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Differential age effects on lexical ambiguity resolution mechanisms

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Abstract

Multiple neurocognitive subsystems are involved in resolving lexical ambiguity under different circumstances. We examined how processing in these subsystems changes with normal aging by comparing ERP responses to homographs and unambiguous words completing congruent sentences (with both semantic and syntactic contextual information) or syntactic prose (syntactic information only). Like young adults in prior work, older adults elicited more negative N400s to homographs in congruent sentences, suggesting mismatch between the context and residual activation of the contextually-irrelevant sense. However, the frontal negativity seen in young adults to homographs in syntactically well-defined but semantically neutral contexts was absent in older adults as a group, suggesting decline in recruiting additional neural resources to aid difficult semantic selection. A subset of older adults with high verbal fluency maintained a young-like effect pattern.

Human language is difficult in part because it consists of inherently arbitrary pairings between forms and meanings. Moreover, a single form is oftentimes associated with multiple interpretations. For example, '*watch*' can refer to a timing device or an action of observing. One of the challenges of human language processing is therefore to solve these ubiquitous one-to-many mapping problems in the face of time pressure, using (when possible) a variety of contextual constraints such as lexical associations, syntactic structure, and message-level semantic information.

Aging is usually associated with cognitive as well as biological decline. However, it has been shown that different aspects of cerebral and cognitive aging take place along multiple trajectories. For example, frontal lobe regions undergo more age-related deterioration than other brain areas in terms of volume (Raz et al., 2005), amount of grey and white matter (Moseley, 2002; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003), and white matter integrity (Head et al., 2004; Sullivan & Pfefferbaum, 2006). Similar disproportional age-related changes are also found across cognitive domains: in particular, executive/controlled processes (which are usually considered to be frontally mediated), as opposed to stimulus-driven ones, tend to be more affected by age (DiGirolamo et al., 2001; Foster, Black, Buck, & Bronskill, 1997; Hasher, Zacks, & May, 1999; Jonides et al., 2000; Vanderaspoilden, Adam, Van Der Linden, & Morais, 2007).

Differential age effects have also been observed within the specific domain of language processing. Overall, language has been described as a facet of cognitive processing that is

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relatively resistant to age-related decline (Burke & Peters, 1986; Howard, 1980; Park et al., 2002; Stern, Prather, Swinney, & Zurif, 1991). However, in fact, some aspects of language abilities are better preserved than others. On the one hand, there is ample evidence that word-related knowledge and the ability to link perceptual word forms to meaning remains relatively intact across the lifespan. For example, it has been shown that, across adulthood, vocabulary knowledge is fairly well preserved (Park et al., 2002), the organization of semantic features and word associations stay quite stable (Burke & Peters, 1986; Howard, 1980), and automatic aspects of semantic priming remain intact (Burke & Harrold, 1993). On the other hand, the efficacy with which top-down processes are recruited to aid the analysis of the bottom-up signal has been shown to deteriorate with age. For example, it has been found that older adults are less efficient in using contextual constraints to anticipate and prepare to process likely upcoming words (Cameli & Phillips, 2000; Federmeier & Kutas, 2005; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Hamberger & Friedman, 1992). In addition, older adults are less likely to engage controlled processes to revise an existing interpretation in order to adapt to a change of contextual focus (Meyer & Federmeier, 2010). Furthermore, age-related differences in language processing tend to be more pronounced when task demands are increased, especially when linguistic input is syntactically complex (Kemper, 1986, 1987), temporally compressed (Tun, Wingfield, Stine, & Mecsas, 1992), or propositionally dense (Stine & Wingfield, 1990).

These general age-related changes in recruiting top-down processes, however, are often importantly modulated by individual differences in cognitive abilities pertaining to comprehension. For example, despite the general trend of older adults being less likely to use sentential context to pre-activate semantic features of likely upcoming words in order to expedite processing, such predictive processing has been found to be relatively well maintained in older adults with higher verbal fluency performance (Federmeier, Kutas, & Schul, In press; Federmeier, McLennan, De Ochoa, & Kutas, 2002). It has also been suggested that working memory resources, particularly with respect to functions that block irrelevant information from entering working memory or suppress irrelevant information that is already in working memory, play an important role in determining the degree of age-related differences in linguistic performance (e.g. Hasher & Zacks, 1988; Stoltzfus, Hasher, & Zacks, 1996; Van der Linden et al., 1999). For example, Kwong See and Ryan (1995) showed that inhibitory efficiency (as indexed by Stroop interference) as well as processing speed (color naming) predicted language performance (as measured by paper-and-pencil tests) and attenuated variance that would otherwise be attributed to age. Similar conclusions have been drawn from ERP data showing that older adults who are better at suppressing task irrelevant semantic information displayed more young-like ERP patterns in allocating hemispheric resources to comprehend or revise word meanings (Meyer & Federmeier, 2010).

