Published in final edited form as:
Psychol Aging. 2012 December ; 27(4): 975–988. doi:10.1037/a0029206.

To predict or not to predict: Age-related differences in the use of sentential context

Edward W. Wlotko[1], **Kara D. Federmeier**[1], and **Marta Kutas**[2]
[1]University of Illinois
[2]University of California, San Diego

Abstract

Older adults (as a group) are less likely than younger adults to engage in an anticipatory mode of language comprehension, failing to successfully pre-activate information about upcoming likely (predictable) words during online processing. To assess (within one set of materials) age-related changes in the use of sentential context to affect processing of predictable words and in the consequences of violating predictions, event-related brain potentials were recorded while older adults read sentences that varied in sentence-level constraint and expectancy of sentence-final words. Strongly constraining sentences were completed by their most expected, predictable words and weakly constraining sentences were completed by their most expected, less predictable words. Both types of sentences also were completed by unexpected (but plausible) words. Older adults showed reduced and delayed effects of sentential context on processing predictable words. Whereas younger adults elicit an enhanced positive ERP (starting around 500 ms post-stimulus onset, largest over prefrontal electrode sites), specifically for unexpected words that violate strong expectancies for a different word, older adults as a group did not exhibit this neural consequence of disconfirmed predictions. Older adults were instead more likely to show a left-lateralized frontal negativity for predictable items. This ERP response has been attributed to processes needed to revisit contextual material in forming an interpretation of message-level meaning, which may be more likely when anticipatory modes of comprehension are not engaged. Taken together, the results suggest that normal aging can affect allocation of resources to different cognitive and neural pathways in achieving comprehension outcomes.

Keywords

language; event-related potentials; sentential context; N400; frontal negativity

---

Garnering meaning from an utterance or a written message during everyday language comprehension requires the rapid analysis of information at many levels, from perception of the physical stimulus, to the analysis of the features of the individual words, to the construction of the message via sentence- and discourse-level processes, all augmented by world knowledge and situational context. Although all listeners and readers must bring these cognitive processes to bear during normal comprehension, there may be changes across the lifespan in how they are used in the construction of message-level meaning.

Correspondence can be addressed to: Edward W. Wlotko, Beckman Institute, University of Illinois, 405 N Mathews Avenue, Urbana, IL, 61801. ewwlotko@alumni.pitt.edu.
Edward W. Wlotko, Beckman Institute, University of Illinois; Kara D. Federmeier, Department of Psychology, Neuroscience Program, and Beckman Institute, University of Illinois; Marta Kutas, Departments of Cognitive Science and Neurosciences, University of California, San Diego.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

For young adults, a large body of empirical data attests to the impact of sentential context on word processing (Tulving & Gold, 1963; Stanovich & West, 1979; Fischler & Bloom, 1979; Erlich & Rayner, 1981; Kutas & Hillyard, 1984). More recently, a growing set of studies has demonstrated that one way for sentential context to affect word processing is by supporting the prediction of information about likely upcoming words (Schwanenflugel & LaCount, 1988; Lau et al., 2006; Kamide et al., 2003; Dikker et al., 2009). Electrophysiological studies have shown that as context accrues, semantic features (Federmeier & Kutas, 1999), phonological information (DeLong et al., 2005), grammatical gender (Wicha et al., 2004; Van Berkum et al., 2005), and orthographic representations (Laszlo & Federmeier, 2009) of predictable words become neurally active before those words are actually (if ever) presented. Thus, as young adults process sentences, context information serves to pave the way for likely upcoming words, such that when predictable words are actually encountered, processing demands are reduced.

Older adults, although retaining vocabulary and stores of knowledge, do not on average seem to make routine use of sentential context in the same way as younger adults (see Wlotko etal., 2010 for review). Whereas offline measures of the organization of semantic memory generally show qualitatively similar performance by younger and older adults (Bowles et al., 1983; Howard, 1980), differences emerge across age in the information gleaned from sentences and discourses (e.g. Noh et al., 2007). For example, event-related brain potential (ERP) studies, which allow recording of neural activity concurrently with comprehension processes, have shown differential effects of sentential context on word processing for older as compared to younger adults. In particular, age-related changes during normal comprehension tasks have been observed in studies measuring the N400 component, a functionally specific measure of semantic processing that is sensitive to the impact of sentential context on word processing (see Kutas et al., 2007). The N400 is part of the typical brain response to all meaningful and potentially meaningful stimuli, including written and spoken words, and has been linked to the retrieval of information from semantic memory (for reviews see Kutas & Federmeier, 2000; Federmeier & Laszlo, 2009; Kutas & Federmeier, 2011). The N400 manifests as a negative-going wave peaking approximately 400 ms after stimulus onset, following sensory components indexing perceptual processing of the stimulus. N400 amplitudes become smaller (more positive) when demands associated with semantic processing are reduced, such as when words are encountered in the presence of supportive sentential context; the size of this reduction is referred to as the N400 effect.

Several studies have found both reduced and delayed N400 effects of sentential context for older as compared to younger adults (Wlotko & Federmeier, in press; Federmeier et al., 2002, 2003, 2005; Gunter et al., 1992; Woodward et al., 1993; Hamburger et al., 1995). In these studies, N400s to unexpected words or unpredictable ones are not as affected by aging; in other words, the age-related reductions and delays in N400 effects are generally driven by the response to predictable endings in richly supportive contexts. These findings therefore have been taken as an indication of less efficient or less effective use of sentential context to facilitate word processing.

In line with this, one explanation that has been put forward for the locus of age-related change in online comprehension at the sentence level is a relative decrease in real-time predictive processing for older adults. Whether because of slowing, reduced efficacy of top-down connections, changes in hemispheric dominance, or other factors (see, e.g., Salthouse, 2002; Raz, 2004; Cabeza, 2002; Zacks & Hasher, 1997), it seems that older adults may not engage in predictive processing to the degree that younger adults do. Federmeier et al. (2002), for instance, observed that during auditory sentence comprehension, older adults as a group, unlike younger adults, did not preactivate semantic features of likely upcoming words. To the extent that older adults do not use context to pre-activate upcoming items, the benefits of sentential context for normal comprehension are likely to be diminished. Indeed, Wlotko & Federmeier (in press) observed that in contrast to the close association in young adults between N400 amplitude and strength of contextual constraint for sentence-final words, older adults' N400 amplitudes exhibited less sensitivity to constraint, a change which they attributed in part to reduced engagement of anticipatory comprehension mechanisms.

Predictive processing not only can engender benefits for comprehension, but can also incur consequences when predictions are incorrect. Federmeier et al. (2007) examined these processing consequences for young adults using sentences that were strongly or weakly constraining and that were completed by either an expected or unexpected -- but always plausible -- ending. As already discussed, prediction is one way sentential context can influence processing of upcoming words. However, for expected words in rich contexts, facilitation cannot be unambiguously attributed to predictive processes, as predictable words are also better fits with the prior context once encountered, and may thus be easier to process (i.e., integrate into the message-level representation) even in the absence of any preactivation of information about the words. By contrast, for wholly unexpected endings, a difference in processing across levels of constraint can be directly attributed to predictive processing, because the only difference between the two conditions is the presence or absence of an expected (i.e., predictable), but not presented, completion.

When examining the N400, Federmeier et al. (2007) observed the typical expectancy effect, such that expected words elicited reduced N400s compared to unexpected words, and this effect was larger for strongly versus weakly constraining contexts. For the unexpected words, though, N400 amplitudes were identical for both strongly and weakly constraining contexts. Thus, it seems that the N400 per se did not reflect processing consequences of encountering a word different from that predicted by the context. However, unexpected endings in strongly constraining contexts, as opposed to those in weakly constraining contexts, were more positive over (pre)frontal sites after the N400 timewindow, beginning around 500 ms post-stimulus onset and continuing throughout the one second epoch. This positivity was therefore linked to processes brought online when an unexpected word is encountered in the face of strong expectations for a different word. This type of process could be something like semantic "revision" as discussed by Federmeier et al. (2007), an inhibitory process, and/or a "learning signal" from which to update future predictions (see also Federmeier, Kutas, & Schul, 2010).

The precise nature of this effect notwithstanding, its hypothesized link with the use of predictive processing mechanisms during language comprehension suggests that it would be affected by normal aging, given that aging impacts the tendency or ability to use context information predictively. Indeed, Federmeier, Kutas, and Schul (2010) examined consequences of prediction in a task with minimal contexts: using a semantic category task with definitional cues (e.g., *A member of royalty*), targets could be typical members of the category (e.g., *king*), atypical members (e.g., *duke*), or nonmembers (e.g., *chair*). When comparing typical category members (that confirm expectations of the cue) to atypical members (which are acceptable targets but violate expectations produced by the cue), younger participants elicited a late frontal positivity for the atypical targets, similar to that observed by Federmeier et al. (2007) for plausible, unexpected endings in strongly constraining sentence contexts. Older adults as a group, however, did not reliably elicit this positivity. Thus, concordant with past findings, older adults were less likely to engage predictive mechanisms. In this same vein, then, it seems that an investigation aimed at examining potential consequences of prediction for older adults in constraining sentential contexts more typical of normal language comprehension could be illuminating in further establishing the boundaries of conditions under which older adults do not characteristically engage anticipatory modes of comprehension.

To further assess how older adults use context during online sentence comprehension, in the present study we recorded electrical brain activity from a group of older adult participants who were asked to read for comprehension the same stimuli used in Federmeier et al. (2007). Because all the sentences are entirely plausible (without semantic anomalies), we are able to assess comprehension processes under more naturalistic circumstances than in past research (e.g., Federmeier et al., 2002). In addition, whereas Federmeier et al. (2002) showed that older adults are less likely to predict during comprehension of natural speech, here we use visual presentation, allowing a comparison of age-related changes in comprehension across modality. If age-related slowing does contribute to the changes in predictive processing that have been observed in prior work, it is possible that the slower pace of word-by-word reading (two words per second, as in Federmeier et al., 2007) as compared with natural speech could afford older adults the opportunity to engage predictive processes more successfully.

