however, there is a significant negative correlation between peak latency and recognition accuracy for older adults.

APPENDIX

Stimuli used in the experiment

Context-establishing Sentences, and 1) Expected, 2) Unexpected but Semantically Related, and 3) Unexpected but Semantically Related Sentences

Stimulus	Expected	Unexpected-related	Unexpected-unrelated
As a kid, he used to enjoy watching them march in a file, carrying objects many times their weight. He imagined life would be hard as a small...	ant	bee	squirrel
Chris moped around all morning when he discovered there was no cream cheese. He complained that without it he couldn't eat his	bagel.	toast.	cookies.
Rich couldn't count the number of Yankees games he had seen with his father. They both shared a lifelong interest in	baseball.	football.	chess.
The grizzly stood up on his hind legs and roared at the campers. They had never expected to be attacked by a...	bear	wolf	cat
Hitting the huge animal with a tranquilizer dart was difficult in the Arctic winds. Eventually, however, they were able to approach and tag the	bear.	panda.	lion.
At halftime, Carmen went to see if there was another six-pack in the cooler. Unfortunately, they were already out of...	beer	wine	water
I love their honey but am always afraid to be stung. That's why I always keep my distance from...	bees	ants	mice
On August 6, 1945, the United States detonated "Little Boy" over Hiroshima. At the time, it was the newest type of...	bomb	gun	stone
By the end of the day, the hiker's feet were extremely cold and wet. It was the last time he would ever buy a cheap pair of	boots.	sandals.	jeans.
My aunt fixed my brother some cereal using her best china. Of course, the first thing he did was drop the	bowl.	cup.	knife.
After they unpacked the new refrigerator, they let Billy have his fun. He played for days afterwards with the big	box.	jar.	button.

Humans are much smarter than elephants. However, compared to a human an elephant has a much bigger...	brain.	spine.	mouth.
Before the civil rights movement, African Americans suffered much discrimination. For instance, they were made to sit at the back of the...	bus.	train.	truck.
"You've got to churn it harder than that!" Phil exclaimed. He wanted to make high-quality...	butter.	milk.	coffee.
One fell off her blouse and got lost, and she didn't have any extras. She ended up searching all over town to find a matching	button.	zipper.	jar.
The day before the wedding, the kitchen was covered with frosting. Annette's sister was responsible for making the	cake.	cookies.	toast.
My Volkswagen needed a new transmission, steering column and tires. I think it's time for a new...	car.	truck.	bus.
It was a perfect winter day to be building a snowman. The nose was the missing piece, so I looked all around for the...	carrot.	potato.	lemon.
Our pet tabby was originally a stray. We were out hiking in the woods one day and came upon a lost...	cat.	dog.	bear.
When Sarah's party of 5 arrived at the restaurant, one of them had nowhere to sit. They requested an extra...	chair.	couch.	table.
Checkmate, Rosaline announced with glee. She was getting to be really good at	chess.	monopoly.	football.
The farm next door had recently slaughtered a whole coop. Jamie went over to buy some...	chicken.	fish.	salt.
Six months ago, Charlie had moved to Vancouver, British Columbia from Vermilion, Alberta. He was finding it hard to get used to living in such a big...	city.	town.	country.
The caveman knew his weapon couldn't win a fight with the creature. After all, all he was wielding was a blunt, wooden...	club.	stone.	gun.
Marshall had been studying all night for his exam and decided that he needs something to stay awake. He made himself some...	coffee.	tea.	butter.