Given these patterns of age-related decline in language processing, older adults might be expected to experience difficulty processing words with multiple semantic or grammatical usages (e.g., '*watch*', '*park*'), since resolving such lexical ambiguity requires one to effectively integrate context information, select and maintain appropriate meanings, and inhibit irrelevant semantic features – factors that, as described, have all been documented to become less effective with age (Hasher & Zacks, 1988; Stoltzfus, Hasher, & Zacks, 1996; Van der Linden et al., 1999; also see Wlotko, Lee, & Federmeier, in press, for a review). However, perhaps surprisingly, empirical work looking at the effects of aging on lexical ambiguity resolution has yielded mixed results. On the one hand, several studies, including Hopkins, Kellas, & Paul (1995), Swaab, Brown, & Hagoort (1998), Balota & Duchek (1991), and Meyer & Federmeier (2010) have found that older adults, like younger ones, are able to use linguistic context to rapidly ascertain the contextually appropriate meaning of ambiguous words. On the other hand, Dagerman, MacDonald, & Harm (2006) found that older adults did not demonstrate the kind of rapid, online context use in the service of ambiguity resolution that was seen for younger adults, even though both groups were identical in their context use in off-line sentence completions and compatibility judgment tasks.

Apart from methodological differences, including type of measure (behavioral or electrophysiological) and task (naming vs. passive reading), one critical difference between these studies is in the nature and availability of the disambiguating information provided by the experimental materials. Specifically, all four studies showing young-like patterns in healthy older adults used contexts that provided coherent lexical-semantic constraints. Swaab et al. (1998) and Hopkins et al. (1995), for example, used sentences that biased to either the dominant or the subordinate meaning of sentence final homographs (e.g., English translation of the original Dutch materials: '*The surgeon removes skillfully the painful TONSILS*'). Balota & Duchek (1991) and Meyer & Federmeier (2010) used one-word semantic contexts (e.g. '*music-organ*' or '*kidney-organ*') that clearly cued one of the meanings of the homograph. In contrast, the sentences used in Dagerman et al. (2006) contained no semantically biasing information, such that the contexts did not increase or decrease the plausibility of either meaning of the ambiguous word prior to its encounter. For example, in 'The union told the reporters that the warehouse fires us' ('*us*' being the visual naming target after the auditory sentence fragment), the context preceding the ambiguous word 'fires" is neutral in meaning. Taken together, this pattern across studies suggests that the availability of constraining semantic support in the context may be an important factor in determining whether or not older adults resolve lexical ambiguity similarly to younger adults.

Indeed, our prior work with young adults has shown that the availability of context information critically determines the type of neural and cognitive resources engaged to resolve lexical ambiguity (Lee & Federmeier, 2009). Critical words, including homographs with different meaning senses across a noun and verb usage (NV-homographs, such as *boil*) and matched unambiguous words (e.g., *drama*) were used to complete sentences that provided both semantic and syntactic information (congruent sentences, e.g., 'After walking around on her infected foot, she now had a boil.') or only syntactic information (syntactic prose sentences, e.g., 'After trying around on her important jury, she now had a boil.'). ERP responses time-locked to the onset of the NV-homographs were compared to the responses to matched unambiguous words in each type of context (e.g., congruent sentences: 'In the theater, the actors rehearsed before the performance of the drama'; syntactic prose: 'In the food, the laws heated before the predator of the drama.'). The results of this study showed that when biasing semantic information is available, settling down from multiple activated meanings to a single interpretation can be done via more stimulus-driven semantic access, but when semantic contextual support is lacking, additional processing resources are needed to help resolve ambiguity.

In congruent sentences, NV-homographs, as compared to cloze-probability-matched unambiguous words, elicited larger amplitude (more negative) N400 responses (a component considered as an electrophysiological marker for more obligatory and implicit aspects of meaning processing; see Federmeier & Laszlo, 2009; Kutas & Federmeier, In press, for a review), but otherwise qualitatively similar ERP responses. Such N400 differences were further shown to arise mainly when semantic context information picked out the subordinate sense of the ambiguous words, and thus seemed to reflect residual mismatch between meaning features associated with the contextually-irrelevant dominant sense and those highlighted by the context. Thus, although ambiguous words in congruent contexts may still elicit features associated with multiple meaning senses, when information is available to shape semantic activation states in advance, settling into a single interpretation can be done via stimulus-driven activity associated with semantic access that unfolds in a qualitatively similar manner for ambiguous as for unambiguous words.