We expect, in line with past studies, that modulations of the N400 will be smaller and delayed overall compared to younger adults. Of specific interest will be whether there are also qualitative differences in the pattern across conditions of contextual strength, suggesting age-related changes in the ability to make use of contextual information. In particular, a recent study showed that in addition to the smaller overall effect of sentential context, older adults may generally be less sensitive to weak contextual information (Wlotko & Federmeier, in press). That study examined ERP responses to sentences that varied continuously in the amount of contextual information available. Here, we compare the responses to expected and unexpected endings within (the same) weak contexts, and predict that compared to younger adults, older adults will less efficiently make use of the information available in weak contexts to affect online processing.

To specifically address the question of whether older adults are less likely to engage in predictive modes of comprehension in constraining sentential contexts, we will look for differences in the processing of the unexpected words (across strong and weak constraint) at frontal channels in the post 500 ms time window, where young adults have reportedly manifested consequences of predictive comprehension. In addition, it has been previously suggested that a reduced reliance on predictive processing for older adults could lead to downstream changes in processes of comprehension. One such process may manifest in a late frontal negativity observed for items of moderate to strong constraint (Wlotko & Federmeier, submitted). This effect was hypothetically linked to processes engaged as a result of revisiting contextual information when multiple interpretations of a sentence were likely. This negative-going brain response (beginning around 500 ms post-stimulus onset) was more robust – and evident over a wider range of contextual strength – for older compared to younger adults. Wlotko & Federmeier (in press) suggested that older adults may show a greater tendency to revisit contextual material as a consequence of decreased processing advantages afforded by anticipatory comprehension mechanisms that, for younger adults, make more efficient use of the context in the first pass. The items in the current study include sentential contexts over a similar range of constraint. To the extent that a decreased reliance on predictive comprehension leads to engagement of the processes reflected by the frontal negativity, that effect also will be evident for older adults for the present materials.

Method

Participants

Twenty-four native speakers of English (12 female, 12 male) between the ages of 59 and 88 (mean = 72.4 years) were recruited from the local community at the University of California, San Diego and compensated with cash payment for their time. Two additional participants completed the study but their data were excluded from analysis due to excessive artifactual contamination of the EEG recordings. All participants were right-handed as assessed by self-report and the Edinburgh inventory (Oldfield, 1971); three reported having left-handed or ambidextrous family members. All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders.

Each potential participant was screened for cognitive impairment using the Mattis Dementia Rating Scale (Mattis, 1976) before being admitted to the study (range of 136–144 out of a maximum of 144; mean=141.6, median=142). Participants were on average more educated than a college student population (all participants received a high school diploma or equivalent, all but 4 participants received some form of post-secondary education, and 6 participants completed an advanced degree). All participants also completed a battery of standard neuropsychological tests given to all older participants who enroll in a study in our lab. Several of these tests were selected and also administered to a younger adult sample (see below) because they have been previously related to individual differences in sentence comprehension. These include reading span (Daneman and Carpenter, 1980), author and magazine recognition tests (Stanovich, 1989), and category and letter verbal fluency (Gladsjo et al., 1999). Table 1 presents descriptive statistics and significant group differences for these test scores for the older adult sample and a randomly selected sample of 24 younger adults from Federmeier et al. (2007).

Materials

The experimental stimuli were identical to those used by Federmeier et al. (2007). Each participant read 282 sentence frames, half of which were strongly constraining and half of which were weakly constraining (as determined by cloze probability norming with younger adults, described below). Each sentence stem was completed with both its most expected ending (the word with the highest cloze probability for that sentence) and an unexpected but plausible ending (with a cloze value near 0). The endings of the sentences served as the critical words for the experiment, leading to four conditions: expected endings in strongly constraining sentence frames (SCE), expected endings in weakly constraining sentence frames (WCE), unexpected endings in strongly constraining sentence frames (SCU), and unexpected endings in weakly constraining sentence frames (WCU).

To determine the cloze probability of the endings in their sentence frames, a norming procedure was conducted with native English speakers at the University of California, San Diego (see Federmeier et al., 2007 for complete details). Candidate sentence frames (368 total) were divided into four lists of 92 each; three of the four lists were completed by 34 participants and one list by 35 participants. Prior work has shown that offline cloze probability results are qualitatively similar for younger and older adults (Lahar et al., 2004). Participants completed each sentence frame with a word they would “generally expect to find completing the sentence fragment” and with two additional possible completions. We thus could compute cloze probabilities not only for the standard best completion of the sentence frame but also for a larger set of “next best” endings. This procedure allowed us to ensure that the unexpected endings were not considered as a good alternative to the best completions and were truly unexpected.

From the resulting set of normed sentences, 141 strongly constraining sentence frames, for which the best completion had a cloze value of 67% or greater (mean 85.3%; mean as next best 4.9%), and 141 weakly constraining sentence frames, for which the best completion had a cloze value of 42% or lower (mean 26.9%; mean as next best 9.3%), were selected for the stimulus set. Sentence frames of the two types were matched for length (average of 10 words per sentence in each type) and the two types of expected items were also matched for word frequency (Francis & Kucera, 1982) and word length.

The experimenters then chose unexpected endings (cloze value near 0%, total cloze mean=3.1% for both strongly and weakly constraining frames), each of which could be paired with both a strongly constraining and a weakly constraining sentence frame. Across constraint, then, lexical properties of the unexpected endings were perfectly matched. Several experimenters judged each of the unexpected endings to be both plausible in its sentence frame and to come from a different semantic category from (and thus share relatively little feature overlap with) the corresponding expected ending for that sentence frame. Mean association strength (as assessed by the Edinburgh Associative Thesaurus; approximately 90% of the experimental stimuli were in the database) between the expected and unexpected endings for each sentence frame was less than 0.005 for both constraint conditions (and did not differ). To assess association between the sentence ending and the words in the sentence frame, the number of sentences containing at least one moderate to strong associate (0.2 or greater) of the sentence final word was tabulated. Overall, there were few words in the sentence contexts associated with the critical words: 4% for SCE and 1% for the other three conditions. Thus, the constraints at the message level of these sentences cannot be attributed solely to word association or feature overlap.

Stimuli were divided into two lists, such that each participant saw each sentence frame only once; within each list, half of the frames for each constraint condition were completed by the expected ending and half were completed by the unexpected ending (yoked so that the matched unexpected endings did not appear in the same list). Stimulus characteristics were controlled for conditions across and within each list. The order of sentence frames was randomized four times for each list and list order was counterbalanced across participants.

Procedure

Participants were seated 100 cm in front of a 21″ CRT computer monitor inside an electrically shielded chamber. Each trial began with a warning signal (several pluses presented on the screen for 500 ms); the blank screen between the warning signal and the first word of the sentence varied randomly from 500 to 1200 ms (to prevent the consistent buildup of anticipatory slow-wave activity). Sentences were then presented word-by-word in the center of the screen. Each word was presented for 200 ms with an interstimulus interval of 300 ms. A three-second pause separated sentences. Participants were asked to minimize blinks, eye movements, and muscle movement while reading. They were instructed to read the sentences for comprehension while keeping in mind that they would be asked questions about what they had read at the conclusion of the recording session. The recording session began with a short set of practice sentences to acclimate the participants to the task situation. The main experimental session was divided into four blocks of sentences, with participants taking a short rest between each block; recording time was approximately one hour.

After the recording session ended, participants completed a recognition test. A list of 240 words was selected such that, for each participant, 80 of the words were never seen as sentence-final words during the experiment, and, of the remaining 160 words, 40 sentence-final words came from each experimental condition. Participants were asked to circle all the words that they remembered reading as a final word of one of the sentences in the experiment.

EEG recording and processing—EEG was recorded from twenty-six geodesically arranged sites on the scalp using tin electrodes embedded in an Electro-cap. The sites are Midline Prefrontal (MiPf), Left and Right Medial Prefrontal (LMPf and RMPf), Lateral Prefrontal (LLPf and RLPf), Medial Frontal (LMFr and RMFr), Mediolateral Frontal (LDFr RDFr), Lateral Frontal (LLFr and RLFr), Midline Central (MiCe), Medial Central (LMCe and RMCe), Mediolateral Central (LDCe and RDCe), Midline Parietal (MiPa), Mediolateral

Parietal (LDPa and RDPa), Lateral Temporal (LLTe and RLTe), Midline Occipital (MiOc), Medial Occipital (LMOc and RMOc), and Lateral Occipital (LLOc and RLOc); Figure 1 shows this arrangement.

These electrodes were referenced online to the left mastoid and later referenced offline to the average of the left and right mastoids. Eye movements were monitored using a bipolar recording of EOG with electrodes placed on the outer canthus of each eye. Blinks were monitored with an electrode placed over the infraorbital ridge of each eye, both referenced to the left mastoid. Electrode impedances were kept below 5 kΩ and signals were amplified with Grass amplifiers set at a bandpass of 0.01 to 100 Hz. EEG was sampled at 250 Hz and saved on a hard drive. EEG records were examined and marked for EOG, EMG, or other artifactual contamination. These trials (average 3% overall; no differences among conditions) were excluded from further analysis, with the exception of trials containing eye blinks for three subjects, which were corrected (Dale, 1994) and added back into the EEG record. ERPs were computed from 100 ms before the onset of critical words to 920 ms after, and averages of artifact-free ERPs were calculated for each type of critical word (SCE, WCE, SCU, WCU) after subtraction of the 100 ms pre-stimulus baseline. Measurements were taken after a digital bandpass filter of 0.2 to 20 Hz was applied for mean amplitudes and a bandpass filter of 0.2 to 10 Hz for peak measurements.

Except where noted, within-subjects analyses were performed with repeated measures ANOVA. For tests with more than one degree of freedom in the numerator, Huynh-Feldt corrected p-values are reported along with epsilon values. Electrode location was included as a factor in all analyses, but main effects of Electrode are not reported. Interactions of Electrode with the experimental factors are reported only when theoretically significant. For comparisons across age, mixed-effects models were used for comparing younger and older adults (using a between-subjects factor of Age Group). The data for younger adults come from Federmeier et al. (2007) and all reported effects are similar for the full group of 32 participants from that study as well as a randomly selected sample of 24, for which results are presented in this paper to equate sample size across groups.