The little girl was happy that Santa Claus left nothing but crumbs on his plate. She decided he must have really enjoyed the	cookies.	cake.	bagel.
Her brand new t-shirt shrunk in the wash. She should be more careful when washing items made of...	cotton.	silk.	silver.
George's living room was so barren, there was only a TV. Guests always complained that he should buy a...	couch.	chair.	desk.
During his attempted invasion of Russia, Napoleon discovered that it was very large. In fact, it's the biggest...	country.	state.	city.
During his attempted invasion of Russia, Napoleon discovered that it was very large. In fact, it's the biggest	country.	state.	city.
Eleanor offered to fix her visitor some coffee. Then she realized she didn't have a clean	cup.	bowl.	spoon.
The firefighters wanted to have a mascot to live with them at the firehouse. Naturally, they decided it would have to be a	dalmatian.	poodle.	zebra.
While biking home from school, I realized that I'd forgotten my homework in the classroom. I rushed back to find it sitting on my...	desk.	table.	couch.
Tim had been having abdominal pain for three days, so finally went to the hospital. He thought he should be seen by a...	doctor.	nurse.	lawyer.
Rocky was always burying bones in the backyard. He really was a stereotypical...	dog.	cat.	wolf.
"I'm an animal like Eeyore!" the child exclaimed. His mother wondered why he was pretending to be a	donkey.	zebra.	dalmatian.
America prides itself in being a country of independence and freedom. That's why their symbol is a majestic...	eagle.	owl.	lizard.
America prides itself in being a country of independence and freedom. That's why their mascot is a majestic	eagle.	owl.	lizard.
I guess his girlfriend really encouraged him to get it pierced. But his father sure blew up when he came home wearing that	earring.	necklace.	lipstick.
Marvin's favourite animal is a rabbit. He wonders why they have such large...	ears.	eyes.	hands.

Gloria has to squint when the sun is too bright. She feels more comfortable with something to cover her...	eyes.	ears.	feet.
Sammy was learning how to play soccer. He learned that he was only allowed to use his...	feet.	hands.	eyes.
Getting both himself and his car to work on the neighboring island was time-consuming. Every morning he drove for a few minutes and then boarded the	ferry.	gondola.	plane.
They were painting lines on the grass during our soccer practice. We had to stay off the...	field.	hill.	lake.
The men pulled the heavy net onto the deck of the boat. They were glad to see it was full of...	fish.	chicken.	sugar.
She blew across her instrument so gently it sounded like a bird song. It was clear she had mastered the...	flute.	trumpet.	violin.
He caught the pass and scored another touchdown. There was nothing he enjoyed more than a good game of	football.	baseball.	monopoly.
He enjoyed the traditional make of his wedding band. He would have been disappointed with anything other than...	gold.	silver.	cotton.
She felt she couldn't leave Venice without the experience. It might be a touristy thing to do, but she wanted to ride in a	gondola.	ferry.	helicopter.
Jeff was strumming and singing on the subway platform. He made pretty good money playing the...	guitar.	violin.	trumpet.
During his first deployment, the soldier always hesitated before shooting. He was nervous to use his...	gun.	bomb.	club.
When the bell rang, the students all streamed out of the classrooms to their lockers. It was very crowded in the...	hall.	room.	park.
Tina lined up where she thought the nail should go. When she was satisfied, she asked Bruce to hand her the	hammer.	saw.	shovel.
The referee blew his whistle at Luke during the soccer game. Luke had accidentally used his...	hands.	feet.	ears.
The patient was in critical condition and the ambulance wouldn't be fast enough. They decided they would have to use the	helicopter.	plane.	ferry.
Every winter the family loved going tobogganing. They lived	hill.	field.	river.