However, when semantic constraints are relatively unavailable, young adults recruit additional resources to help resolve ambiguity. In particular, in the syntactic prose sentences, NV-homographs elicited sustained frontal negativity (200 – 700 ms) relative to unambiguous words. This frontal negativity was interpreted as reflecting the engagement of top-down, selection-related neural resources when meaning interpretation is difficult (perhaps arising from frontal lobe regions, including the left inferior frontal gyrus, which have been suggested to be associated with selection (Gennari, MacDonald, Postle, & Seidenberg, 2007; Ihara, Hayakawa, Wei, Munetsuna, & Fujimaki, 2007; Novick, Trueswell, & Thompson-Schill, 2005; Rodd, Davis, & Johnsrude, 2005; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007). Importantly, such frontal effects were not present when semantic context was available, even when the context biased to the less frequent meaning, attesting that the facilitatory effects of semantic constraints can alleviate selection demands and, in turn, mitigate the need to recruit additional processes.

Thus, there are at least two mechanisms that can help effect ambiguity resolution, which differ in their cognitive nature (i.e., being more stimulus-driven versus more controlled) and their neural roots (associated with temporal lobe and frontal lobe areas, respectively). It is possible, then, that aging differentially influences processing in these two subsystems. In particular, we hypothesized that the ability to resolve ambiguity via controlled selection mechanisms, as indexed by the frontal negativity, would be more affected by age than the ability to resolve ambiguity when semantic constraints are available. To test this, we used the design from our previous ERP study (Lee & Federmeier, 2009), comparing the processing of NV-homographs and unambiguous words in sentences with only syntactic constraints or in contexts that had both syntactically and semantically biasing information. If, indeed, aging has more important effects on top-down, controlled aspects of language processing, we would expect to replicate, in a sample of healthy older adults, the N400 patterns associated with the processing of ambiguity in semantically biasing sentences but to see notable changes in the frontal negative effect observed when semantic cues are unavailable. In view of the literature showing that age-related decline is modulated by cognitive skills and resources, we also assessed individual differences in working memory, response suppression/inhibition, and executive functions in order to better understand what factors might be protective against – or compensatory for – age related decline in language comprehension processes important for ambiguity resolution.

Methods

Materials

The stimuli are the same as those used in Experiment 1 of Lee & Federmeier (2009). Two types of words were each embedded in two different types of contexts. Word types included NV-homographs, which are both syntactically and semantically ambiguous (e.g., *the season/ to season)*, and semantically and syntactically unambiguous words (e.g., *the drama/to teach*). These two types of words completed sentences that provided different types of contextual constraint. Congruent sentences (e.g., I knew the meat needed more flavor, but found that it wasn't all that easy to season) provided a noun- or verb-specifying syntactic frame as well as constraining semantic information (both pointing to the same sense of the ambiguous word). In contrast, syntactic prose sentences provided the same syntactic frames with no coherent semantics (e.g., I knew the girl threatened more teammates, but commented that it wasn't all that willing to season). Syntactic prose sentences were created by replacing the content words of each congruent sentence with randomly selected words of the same grammatical category from other congruent sentences. Word type and sentence type were fully crossed, resulting in four experimental conditions. In addition to the two experimental context types, fillers were created in which the order of words from syntactic prose sentences was scrambled. Fillers thus served to make the availability of syntactic information, like the availability of semantic information, unpredictable.

Each participant read 172 sentences, including fillers. Six lists were generated to allow target words to be rotated through context types (including scrambled filler sentences). Each participant saw each critical word only once and each viewed at least 28 sentences of each word type in each context type. Across the lists, each homograph appeared equally often as a noun and a verb (in different sentence contexts). Unambiguous words always appeared in syntactically appropriate frames. Ambiguous and unambiguous words were both used in each type of sentence context equally often. Within each list the number of nouns and verbs was matched across the homograph and unambiguous word sets in order to reduce the possibility of any word class influences on the ambiguity effect.

Target words were matched for lexical features including log frequency (Kucera & Francis, 1967), word length, and usage-specific concreteness (Lee & Federmeier, 2008) across conditions, globally and within each individual list. Moreover, the semantic distinctiveness of the homographs – i.e., how different their noun and verb meanings are, as determined by a norming study (Lee & Federmeier, 2006) – was also controlled across context types. The values of these lexico-semantic features are listed in Table 1. Sentence features of congruent sentences ending with unambiguous words and NV-homographs were also matched for length, cloze probability and plausibility. Table 2 provides the values for these sentential features. For a more detailed description of the plausibility and cloze probability norming, please refer to Lee and Federmeier (2009).