Results

Behavior

Overall, older participants recognized an average of 34.5 of the 160 items on the recognition test (22%) and false alarmed to an average of 9.5 items (compared to 36.9, or 23%, remembered and 4.3 false alarms for the younger group). When number of items recognized by older adults from each condition was analyzed, there was a Constraint x Expectancy interaction [$F(1,23)=8.14$, $p=.009$]. Participants remembered strongly expected endings (SCE) least well (7.0 items out of 40). Strongly constrained unexpected endings (SCU) were remembered best (9.5 items), followed closely by weakly constrained unexpected items (WCU, 9.0 items) and weakly constrained expected items (WCE, 9.0 items). Performance for each of the conditions for both younger and older adults is shown in Figure 2.

Overall, older participants remembered about as many items on the recognition test as younger adults from Federmeier et al. (2007), but consistent with prior work in the memory literature, had a higher rate of false alarms (e.g. Isingrini et al., 1995; Benjamin, 2001), leading to a lower d’ overall (0.56 for older adults vs. 1.10 for younger adults, significantly different across age groups [$F(1,46)=9.28$, $p=.004$]). Older participants performed similarly to the younger adults on the recognition test across conditions, in that strongly expected -- and hence not distinctive -- items (SCE) were remembered least well. However, older adults remembered weakly constrained expected endings (WCE) similarly to completely unexpected endings, whereas younger adults showed a memory boost particularly for unexpected endings, and had less memory for the weakly expected endings (in a mixed effects ANOVA with age group as a between-subjects factor, there was no three-way interaction between Age, Constraint, and Expectancy; but Age group did interact with Expectancy [$F(1,46)=9.04$, $p=.004$]). Thus, because older adults may predict less efficiently during comprehension, the weakly expected endings may have been more "surprising" and thus more distinctive for older adults, leading to enhanced memory for these items.

ERPs

Grand average ERPs for sentence-final words in all conditions are presented in Figure 1. These words evoked typical brain responses for visual stimulation in older adults: early sensory components include the posterior P1, N1, and P2, and the anterior N1 and P2. Table 2 shows the latency and amplitude of these components for the participants in this study and the sample of young participants from Federmeier et al., 2007. Posterior P1s and N1s are similar across groups. Posterior P2s are slightly but not significantly smaller for older adults; however, older adults' P2s are significantly earlier than younger adults' by about 15 ms [$F(1,46)=12.71$, $p<.001$]. Consistent with prior work, older adults' N1s are shifted frontally, and therefore the anterior N1 is significantly larger compared to younger adults [$F(1,46)=22.52$, $p<.001$] but not different in latency. As in other studies of visual reading in older adults (see King & Kutas, 1995; Wlotko et al., in press), frontal P2 amplitude is drastically reduced in this group [$F(1,46)=37.53$, $p<.001$].

Following the sensory components, all conditions elicit a negative-going wave (N400) largest for unexpected endings and smallest for strongly expected endings, and at frontal sites, a broad positive-polarity response for all conditions except the negative-going SCE waveform.

N400

Latency: Peak latency was measured on the unexpected conditions (which elicited the largest N400s) in the 300–500 ms timewindow at 6 central-parietal electrode sites (LMCe, MiCe, RMCe, LDPa, MiPa, RDPa) where N400s are typically maximal. No effects of condition were observed, and overall, the N400 peaked at 404 ms, which is about 40 ms later than in the sample of younger adults from Federmeier et al. (2007), a significant delay [$F(1,46)=22.34$, $p<.001$], consistent with the findings from a large-scale study of N400 changes with normal aging (Kutas & Iragui, 1998).

To assess N400 effects, difference waves were computed with a point-by-point subtraction for conditions of interest. The difference between expected and unexpected endings in strongly constraining contexts is the well-studied N400 expectancy effect; this difference peaks at 425 ms. Latency of effects as a function of age group will be discussed together with amplitude, below.

Amplitude: Mean N400 amplitudes were measured in a time window of 325–525 ms post-stimulus onset (centered around the peak of the expectancy effect) at all electrode sites. An omnibus ANOVA revealed a main effect of Expectancy [$F(1,23)=8.55$, $p=.008$], an Expectancy x Electrode interaction [$F(25,575)=10.72$, $p<.001$, $\varepsilon=.111$], a Constraint x Electrode interaction [$F(25,575)=5.45$, $p<.001$, $\varepsilon=.184$], and, importantly, an Expectancy x Constraint x Electrode interaction [$F(25,575)=13.95$, $p<.001$, $\varepsilon=.204$]. Thus, the effect of expectancy is modulated by constraint, and differs by electrode site.

To investigate N400 effects, the analysis was restricted to the 11 most central-posterior electrodes where N400 effects are known to be largest[1] (LMCe, MiCe, RMCe, LDPa, MiPa, RDPa, LLOc, LMOc, MiOc, RMOc, RLOc). Main effects of Constraint [$F(1,23)=7.27$, $p=$.

013] and Expectancy [$F(1,23)=17.6$, $p<.001$] were observed, modulated by a Constraint x Expectancy interaction [$F(1,23)=15.54$, $p<.001$].

To assess the form of the interaction, pairwise comparisons were performed at the same 11 electrode sites. The standard expectancy effect in strongly constraining sentences (SCU-SCE) was significant [$F(1,23)=26.55$, $p<.001$]. The difference between expected and unexpected endings in weak contexts (WCU-WCE), however, was not reliable [$F(1,23)=3.31$, $p=.08$]. The constraint effect for expected endings (WCE-SCE) was significant [$F(1,23)=15.57$, $p<.001$], consistent with their cloze probabilities. Finally, the difference between unexpected endings in the two types of contexts (SCU-WCU) was not significant [$F(1,23)=.54$, $p=.469$].

Group Differences: Consistent with all past work, the expectancy effect (SCE vs SCU) was both smaller [$F(1,46)=22.96$, $p<.001$] and delayed by about 50 ms for older adults [$F(1,46)=18.81$, $p<.001$].[2] The constraint effect for expected endings (WCE-SCE) was significantly smaller [$F(1,46)=8.01$, $p=.007$] and delayed by about 30 ms [$F(1,46)=7.38$, $p=.009$] for older adults, similar to the effect reported in Federmeier & Kutas (2005). Consistent with the lack of a reliable facilitation for weakly expected endings (WCE) in older adults, the difference between expected and unexpected endings in weak contexts (WCU-WCE) was also significantly smaller for older adults [$F(1,46)=10.02$, $p=.003$], and, although there is little difference for the older adults, a measurable 25 ms delay was observed for this effect [$F(1,46)=5.12$, $p=.029$]. The size of the constraint effect on unexpected endings (SCU-WCU), which was not significant for either group, was not significantly different across groups [$F(1,46)=.43$, $p=.514$]. Amplitudes and latencies for each effect and group are presented in Table 3; Figure 3 displays difference waves for the two groups for each of the effects at the Midline Parietal electrode site.

Late time window—An omnibus ANOVA on mean amplitudes measured from 600–900 ms at all electrode sites revealed that both Constraint and Expectancy interacted with Electrode [Constraint, $F(25,575)=6.76$, $p<.001$, $\varepsilon=.185$; Electrode, $F(25,575)=13.12$, $p<.001$, $\varepsilon=.132$], and there was a Constraint x Expectancy interaction [$F(1,23)=5.18$, $p=.033$] as well as a three-way Constraint x Expectancy x Electrode interaction [$F(25,575)=6.99$, $p<.001$, $\varepsilon=.222$].

A central goal in this experiment was to assess consequences of prediction, i.e. the comparison of unexpected endings across the two types of constraint (SCU-WCU). To assess the pattern at frontal sites where younger subjects in Federmeier et al. (2007) showed this effect, the analysis was restricted to the 11 most frontal channels (LLPf, MiPf, RLPf, LMPf, RMPf, LLFr, LDFr, LMFr, RMFr, RDFr, RLFr). A main effect of Expectancy was significant [$F(1,23)=6.64$, $p=.017$] as well as the Constraint x Expectancy interaction [$F(1,23)=9.64$, $p=.005$].

Pairwise comparisons revealed that unexpected endings were not different across sentence types [$F(1,23)=.81$, $p=.377$]. To investigate the possibility that older adults showed the pattern of younger adults in a later time window, the difference between unexpected endings in the two types of contexts (SCU-WCU) was evaluated as mean amplitudes from 900–1500

[1]To gain more precise measurements, a subset of electrodes representing the central-parietal maximum of N400 effects was used for peak latency. However, as the N400 has a broad scalp distribution, an expanded set of sites covering more posterior areas was used to investigate N400 patterns (the same patterns emerge if the amplitude analysis is restricted only to the six central-parietal sites).

[2]For latencies of effects, peaks of difference waves were searched in the 300–500 ms window at the 6 central-parietal sites for both age groups. Mean amplitudes were measured at the same 11 posterior electrode sites for each age group, but for younger adults, in the 275–475 ms window and for older adults, in the 325–525 ms window (centered around the peak of the SCU-SCE expectancy effect for each age group).

ms but was not reliably different across these conditions [$F(1,23)=.01$, interaction with Electrode, $F(10,230)=1.5$]. Thus, for older adults, we observed no evidence for the late frontal positivity elicited by younger adults as a consequence of sentential constraint.

Older adults instead showed a different pattern over frontal channels: strongly constrained expected endings (SCE) were different from all other stimulus types (SCU-SCE [$F(1,23)=13.37$, $p=.001$], WCE-SCE [$F(1,23)=11.52$, $p=.003$], WCU-SCE [$F(1,23)=9.23$, $p=.006$]). Thus, older adults, who differentiated strongly expected endings from all other stimulus types, showed a qualitatively different pattern from younger adults, who differentiated strongly constrained unexpected endings from all other stimulus types. The pattern of ERPs for older adults is reminiscent of an effect observed for sentences of moderate to strong constraint in the form of a late left-frontal negativity (Wlotko & Federmeier, submitted; Wlotko & Federmeier, in press), similar in scalp distribution (left fronto-temporal) and timecourse (beginning around 500 ms post-stimulus onset and continuing throughout the epoch). The timing and scalp distribution of this effect can be visualized from Figure 1. ERP patterns at frontal electrode sites for younger and older adults are presented in Figure 4, including an overlay of all four conditions as well as pairwise comparisons for the frontal positivity effect (SCU-WCU) and the late negativity (WCU-SCE).