near the best...			
She always knew she could count on him to have supper ready after work. That was one of the many reasons she loved her...	husband.	wife.	teacher.
Fred went to the pantry and took out the homemade jelly his grandmother had brought. Fifteen minutes later, however, he was still struggling to open the	jar.	box.	zipper.
Everyone agreed that the stone-washed kind were out of style. But he continued to wear the same old pair of	jeans.	shorts.	sandals.
The prisoner stood in the courtroom for his sentencing. "You should be ashamed of yourself," said the...	judge.	lawyer.	nurse.
Carlos liked to get a good dose of vitamin C in the morning. So, he poured himself a tall glass of...	juice.	water.	wine.
In the dorms, cutting your steak can be a huge struggle. They always give you such a poor quality	knife.	spoon.	cup.
The calm waters made it ideal for Jake to go fishing. He was lucky to be so close to a...	lake.	river.	field.
This case would require all his legal knowledge to defend. This would be his greatest test as a new...	lawyer.	judge.	doctor.
In the summer, she loved to drink iced tea. It was especially delicious with a wedge of...	lemon.	orange.	potato.
He journeyed to the African plains, hoping to get a photograph of the king of the beasts. Unfortunately, the whole time he was there he never saw a	lion.	tiger.	panda.
He complained that after she kissed him, he couldn't get that red color off his face. He finally just asked her to stop wearing that	lipstick.	mascara.	earring.
The scaly reptile crawled onto the rock, stretching its foot into the hot, desert sunlight. This was the first time I'd ever seen that type of...	lizard.	snake.	eagle.
She wanted to make her eyelashes look really black and thick. So she asked to borrow her older friend's	mascara.	lipstick.	necklace.
Dean went up to the cow with a bucket. He wanted to get some...	milk.	butter.	tea.
Justin put a second house on Park Place. He and his sister often	monopoly.	chess.	baseball.

spent hours playing			
I knew I could trap this creature by putting out some cheese. Once I did this, it was easy to catch the...	mouse.	squirrel.	bee.
“Open wide” said the dentist. Sarah couldn't help that she had a small...	mouth.	throat.	spine.
She keeps twirling it around and around under her collar. Stephanie seems really happy that Dan gave her that	necklace.	earring.	mascara.
Lisa carefully checked the patient's vital signs and administered the medication. She thought about how lucky she was to have a job as a...	nurse.	doctor.	judge.
Tropicana is my favourite brand of juice. On the box is a picture of a fresh...	orange.	lemon.	carrot.
Tiptoeing through the forest at night, Livingston heard an eerie hoot from a nearby tree. He guessed that the sound came from a nearby...	owl.	eagle.	snake.
Wendy wondered how they had managed to ship such a large animal all the way from China. She waited in line to see the newly acquired	panda.	bear.	tiger.
The new off-leash area attracted many dog-owners. I’d never seen so many people in the...	park.	yard.	hall.
Amy was very anxious about traveling abroad for the first time. She felt surprisingly better, however, when she actually boarded the	plane.	helicopter.	gondola.
Muffie, Mrs. Smith’s pet, wears a bow on the puff of fur on its head. I don’t know how anyone could want to own a	poodle.	dalmatian.	donkey.
David didn’t care if they were boiled, mashed, fried, baked, or roasted. He felt no meal was complete without some...	potatoes.	carrots.	oranges.
Mrs. Brown was always strict with the trouble-makers who came to her office at school. This made her a good...	principal.	teacher.	wife.
The couple ducked under their umbrella to avoid getting wet. They were having so much fun they didn't mind walking in the...	rain.	snow.	winter.
The yard was completely covered with a thick layer of dead	rake.	shovel.	hammer.