At the same posterior sites used to analyze the N400, a main effect of Expectancy was observed [$F(1,23)=5.4$, $p=.029$], but there was no Constraint x Expectancy interaction. Consistent with this result, a pairwise comparison revealed that unlike in the N400 time window, expected endings in weakly constraining contexts were more positive than unexpected endings in those contexts (WCE vs WCU, [$F(1,23)=4.97$, $p=.036$]). This likely represents activity of the Late Positive Complex (LPC) associated with more explicit processing of the stimuli (cf. Wlotko & Federmeier, 2007; Wlotko & Federmeier, in press).

Individual (random) effects: In repeated-measures designs, individual responses can be thought of as “nested” within participants, and are thus appropriately analyzed with hierarchical linear models (or multilevel models; see Goldstein, 2010). This type of analysis has several advantages for analysis of within-subject ERP experiments (see Wlotko & Federmeier, in press for more detail), including the ability to efficiently estimate effects at different levels. Here, to examine individual responses for the late frontal positivity and the left-frontal negativity, we use empirical best linear unbiased predictors (known as EBLUPs) for the higher-level (participant) effects.[3] These effects are akin to, and are similar to, simple condition mean differences for individual subjects; however, all the data is taken into consideration when estimating the EBLUPs.

The effects for the frontal positivity (SCU-WCU) and negativity (WCU-SCE) were analyzed for the older adults in this study and all 32 participants from Federmeier et al. (2007). The level-one unit of analysis consisted of condition means for each participant, averaged over the 11 most frontal electrode sites, thereby collapsing over the spatial dimension (but covering the focal point of the scalp distributions of both the positivity and the negativity). The effects are estimated such that a positive value indicates a larger effect (either more positive amplitudes for strongly constrained unexpected endings compared to weakly constrained unexpected endings (frontal positivity, SCU-WCU), or more negative amplitudes for strongly constrained expected endings compared to weakly constrained unexpected endings (frontal negativity, WCU-SCE)).[4] As displayed in Figure 5, the

[3]To facilitate transparent comparisons with other studies in this series (e.g. Federmeier et al., 2007), standard repeated-measures ANOVAs are presented except where random effects are specifically of interest. However, no conclusions are altered when examining all analyses presented with hierarchical models.

majority of younger adults evidence a positive effect for the consequence of unfulfilled predictions (SCU-WCU), whereas the pattern for older adults is centered around zero, and only six older adults show a positive value greater than 1 μV. One pattern that emerges is that for both groups, those who show a large effect for the negativity tend to elicit a smaller frontal positivity. Thus, there may be a type of tradeoff between the two effects, consistent with our suggestion that decreased reliance on predictive mechanisms (as indexed by the frontal positivity) may lead to more reinterpretation of contextual material (as manifest in the frontal negativity).

Prior work has shown that older adults scoring high on neuropsychological measures associated with language ability such as verbal fluency and reading span sometimes show comprehension patterns more similar to younger adults (e.g. Federmeier et al., 2002). We attempted to determine whether those older adults with higher abilities in language production and verbal working memory are the ones more likely to show young-like predictive patterns. Effects of interest were regressed on scores of verbal fluency and reading span to determine if these sources of variation could predict late frontal patterns observed in our study. In our particular sample, no effects in the late time window were predicted from verbal fluency and reading span, using either simple or multiple linear regression.

Discussion

The aging brain experiences changes in structure and function that have consequences for many facets of cognition. Some of these changes, such as in the domains of memory and executive function, have been associated with declines in cognitive ability with age. Language comprehension, too, has been shown to be affected by aging, particularly when assessed with online measures of processing such as ERPs (see Wlotko et al., 2010). Yet many older adults who evidence these age-related changes have little trouble with everyday language comprehension in conversation or reading, highlighting the idea that comprehension can succeed via multiple pathways or strategies.

Age-related changes in the use of sentential context have been well-documented, supporting the suggestion that the mechanisms engaged during sentence comprehension may not be identical across the lifespan. Federmeier and colleagues have shown that older adults as a group do not engage predictive processing mechanisms as younger adults do. For example, in Federmeier et al. (2002), young adults showed a benefit (evidenced by N400 reduction) when processing sentence completions that were categorically related to predictable endings of the sentences, compared to completions from a different semantic category, even though both completion types were contextually anomalous. Older adults, by contrast, did not use the context to pre-activate semantic features of likely upcoming words; ERPs to the anomalous endings related to strongly expected endings were not reduced in their N400 amplitudes as they were for younger adults.

While the N400 patterns from Federmeier et al. (2002) demonstrate that older adults in general are less likely to engage in prediction of features of likely upcoming words, the

[4]These were obtained via the Estimate statement from SAS PROC MIXED. The hierarchical linear models included all condition means (from the 11 most frontal electrode channels) per participant, estimating random parameters for intercepts and for all effects (Constraint, Expectancy, and the interaction). The data were coded such that the intercept equaled the condition mean for WCU, which was used as the "baseline" for comparison of both the frontal positivity and negativity, concordant with analyses from Federmeier et al. (2007) for the positivity and Wlotko & Federmeier (submitted; in press) for the negativity. The models were fit separately for each age group; thus, we used all available data for this analysis (specifically all subjects from Federmeier et al. (2007) rather than the randomly selected subset of 24). More details about hierarchical linear models in the context of ERP research can be found in Wlotko & Federmeier (in press).

NIH-PA Author Manuscript
NIH-PA Author Manuscript

N400 is not solely an index of predictive processing. In this study, we used the design of Federmeier et al. (2007) to investigate possible consequences of prediction in older adults in other parts of the ERP waveform. By comparing the same unexpected words as plausible endings to both strongly and weakly constraining sentence frames, Federmeier et al. (2007) showed that N400 amplitudes (or latencies) did not seem to reflect any consequence of pre-activating a strongly predictable sentence completion when encountering an unexpected item, as N400s were equivalent for the unexpected items regardless of contextual constraint. For this same comparison, however, a post-N400 frontal positivity was enhanced specifically for unexpected items completing strongly constraining frames -- the case where consequences of prediction might be expected to manifest. This positivity was linked to processes needed when predictions are disconfirmed, such as a kind of semantic revision, suppression, or learning signal for use in future prediction.

In the present study, then, we expected to replicate results showing that older adults make less use of sentential context, resulting in smaller and delayed N400 effects, with different patterns as a function of contextual strength. We also expected that if older adults as a group do not engage in predictive processing as younger adults do, they should not elicit the frontal positivity hypothesized to be associated with predictive processing. Moreover, a negative-going frontal effect that was previously associated with reinterpretation of contextual material, and hypothesized to be more likely to occur when prediction is not engaged, may be more pronounced for older adults.

N400

We examined the N400 in response to the manipulations of sentential constraint and sentence-final expectancy, and observed evidence consistent with all past ERP studies of age-related change in sentence comprehension: N400 effects were smaller and delayed compared to younger adults, with the exception of the difference between the unexpected endings across the two types of sentence contexts, which, for both age groups, was not a significant effect. Thus, the N400 was not sensitive to the consequences of violating strong expectations for either age group.

Another important difference in N400 patterns across the two groups was a reduced effect of expectancy in weakly constraining contexts. Older adults did not show a reliable N400 amplitude difference between weakly expected endings and unexpected endings in the same contexts, whereas younger adults did (consistent with the typical graded sensitivity of N400 to sentence-level expectancy, cf. Wlotko & Federmeier, in press). Thus, older adults seem to need a strong base of contextual support from sentence contexts to evidence facilitation of early semantic processing in those contexts (see also Wlotko & Federmeier, 2010). Support for this claim is also found in the recognition performance: older adults remembered weakly expected endings as well as unexpected endings, perhaps because the weakly expected endings were just as “surprising” or distinctive as the unexpected endings for the older adults.

These N400 changes with age can be compared to findings suggesting that older adults sometimes gain *more* facilitation than younger adults from rich contextual information when identifying “difficult” or “noisy” stimuli (e.g Cohen & Faulkner, 1983; Bowles & Poon, 1988; Madden, 1988; Sommers & Danielson, 1999; Sheldon et al., 2008; but see e.g., Holtzman et al., 1986; or Giffard et al., 2003 for the idea that this notion of “hyperpriming” in older adults may be a consequence of their overall longer reaction times). Similar arguments have been made for contexts effects or use of background knowledge at the discourse level (Miller et al., 1998; Stine-Morrow et al., 2006; Stine-Morrow & Miller, 2008). Thus, while older adults may be more dependent on context to affect bottom-up stimulus processing that may be degraded or slowed with advancing age, the current (and past) ERP results suggest they are also less efficient in using that context to affect ongoing sentence comprehension.

The N400 pattern observed in this study is also strikingly similar to the pattern of RH-biased processing in younger adults (Wlotko & Federmeier, 2007). In that study, both hemispheres departed from the typical graded relationship between N400 amplitude and expectancy. The LH seemed to gain as much facilitation from weak contexts as from strong contexts, perhaps boosted by its predictive mode of comprehension, whereas the non-predictive RH gained little facilitation for weakly expected endings compared to unexpected endings, like the pattern observed here for older adults. For older adults in this study and for RH-biased processing in young adults, significant differences between expected and unexpected endings in weak contexts were observed only after 600 ms post-stimulus onset, on the Late Positive Complex (LPC), typically associated with more explicit or controlled processing of the stimuli. Thus, as in Federmeier et al. (2002), older adults as a group resembled the non-predictive pattern of the young RH, whereas younger adults, similar to LH-biased processing, evidenced predictive patterns of comprehension. Federmeier (2007) has proposed that predictive processing may be supported by the strong top-down connections in the LH used for language production, and a decline in the number and/or efficacy of these top-down connections could be one possible cause for the decreased use of predictive processing in older adults.

Later comprehension mechanisms

Consistent with the hypothesis that older adults are less likely to use context information predictively, they exhibited no differentiation between unexpected endings across strong versus weak levels of constraint. Thus, the pattern of ERPs over frontal sites in the 600–900 ms post-stimulus timewindow was qualitatively different for younger and older adults. For young adults, the late frontal positivity was selectively enhanced for unexpected endings completing strongly constraining contexts (SCU) compared to all other sentence endings; older adults instead showed differentiation between strongly expected endings (SCE) and all other ending types.

The lack of a frontal positivity effect (difference between the two unexpected ending types) in older adults provides further support for the claim that older adults are less likely to engage predictive mechanisms in sentence comprehension. As the positivity has been linked to processes engaged when a prediction has been disconfirmed, the lack of a frontal positivity in the older group suggests that they are less committed to a prediction and therefore less likely to show consequences of incorrect predictions. Thus, older adults may not gain as much information from sentential context (as supported by the N400 results) and may not use the context to generate predictions, and in turn they may also not need to invoke "semantic revision" processes indexed by the positivity. The frontal positivity could also be a kind of "learning signal", and the failure to invoke the processes indexed by the positivity could indicate decreased ability to update contextual representations based on incorrect predictions, leading to inflexibility or decreased learning over time.

At the same time, older adults do engage other kinds of post-N400 processing mechanisms, showing a frontal negativity for strongly expected endings compared to other sentence endings. We did not readily observe this effect in the grand average in the sample of young adults from Federmeier et al. (2007), although a reanalysis prompted by recent studies manipulating contextual strength uncovered a subset of young participants who robustly showed the effect (see Wlotko & Federmeier, submitted). For younger adults, predictive processing could mitigate the need to engage in reconsideration of contextual material, as anticipatory comprehension must rely on the efficient use of context in the first pass. Decreased reliance on prediction could engender more reconsideration of prior context, especially when induced by a sentence completion inconsistent with the initial reading of the context, as investigated by Wlotko & Federmeier (submitted). A similar idea has been put forth to explain age-related differences in reading behavior in eye tracking studies (Rayner et al., 2006; Stites et al., 2011).

While the lack of evidence for consequences of anticipatory comprehension mechanisms in older adults is in accord with most prior studies, one recent sentence processing study, similar in some ways to the current investigation, examined ERP responses while varying predictability of sentence-medial words (DeLong, Urbach, Groppe, & Kutas, in press). In a design previously used to demonstrate pre-activation of phonological information about likely upcoming words for younger adults (depending on whether the upcoming predictable item would take *a* or *an* as its indefinite article; DeLong, Urbach, & Kutas, 2005), DeLong et al. showed that older adults do not manifest a differential effect for an article disagreeing (vs. agreeing) with a predictable but not-yet-presented noun. Thus, consistent with other studies, these results suggest older adults do not engage anticipatory comprehension to the degree that younger adults do. DeLong et al. also suggest, however, that older adults, like the younger adults (DeLong, Urbach, Groppe, & Kutas, 2010), show a late frontal positivity for unpredictable nouns presented after the articles. As they themselves point out, however, their frontal effect is not compared for unexpected items across levels of constraint. Instead, they compare unexpected to expected words within strong contexts (i.e., conditions similar to SCU-SCE in the current study). Importantly, these conditions could differ either because of a positivity to the SCU condition (associated with predictive processing) or a negativity to the SCE condition (as in the present study and Wlotko & Federmeier, submitted) -- or, indeed, a combination of the two effects -- and determining the identity of the effect from this kind of difference alone, therefore, could be difficult. As demonstrated in the random effects analysis from Figure 5, most participants (younger and older) would show a positive response when these two conditions are compared (the SCU-WCU and the WCU-SCE differences added together, leading to SCU-SCE).

The design of DeLong et al. includes some aspects that could make prediction more likely for older adults, as the presence of an unexpected article prior to the noun provides additional cues that the sentence is not unfolding as expected, as well as additional processing time prior to the apprehension of the critical noun. However, their materials do not allow for the direct assessment of consequences of prediction as in the current study, leaving open the possibility that most of their older participants do not manifest the late frontal positivity and instead show the negative-going effect, consistent with the literature examining older adults' online comprehension processes, which has failed to find consistent evidence for predictive processing in the majority of older adults.

In sentence contexts, it is possible that the failure to engage in predictive mechanisms by older adults is due to their reduced ability to gain information from strong sentence contexts (as evidenced by reduced N400 effects) and not due to decreased ability to predict per se. However, the results from the category typicality study of Federmeier, Kutas, and Schul (2010) demonstrate that predictive mechanisms are not readily observed in older adults even in relatively undemanding contexts. Further, in the current study, we did not find evidence of prediction for older adults presented with a relatively slow reading rate of two words per second, even when examining ERP responses 1.5 seconds after the presentation of sentence-final critical words. Federmeier et al. (2010) clearly demonstrated that timing does not seem to play a crucial role in the ability to observe consequences of prediction for older adults, as their design included ample time for predictions to be generated. In fact, they found that the same participants who failed to show the positivity for unpredictable (atypical) items were able to overtly produce the predictable item in response to the cue in a separate naming task, and did so within the temporal bounds of the cue-target interval in the ERP experiment.

Thus, even when given more than enough time to predict in a relatively simple language comprehension task, most older adults do not seem to routinely engage predictive mechanisms.

Although the literature attests to a decreased tendency for older adults as a group to use predictive mechanisms during comprehension, a subset of older participants, particularly those that scored high on a test of verbal fluency, have shown a young-like, predictive pattern in some studies (Federmeier, Kutas, & Schul, 2010; Federmeier et al., 2002; Lee & Federmeier, 2011). Verbal fluency is a production task that requires many of the same processes that are likely to be engaged for predictive comprehension, e.g., the *generation* of words given a cue or a context). Thus, those older adults who score high on tests of fluency may have better preserved language production pathways and thus may be able to use these pathways in service of comprehension more effectively than those who score low on fluency tests (see Federmeier, 2007 for an in-depth discussion on the relationship between language production and predictive comprehension). Different from the present study, the size of the frontal positivity for older adults in Federmeier, Kutas, & Schul (2010) was predicted by verbal fluency scores. Our failure to find a reliable predictor of the positivity in the present experiment could be due to our small sample size, although it is comparable to prior studies. Another possibility is that the type of information used to predict in sentence contexts is varied and multiple, whereas the type of information used to predict in the category task is more stereotyped and may have been particularly well-tapped by the verbal fluency category generation task. Indeed, Federmeier, Kutas, and Schul found that it was category verbal fluency -- and not letter fluency -- that was predictive of the positivity. Thus, strong overlap between neuropsychological assessment and experimental material may have allowed more of the variance in the ERP effects to be explained than in the current study. In line with this idea, the patterns of effects predicted by verbal fluency in Federmeier et al. (2002) in a sentence processing study were also based on category membership. However, even though the neuropsychological measures available in the current study did not differentiate participants who did or did not elicit the frontal positivity, the analysis of random subject effects suggests that a subgroup of older participants did show the predictive pattern (see Fig. 5, older subjects with positive values for the SCU-WCU comparison, subject numbers 5, 24, 21, 19, 2, 14, 23, 20, 12, 7, 11, 4), leaving open the possibility that there are some factors that promote or protect the mechanisms supporting anticipatory comprehension in older adults.[5]

Conclusion

In conclusion, we have shown that during normal sentence processing, older adults do not routinely engage in predictive comprehension to the degree that younger adults do. This seems to result in a decrease in the efficacy with which older adults make use of sentence context information -- especially weaker context information -- to facilitate the semantic processing of upcoming words. At the same time, in not predicting during online comprehension, older adults are also less likely to require processes that, in young adults, have been associated with the consequences of encountering an unexpected word/concept in the face of a strong prediction for a different word/concept. Building on past work, these findings lead to a scenario where young adults rapidly and incrementally gather information from ongoing context in order to build a representation of message-level meaning. The contextual information is unconsciously used to generate predictions, which may ease comprehension in a normally unfolding sentence or discourse, and may be particularly beneficial when context is only moderately predictive. However, predictions may

[5]None of the demographic variables (e.g., age, education) nor the Mattis Demential Rating scores significantly explained variance in the size of the frontal positivity.

occasionally be wrong, requiring a type of revision reflected by the late frontal positivity (which could then be used to update future predictions). Older adults, instead, are less effective and slower in gaining information from context, and as a result have an impoverished basis from which to form predictions, and overall, are less effective in engaging predictive mechanisms even from simple contexts and with ample time. Without strong predictions, there is no need to recover from incorrect predictions. Instead, however, older adults' less efficient use of context may necessitate an increased reconsideration of prior context as reflected in the frontal negativity observed here.

Anticipatory, predictive processing and more passive, feed-forward approaches both have advantages and disadvantages for comprehension. In young adults, predictive and integrative processing strategies seem to be implemented in parallel, across the cerebral hemispheres (Federmeier, 2007). Older adults show a shift away from prediction, although at least a subset of older adults may retain a young-like pattern, highlighting the importance of examining individual differences in neural and cognitive function. Thus, the brain uses whatever sources of information and mechanisms of comprehension are available and applicable to the context in order to flexibly implement pathways to comprehension.

Acknowledgments

This research was supported by the McDonnell Foundation and NIH grant AG026308 to Kara Federmeier, NIH grants HD22614 and AG08313 to Marta Kutas, and an NIMH START-MH fellowship (at the University of California, San Diego School of Medicine) to Edward Wlotko.

We gratefully acknowledge the role of Esmeralda De Ochoa-Dewald in recruiting participants and collecting the data.