leaves. Erica decided it was time to get out the			
Karen was an adrenaline junkie who really enjoyed rafting. You could find her every weekend on the...	river.	lake.	hill.
The metal device in his bag had set off the metal detector at the airport. He was led away by a guard and asked to wait in another...	room.	hall.	yard.
The chef wanted to make sure his pasta was not too bland. Once the water was boiling, he added...	salt.	sugar.	chicken.
Barb loved the feel of the waves on her feet, but she hated to walk barefoot. As a compromise, she usually wore a pair of	sandals.	boots.	shorts.
Pablo wanted to cut the lumber he had bought to make some shelves. He asked his neighbor if he could borrow her	saw.	hammer.	rake.
As the afternoon progressed, it became hotter and hotter. Keith finally decided to put on a pair of	shorts.	jeans.	boots.
The snow had piled up on the drive so high that they couldn't get the car out. When Albert woke up, his father handed him a	shovel.	rake.	saw.
She owed the smoothness of the dresses she made to the worms who spun the fabric. She only ever used...	silk.	cotton.	gold.
His car was a shiny metallic grey colour. Of course, he still knew that it was not made out of...	silver.	gold.	silk.
The creature slithered in its cage, hissing at me with its forked tongue. I recoiled, terrified of the...	snake.	lizard.	owl.
It was a whirlwind of white, powdery fluff. The children loved playing in the...	snow.	rain.	summer.
Amy grew up with scoliosis and had to wear a back brace. This was due to her deformed...	spine.	brain.	throat.
At the dinner party, I wondered why my mother wasn't eating her soup. Then I noticed that she didn't have a	spoon.	knife.	bowl.
At the end of fall, you could see them scouring the earth for nuts before the winter settled in. This crucial period determined the survival of the...	squirrels.	mice.	ants.
Michael just loved living in Florida. Even though he liked all of the USA, he knew he would always live in that...	state.	country.	town.

The caveman had run out of ammunition for his slingshot. He reached into his sack for another...	stone.	club.	bomb.
Scott liked his coffee very sweet. He always kept his kitchen well-stocked with...	sugar.	salt.	fish.
The freshly picked berries were still warm from the sun. They were her favourite food to eat in the...	summer.	winter.	snow.
Mrs. Smith called out to her family that dinner was ready. They quickly ran downstairs and sat at the...	table.	desk.	chair.
Lily stared at her drink longingly as it steeped on the kitchen counter. She was eager to drink her cup of...	tea.	coffee.	milk.
Mr. White spent lots of time playing games with his class. This is why all the children wanted him as their...	teacher.	principal.	husband.
John went out to buy a bag of cough drops. He had been suffering from a sore...	throat.	mouth.	brain.
George was hiking in India when he saw the orange and black striped animal leap out at him. He sustained serious injuries before he managed to kill the	tiger.	lion.	bear.
He wanted to make his wife breakfast, but he burned piece after piece. I couldn't believe he was ruining even the	toast.	bagel.	cookies.
Moving to New York from rural Kansas made her nervous. She has always lived in a small...	town.	city.	state.
My mother took a trip across Canada on the VIA rail. She saw the most beautiful landscapes from the window of the...	train.	bus.	car.
Jack was excited about buying himself a treadmill, but wondered how he'd get it back to his house. He called Ben, the only person he knew who owned a...	truck.	car.	train.
Every morning, the soldiers were woken by the same blaring song. Their least favorite instrument was now the...	trumpet.	flute.	guitar.
Angela bought a new bow for her big orchestra solo. She was well-known for playing the...	violin.	guitar.	flute.
The triathlon had been a grueling four hours in the hot sun. Upon crossing the finishing line, the runners immediately began to drink...	water.	juice.	beer.

"You may kiss the bride!" the minister told the groom. With this action, she was officially his...	wife.	husband.	principal.
Cecil sent back the bottle of 2010 Pinot Noir the waiter had brought him. He was very particular about his...	wine.	beer.	juice.
The forest animals had already started gathering food in preparation for colder days. It promised to be a long...	winter.	summer.	rain.
He looked on in awe as the lone animal howled at the moon. His favourite animal was always the...	wolf.	bear.	dog.
Jacob mowed his lawn and trimmed the hedges. As a result, it was a nice-looking...	yard.	park.	room.
At the zoo, my sister asked if they painted the black and white stripes on the animal. I explained to her that they were natural features of a	zebra.	donkey.	poodle.
It seemed to catch every time she opened or closed her backpack. She decided she would have to replace the	zipper.	button.	box.

Filler sentences and the corresponding target words.