References

Benjamin AS. On the dual effects of repetition on false recognition. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2001; 27:941–947.10.1037/0278-7393.27.4.941

Bowles NL, Poon LW. Age and context effects in lexical decision: An age by context interaction. Experimental Aging Research. 1988; 14:201–205.10.1080/03610738808259748 [PubMed: 3251766]

Bowles NL, Williams D, Poon LW. On the use of word association norms in aging research. Experimental Aging Research. 1983; 9:175–177.10.1080/03610738308258448 [PubMed: 6641778]

Cabeza R, Anderson ND, Locantore JK, McIntosh AR. Aging gracefully: Compensatory brain activity in high-performing older adults. Neuroimage. 2002; 17:1394–1402.10.1006/nimg.2002.1280 [PubMed: 12414279]

Cohen G, Faulkner D. Word recognition: Age differences in contextual facilitation effects. British Journal of Psychology. 1983; 74:239–251.10.1111/j.2044-8295.1983.tb01860.x [PubMed: 6883014]

Dale, AM. Unpublished Thesis. University of California; San Diego, La Jolla, CA: 1994. Source localization and spatial discriminant analysis of event-related potentials: Linear approaches.

Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Memory and Language. 1980; 19:450–466.10.1016/S0022-5371(80)90312-6

DeLong KA, Urbach TP, Groppe DM, Kutas M. Overlapping dual ERP responses to low cloze probability sentence continuations. Psychophysiology. 2011; 48:1203–1207.10.1111/j. 1469-8986.2011.01199.x [PubMed: 21457275]

DeLong KA, Urbach TP, Groppe DM, Kutas M. Thinking ahead or not? Natural aging and anticipation during reading. Brain and Language. (in press).

DeLong KA, Urbach TP, Kutas M. Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. Nature Neuroscience. 2005; 8:1117–1121.10.1038/nn1504

Dikker S, Rabagliati H, Pylkkänen L. Sensitivity to syntax in visual cortex. Cognition. 2009; 110:293–321.10.1016/j.cognition.2008.09.008 [PubMed: 19121826]

Ehrlich SF, Rayner K. Contextual effects on word perception and eye movements during reading. Journal of Verbal Learning and Verbal Behavior. 1981; 20:641–655.10.1016/S0022-5371(81)90220-6

Federmeier KD. Thinking ahead: The role and roots of prediction in language comprehension. Psychophysiology. 2007; 44:491–505.10.1111/j.1469-8986.2007.00531.x [PubMed: 17521377]

Federmeier KD, Kutas M. A rose by any other name: Long-term memory structure and sentence processing. Journal of Memory and Language. 1999; 41:469–495.10.1006/jmla.1999.2660

Federmeier KD, Kutas M. Aging in context: Age-related changes in context use during language comprehension. Psychophysiology. 2005; 42:133–141.10.1111/j.1469-8986.2005.00274.x [PubMed: 15787850]

Federmeier KD, Kutas M, Schul R. Age-related and individual differences in the use of prediction during language comprehension. Brain and Language. 2010; 115:149–161.10.1016/j.bandl.2010.07.006 [PubMed: 20728207]

Federmeier, KD.; Laszlo, S. The Psychology of Learning and Motivation. Vol. 51. San Diego, CA, US: Elsevier Academic Press; 2009. Time for meaning: Electrophysiology provides insights into the dynamics of representation and processing in semantic memory; p. 1-44.

Federmeier KD, McLennan DB, De Ochoa E, Kutas M. The impact of semantic memory organization and sentence context information on spoken language processing by younger and older adults: An ERP study. Psychophysiology. 2002; 39:133–146.10.1017/S0048577202001373 [PubMed: 12212662]

Federmeier KD, Van Petten C, Schwartz TJ, Kutas M. Sounds, words, sentences: Age-related changes across levels of language processing. Psychology and Aging. 2003; 18:858–872.10.1037/0882-7974.18.4.858 [PubMed: 14692871]

Federmeier KD, Wlotko EW, De Ochoa-Dewald E, Kutas M. Multiple effects of sentential constraint on word processing. Brain Research. 2007; 1146:75–84.10.1016/j.brainres.2006.06.101 [PubMed: 16901469]

Fischler I, Bloom PA. Automatic and attentional processes in the effects of sentence contexts on word recognition. Journal of Verbal Learning and Verbal Behavior. 1979; 18:p1-1–20.10.1016/S0022-5371(79)90534-6

Francis, WN.; Kucera, H. Frequency Analysis of English Usage: Lexicon and Grammar. Boston: Houghton Mifflin; 1982.

Gladsjo JA, Schuman CC, Evans JD, Peavy GM, Miller SW, Heaton RK. Norms for letter and category fluency: Demographic corrections for age, education, and ethnicity. Assessment. 1999; 6:147–178.10.1177/107319119900600204 [PubMed: 10335019]

Goldstein, H. Multilevel Statistical Models. 4. West Sussex, UK: John Wiley & Sons, Ltd; 2011.

Gunter TC, Jackson JL, Mulder G. An electrophysiological study of semantic processing in young and middle-aged academics. Psychophysiology. 1992; 29:38–54.10.1111/j.1469-8986.1992.tb02009.x [PubMed: 1609026]

Hamberger MJ, Friedman D, Ritter W, Rosen J. Event-related potential and behavioral correlates of semantic processing in alzheimer's patients and normal controls. Brain and Language. 1995; 48:33–68.10.1006/brln.1995.1002 [PubMed: 7712148]

Holtzman RE, Familitant ME, Deptula P, Hoyer WJ. Aging and the use of sentential structure to facilitate word recognition. Experimental Aging Research. 1986; 12:85–88.10.1080/03610738608259441 [PubMed: 3569389]

Howard DV. 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. 1980; 35:225–231.10.1093/geronj/35.2.225 [PubMed: 7410780]

Isingrini M, Fontaine R, Taconnat L, Duportal A. Aging and encoding in memory: False alarms and decision criteria in a word-pair recognition task. International Journal of Aging & Human Development. 1995; 41:79–88.10.2190/ERDG-LHA8-EBYN-L9LX [PubMed: 8530195]

Kamide Y, Altmann GTM, Haywood SL. The time-course of prediction in incremental sentence processing: Evidence from anticipatory eye movements. Journal of Memory and Language. 2003; 49:133–156.10.1016/S0749-596X(03)00023-8

King, JW.; Kutas, M. Do the waves begin to waver? ERP studies of language processing in the elderly. In: Allen, PA.; Bashore, TR., editors. Age Differences in Word and Language Processing. Amsterdam, Netherlands: North-Holland/Elsevier Science Publishers; 1995. p. 314-344.

Kutas M, Federmeier KD. Electrophysiology reveals semantic memory use in language comprehension. Trends in Cognitive Sciences. 2000; 4:463–470.10.1016/S1364-6613(00)01560-6 [PubMed: 11115760]

Kutas M, Federmeier KD. Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). Annual Review of Psychology. 2011; 62:621–647.10.1146/annurev.psych.093008.131123

Kutas, M.; Federmeier, KD.; Staab, J.; Kluender, R. Language. In: Cacioppo, JT.; Tassinary, LG.; Berntson, GG., editors. Handbook of Psychophysiology. 3. New York, NY, US: Cambridge University Press; 2007. p. 555-580.

Kutas M, Hillyard SA. Brain potentials during reading reflect word expectancy and semantic association. Nature. 1984; 307:161–163.10.1038/307161a0 [PubMed: 6690995]

Kutas M, Iragui V. The N400 in a semantic categorization task across 6 decades. Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section. 1998; 108:456–471.10.1016/S0168-5597(98)00023-9

Lahar CJ, Tun PA, Wingfield A. Sentence-final word completion norms for young, middle-aged, and older adults. The Journals of Gerontology. Series B: Psychological Sciences and Social Sciences. 2004; 59B:P7–P10.10.1093/geronb/59.1.P7

Laszlo S, Federmeier KD. A beautiful day in the neighborhood: An event-related potential study of lexical relationships and prediction in context. Journal of Memory and Language. 2009; 61:326–338.10.1016/j.jml.2009.06.004 [PubMed: 20161064]

Lau E, Stroud C, Plesch S, Phillips C. The role of structural prediction in rapid syntactic analysis. Brain and Language. 2006; 98:74–88.10.1016/j.bandl.2006.02.003 [PubMed: 16620944]

Lee C, Federmeier KD. Differential age effects on lexical ambiguity resolution mechanisms. Psychophysiology. 2011; 48:960–972.10.1111/j.1469-8986.2010.01158.x [PubMed: 21175671]

Madden DJ. Adult age differences in the effects of sentence context and stimulus degradation during visual word recognition. Psychology and Aging. 1988; 3:167–172.10.1037/0882-7974.3.2.167 [PubMed: 3268255]

Mattis, S. Mental status examination for organic mental syndrome in the elderly patient. In: Bellack, R.; Karasu, B., editors. Geriatric Psychiatry. 1976. p. 77-121.

Miller LMS, Stine-Morrow EAL. Aging and the effects of knowledge on on-line reading strategies. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences. 1998; 53B:P223–P233.10.1093/geronb/58.4.P217

Noh SR, Shake MC, Parisi JM, Joncich AD, Morrow DG, Stine-Morrow EAL. Age differences in learning from text: The effects of content preexposure on reading. International Journal of Behavioral Development. 2007; 31:133-133–148.10.1177/0165025407073581

Oldfield RC. The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia. 1971; 9:97–113. [PubMed: 5146491]

Rayner K, Reichle ED, Stroud MJ, Williams CC, Pollatsek A. The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. Psychology and Aging. 2006; 21:448–465.10.1037/0882-7974.21.3.448 [PubMed: 16953709]

Raz, N. The aging brain: Structural changes and their implications for cognitive aging. In: Dixon, R.; Backman, L.; Nilsson, L., editors. New Frontiers in Cognitive Aging. Oxford: Oxford University Press; 2004. p. 115-134.

Salthouse TA, Miles JD. Aging and time-sharing aspects of executive control. Memory & Cognition. 2002; 30:572–582.

Schwanenflugel PJ, LaCount KL. Semantic relatedness and the scope of facilitation for upcoming words in sentences. Journal of Experimental Psychology: Learning, Memory, and Cognition. 1988; 14:344–354.10.1037/0278-7393.14.2.344

Sheldon S, Pichora-Fuller MK, Schneider BA. Priming and sentence context support listening to noise-vocoded speech by younger and older adults. The Journal of the Acoustical Society of America. 2008; 123:489–499.10.1121/1.2783762 [PubMed: 18177176]

Sommers MS, Danielson SM. Inhibitory processes and spoken word recognition in young and older adults: The interaction of lexical competition and semantic context. Psychology and Aging. 1999; 14:458–472.10.1037/0882-7974.14.3.458 [PubMed: 10509700]

Stanovich KE, West RF. Mechanisms of sentence context effects in reading: Automatic activation and conscious attention. Memory & Cognition. 1979; 7:77–85.10.3758/BF03197588

Stanovich KE, West RF. Exposure to print and orthographic processing. Reading Research Quarterly. 1989; 24:402–433. http://www.jstor.org/stable/747605.

Stine-Morrow, EAL.; Miller, LMS. Aging, self-regulation, and learning from text. In: Ross, BH., editor. Psychology of Learning and Motivation. Vol. 51. 2009. p. 255-296.

Stine-Morrow EAL, Miller LMS, Hertzog C. Aging and self-regulated language processing. Psychological Bulletin. 2006; 132:582–606.10.1037/0033-2909.132.4.582 [PubMed: 16822168]

Stites MC, Lee C, Federmeier KD, Stine-Morrow EAL. Get to/the point: How older adults resolve ambiguity of noun/verb homographs. Psychophysiology. 2011; 48:S54.10.1111/j.1469-8986.2011.01259.x

Tulving E, Gold C. Stimulus information and contextual information as determinants of tachistoscopic recognition of words. Journal of Experimental Psychology. 1963; 66:319–327.10.1037/h0048802 [PubMed: 14053250]

Van Berkum JJA, Brown CM, Zwitserlood P, Kooijman V, Hagoort P. Anticipating upcoming words in discourse: Evidence from ERPs and reading times. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2005; 31:443–467.10.1037/0278-7393.31.3.443

Wicha NYY, Moreno EM, Kutas M. Anticipating words and their gender: An event-related brain potential study of semantic integration, gender expectancy, and gender agreement in Spanish sentence reading. Journal of Cognitive Neuroscience. 2004; 16:1272–1288.10.1162/0898929041920487 [PubMed: 15453979]

Wlotko EW, Federmeier KD. Finding the right word: Hemispheric asymmetries in the use of sentence context information. Neuropsychologia. 2007; 45:3001–3014.10.1016/j.neuropsychologia.2007.05.013 [PubMed: 17659309]

Wlotko, EW.; Federmeier, KD. So that's what you meant! Event-related potentials reveal multiple aspects of context use during construction of message-level meaning. (submitted)

Wlotko EW, Federmeier KD. Age-related changes in the impact of contextual strength on multiple aspects of sentence comprehension. Psychophysiology. (in press).

Wlotko EW, Lee C, Federmeier KD. Language of the aging brain: Event-related potential studies of comprehension in older adults. Language and Linguistics Compass. 2010; 4:623–638.10.1111/j.1749-818X.2010.00224.x [PubMed: 20823949]

Woodward SH, Ford JM, Hammett SC. N4 to spoken sentences in young and older subjects. Electroencephalography & Clinical Neurophysiology. 1993; 87:306–320.10.1016/0013-4694(93)90184-W [PubMed: 7693442]

Zacks R, Hasher L. Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. The Journals of Gerontology: Series B: Psychological Sciences and Social Sciences. 1997; 52B:P274–P283.10.1093/geronb/52B.6.P274

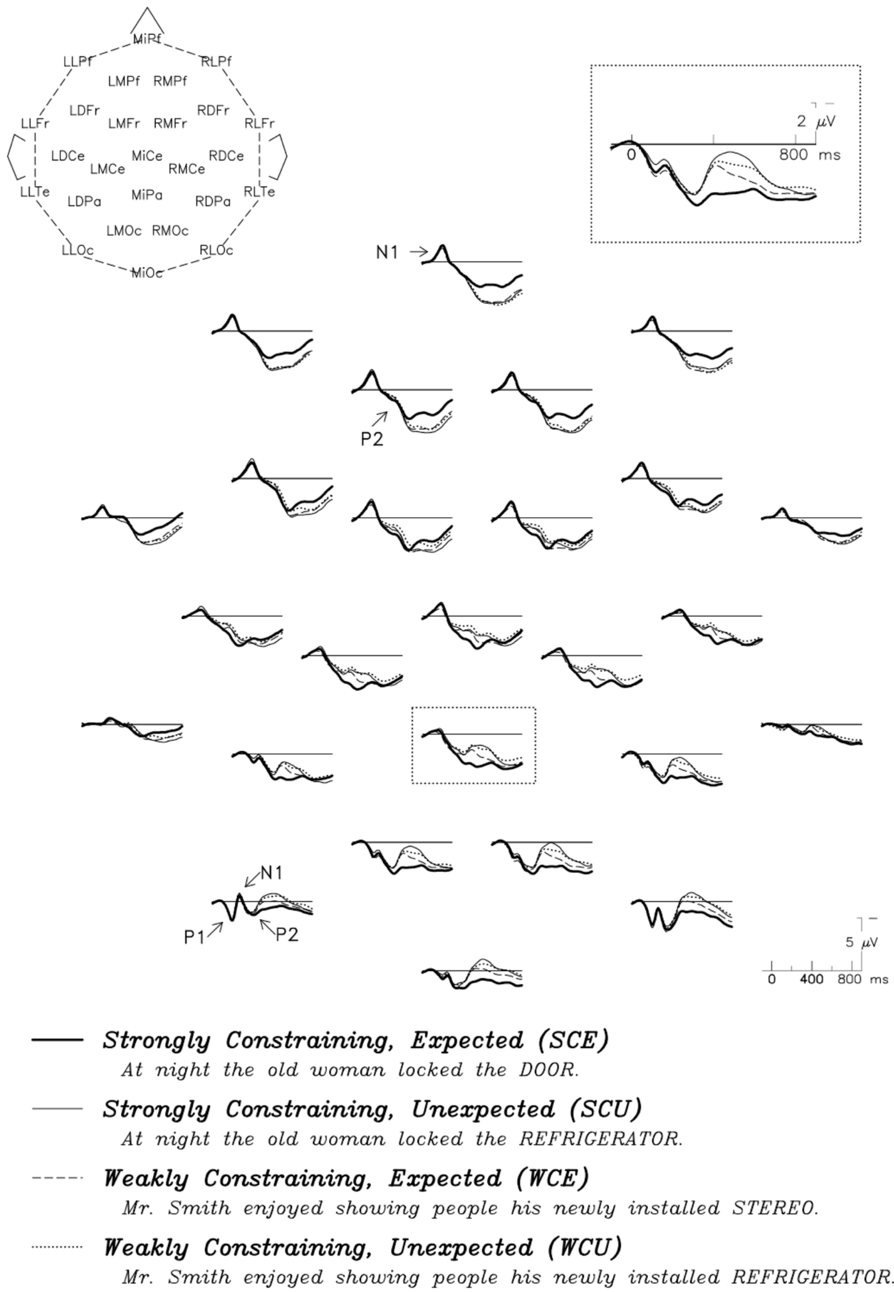

Figure 1.

Sentence-final ERPs from all four experimental conditions, arranged as laid out over the head. A schematic showing electrode positions with labels is at top left. The inset (top right) contains an enlarged view of the middle parietal channel (boxed). Sensory components are labeled. At posterior sites, the negative-going wave peaking around 400 ms is the N400 component. The later negative-going effect for the SCE condition is visible at anterior sites. Negative is plotted up.

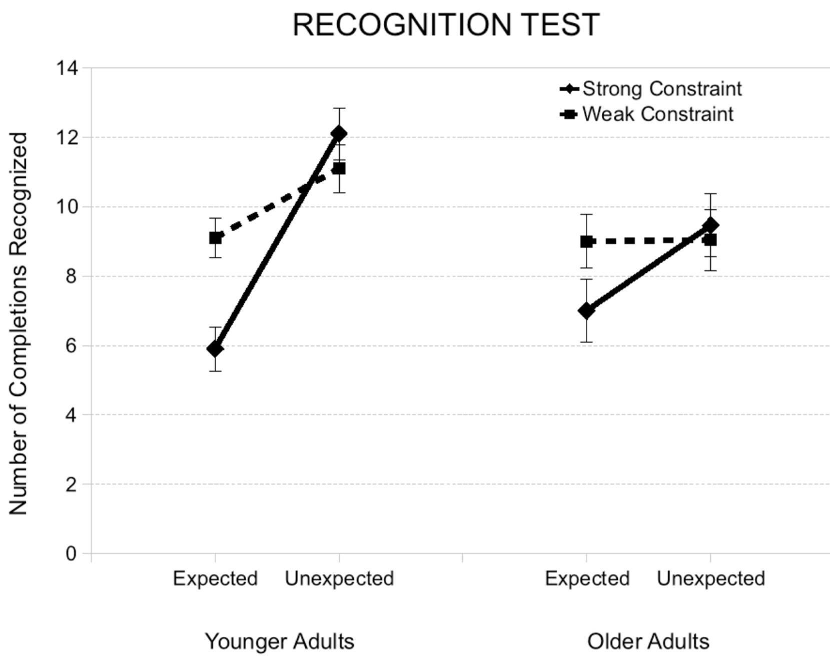

Figure 2.
Recognition test performance for both age groups.