Stimulus	**Target Word**
It had been the worst drought in history, with no rain for weeks. In these conditions, even a tiny spark could start a...	fire
Ashley's grandma suggested that she should write down every day's events during her trip abroad. Ashley decided she would keep a...	journal
At the end of the night, Teresa smiled as her date leaned in with puckered lips. She had been hopeful for a...	kiss
Due to the car accident, Sarah had to hobble around on crutches but at least she wasn't in a wheelchair. She was lucky that she had only broken one...	leg
After coming home from college, John was excited to see that his mom had made meatloaf and mashed potatoes. This had always been his favorite…	meal
The entrepreneur valued his growing fortune more than his growing family. He had forgotten that there are more important things in life than...	money
Even though it was plugged in, the electric fan wouldn't spin. It must be due to a broken...	motor
Matt liked to stay informed of current events. Every morning, he would watch the...	news
A small light lit up on the dashboard when she started the car. Looks like it's time to change the...	oil
David wanted to eat the cookies he made, but they were still too hot. He had just pulled them out of the...	oven
Rose had found a lost puppy wandering around outside her house earlier. She took it in and immediately tried to find its...	owner
Heather spent all night packing for her big trip to Europe. She had to leave early in the morning to board the...	plane
The pirate captain did not stand for mutineers. Therefore, he forced the rebels to walk the...	plank
Jean and Doug loved to spend summer afternoons in their rockers, drinking ice tea. The neighbours would often see them sitting out on their...	porch
Maria stood in the aisle, looking at the displays. There was a sale on laundry detergent and she was trying to decide between liquid or...	powder

As Cliff answered the final question, cheers erupted from the audience and he knew he'd won. The host shook his hand and presented him with the...	prize
Bob tried not to get too excited as the finish line came into view and he was still in first place. He had run so well, you would never guess that this was his first...	race
As part of the history course, the class was taking a train trip across Canada. There were very excited to learn all about the Canadian Pacific...	Railway
John enjoyed decorating the house with lights during the holiday season. He was always sure to carefully secure the ladder before climbing on the...	roof
The morning breeze was ideal for taking out the boat. It wasn't long before the boat took off as the wind caught the...	sail
In lieu of the upcoming wedding, Jane was trying to lose weight. Each day for lunch and dinner she only ate a…	salad
When she makes spaghetti, it usually takes all day. It takes a long time to simmer the….	sauce
The director cried "cut" after the actors were done. He did this at the end of every…	scene
Mary has a fear of heights, spiders and small spaces. She's practically afraid of her own…	shadow
Martin wanted to be a ghost for Halloween. He cut two big holes out of a white...	sheet
Many early settlers came over from Europe on the Mayflower. It must have been a hard few months before they arrived in New York, living on a...	ship
I ordered pepperoni pizza for dinner -- Joey's favourite. When Joey came over, I offered him a…	slice
Today, my sister's boyfriend broke up with her, sending her into a pit of despair. At night, from her room, I heard a quiet…	sob
The basil plant on my windowsill had finally sprouted. A single, green stem poked out from the...	soil
From Shreddies cereal, to Saltines, to toast, to lemon bars -- I'll eat them all. I love food in the shape of a…	square
Henry was worried he would be late and miss his train. Luckily, he arrived just in time to see the train pull into the...	station
At first, the little girl excitedly reached out for the goodies the unfamiliar man was offering to her. But then she remembered her mother telling her to never take candy from a….	stranger
Mike got a job as a lawyer for one of the top firms in Manhattan. He was told to go out and	suit

buy a new…	
Every summer she looked forward to her family's vacation to the coast. Her favorite pastime was lying on the beach, soaking up rays from the…	sun
Some proposed increasing it for the rich while others argued that it would scare them away. No one seemed to agree on the…	taxes
George wasn't allowed to board the ferry without it. But wherever he looked, he just couldn't find his….	ticket
Robin had visited Thailand, Singapore, Malaysia and Laos in the past month. He really liked to…	travel
Although they had lost the battle. They were sure to win the…	war
A whole year of healthy eating and exercise made Jim hard to recognize. He had lost a lot of…	weight