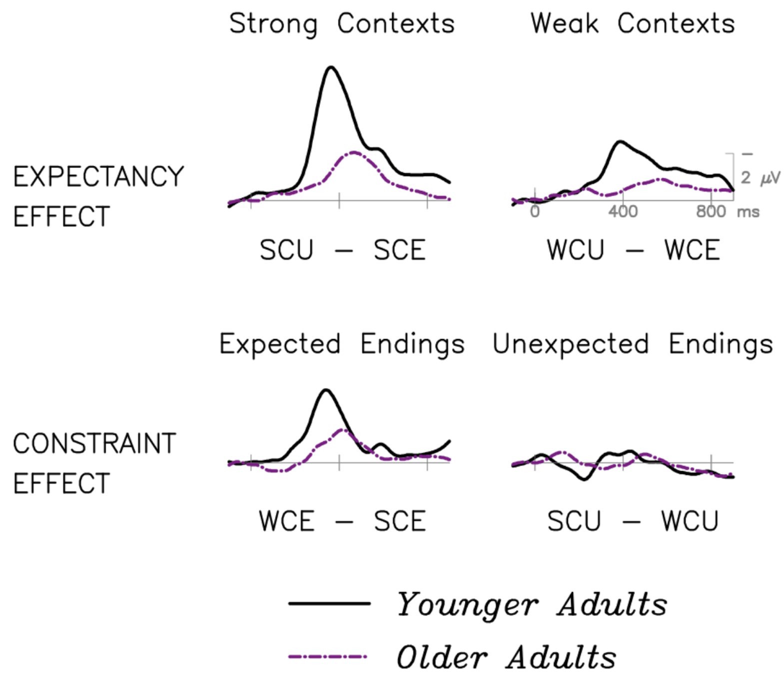

Figure 3.

Difference waves for effects of interest overplotted (at the Middle Parietal channel) for younger and older adults. Negative is plotted up.

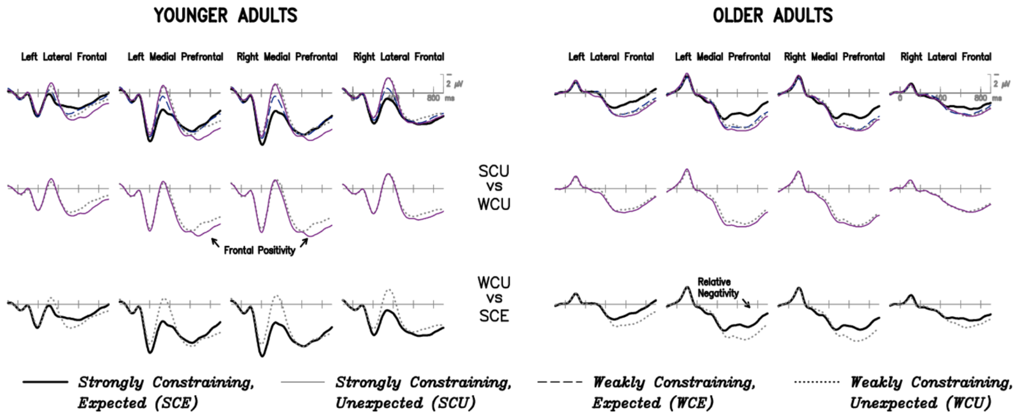

Figure 4.
ERPs at frontal electrode sites for the older adults in this study and the 24 randomly selected participants from Federmeier et al. (2007). For younger adults, the frontal positivity is evident in the comparison of unexpected endings across strong versus weak levels of constraint (SCU – WCU). Older adults, instead, show a negative-going effect for the strongly constrained expected items compared to the other conditions. Negative is plotted up.

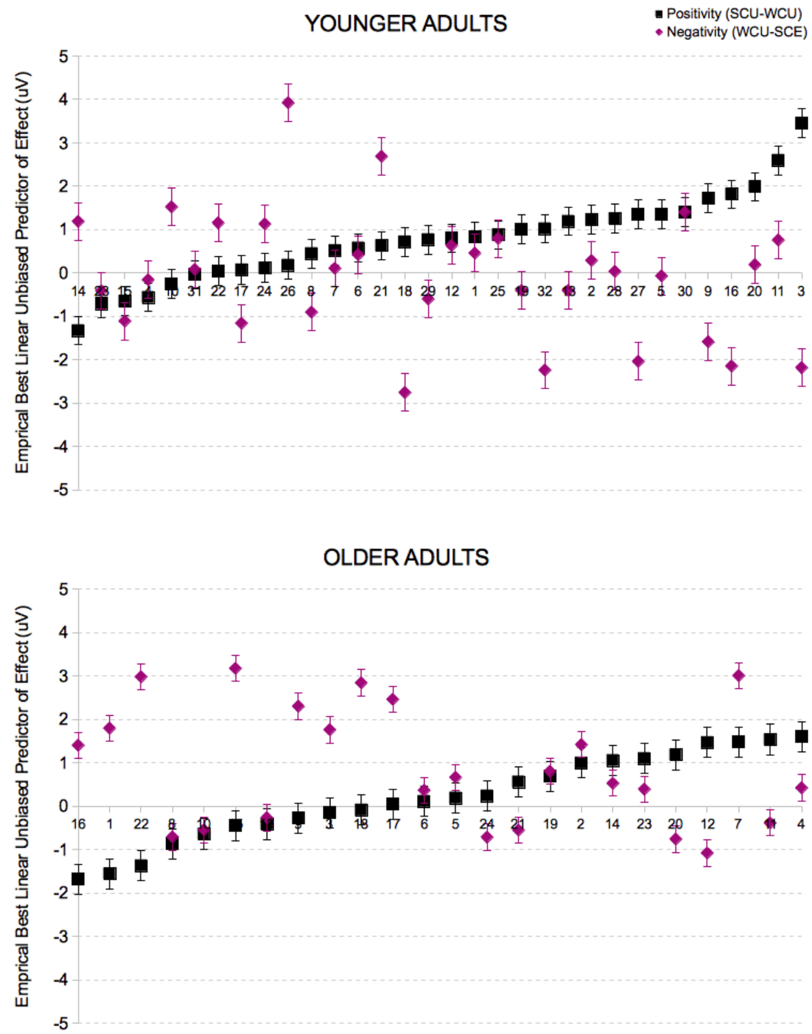

Figure 5.

Empirical Best Linear Unbiased Predictors (EBLUPs) for the SCU vs WCU (frontal positivity) and WCU vs SCE (frontal negativity) comparisons, by age group. More positive values indicate a larger effect (a larger positivity to the SCU compared to WCU condition; or a larger relative negativity to the SCE compared to WCU condition). Participants in each age group are ordered from smallest to largest estimate of the frontal positivity effect. Whereas most younger adults show a positive value for the frontal positivity effect, only about half of the older adults do (and only about one-fourth show positive effect greater than 1 μV). However, more older than younger adults show a positive value for the WCU vs SCE comparison (a larger negativity for the SCE condition). This pattern is very similar for the full group of 32 participants from Federmeier et al. (2007) as well as the randomly selected 24 (participants 6, 7, 11, 12, 24, 29, 30, and 31 were not included the random subset of participants).

Table 1

Neuropsychological test scores for younger and older adults

Test	Younger Adults	Older Adults
Reading Span	4.0 (1.04)	2.2* (0.64)
Author Recog.	7.3 (3.03)	21.3* (9.31)
Magazine Recog.	13.7 (5.06)	23.9* (5.46)
Verbal Fluency	114.8 (18.13)	104.9 (23.98)

Note. Reading Span Test scores are out of a maximum level of 6. Author and Magazine Recognition Tests scores are presented as hits minus false alarms; maximum score of 40. Verbal fluency is the total number of appropriate words produced in a one minute minute interval, summed over the letter cues (F, A, and S) and the category cutes (Fruits & Vegetables, Animals, First Names). Standard deviations are given in parentheses.

*p<.05 for effects significantly different from younger adults.

Table 2

Latency (ms) and amplitude (μV) of sensory components (averaged over all sentence-final words) for younger and older adults

Component	Younger Latency	Older Latency	Younger Amplitude	Older Amplitude
Posterior P1[a]	106 (24.8)	112 (20.7)	1.37 (2.75)	2.18 (2.80)
Posterior N1[b]	164 (23.6)	161 (23.4)	−0.72 (3.24)	−0.24 (3.15)
Posterior P2[c]	246 (30.3)	229* (33.5)	2.52 (3.47)	2.07 (2.24)
Anterior N1[d]	103 (23.5)	113 (25.3)	0.51 (2.26)	−1.93* (1.59)
Anterior P2[e]	192 (26.7)	181 (34.8)	4.12 (2.56)	0.41* (1.98)

Note. Posterior components were measured across the five occipital electrode sites; anterior components were measured across the five prefrontal sites. Standard deviations are given in parentheses.

* $p<.05$ for effects significantly different from younger adults.

[a] Peak latency search in 50–200 ms; mean amplitude measured in 90–140 ms window

[b] Peak latency search in 100–200 ms; mean amplitude measured in 135–185 ms window

[c] Peak latency search in 150–300 ms; mean amplitude measured in 220–270 ms window for young adults and 205–255 ms window for older adults

[d] Peak latency search in 50–200 ms; mean amplitude measured in 90–140 ms window

[e] Peak latency search in 100–250 ms; mean amplitude measured in 155–205 ms window

Table 3

Latency (ms) and amplitude (μV) of N400 effects for younger and older adults

Effect	Younger Latency	Older Latency	Younger Amplitude	Older Amplitude
SCU - SCE	376 (47.4)	425* (41.1)	−3.71 (2.24)	−1.37* (1.41)
WCE - SCE	368 (46.7)	398* (47.1)	−1.84 (1.51)	−0.86* (1.18)
WCU - WCE	400 (44.3)	425* (50.1)[a]	−1.54 (1.52)	−0.40* (1.16)
SCU - WCU	397 (56.7)[a]	416 (57.7)[a]	−0.33 (1.65)	−0.11 (0.85)

Note. Each effect was measured on a difference wave formed by the indicated subtractions. Peak latencies were searched in a 300–500 ms window at the 6 central-parietal sites where N400s are maximal. Mean amplitudes were measured at the 11 most posterior sites in a 200 ms window surrounding the peak of the SCU-SCE difference for each age group (275–475 for young adults and 325–525 for older adults). Standard deviations are given in parentheses.

* $p<.05$ for effects significantly different from younger adults.

[a] Because there is essentially no effect for these comparisons, the measure of peak latency is less informative