Participants

Twenty-four older adults (12 males; mean age 68 years, range 60–80) participated in the ERP experiment and were compensated with a cash payment. All participants were right-handed as assessed by the Edinburgh inventory (Oldfield, 1971); 11 reported having left handed family members. All were also monolingual speakers of English with no consistent exposure to other languages before age 5. Participants had no history of neurological/psychiatric disorders or brain damage and scored in the normal range on screening for cognitive impairment (average Mini Mental State Exam score: 29, range 27-30; Folstein, Folstein, & McHugh, 1975) as well as on the neuropsychological battery (described below). On average, participants were more educated than the undergraduate participants reported in Lee & Federmeier (2009) [1] with a mean of 16.7 years of formal education. Participants were randomly assigned to one of the six experimental lists and response hand was counterbalanced across participants.

Procedure

Participants were seated 100 cm in front of a 21” computer monitor in a dim, quiet testing room. They were given written instructions and a 9-trial practice session before the experiment to familiarize them with the experimental environment and the task. At the start of each trial, a series of plus signs appeared in the center of the screen for 500 ms. After an SOA ranging randomly between 1000 and 1500 ms (jittered to lessen the influence of slow, anticipatory potentials on the average ERPs), a sentence was displayed word by word in upper case in the center of the screen. Each word was presented in white color for 200 ms,

[1]Participants in Lee & Federmeier (2009) were 24 healthy undergraduate students from the University of Illinois (12 males; mean age 20 years, range 18–37). All participants were right handed and monolingual native speakers of English without a history of neurological/psychiatric disorders or brain damage.

followed by a 300 ms blank screen. At the end of the sentence, the screen went blank for one and a half seconds before a probe word appeared in upper case, red letters. Half of the probe words were new words; among the old probe words, half were words chosen randomly from the sentence context (up to the final word) and the other half were the sentence final target words. Participants were instructed to judge whether or not that probe word had appeared in the immediately preceding sentence and to indicate their response by pressing one of two buttons, held in each hand; hand used to respond "yes" was counterbalanced. The probe disappeared upon the participant's button-press response. The next trial then began two and a half seconds after the offset of the probe. A small square (3 by 3 pixels) remained on throughout the experiment, positioned just below the center of the screen, in order to help participants keep their gaze centered.

The whole experiment was divided into eight blocks, each lasting about three minutes. A paper-and-pencil sentence recognition task was administered at the end of every two blocks (approximately every 10-15 minutes). The sentence-recognition test contained 96 sentences in total, half of which were old sentences (drawn in equal numbers from both of the word types in congruent, syntactic prose, and scrambled sentence frames) and half of which were new (also consisting of equal numbers of each context type). New sentences of each type were selected from experimental sentences from other lists. Since many of these sentences contained some of the same words as those the participant actually viewed, word level recognition alone would not be sufficient to allow participants to score well on this test. Participants were asked to check off each sentence that they thought they had seen in the previous two blocks. The word and sentence recognition tasks were used in tandem to ensure that participants were carefully attending to each individual word while also attempting to integrate those words into a holistic unit.

Neuropsychological tests were conducted after the ERP recoding session, following a short break. These included an assessment of working memory (Reading span test: Daneman & Carpenter, 1980), response suppression/inhibition (Hayling test: Burgess & Shallice, 1996) and executive functioning (Verbal fluency tests, including letter fluency (FAS) and category fluency (animals, fruits/vegetables, and first names): Benton & Hamsher, 1978). For the reading span test[2], the average span score was 2.6 (SD = 0.7; range 1.5-4.5) and average total number of recalled words was 56 (SD=11.4; range 31-78). This falls in what would typically be classified as a mid-range for young adult college students (Van Petten, Weckerly, McIsaac, and Kutas, 1997; Miyake, Just, and Carpenter, 1994) and is comparable to performance of educated older adults previously reported in studies using the same span test (e.g., Federmeier & Kutas, 2005; Meyer & Federmeier, 2010). For the Hayling test[2], the average number of correct responses (out of a total of 35 trials) in the initiation and suppression phases were 34.6 (SD=.58; range 33-35) and 24.6 (SD=7.9; range 11-34), respectively – again, comparable to previous reports (Meyer & Federmeier, 2010). On the fluency tests[2], the participants generated, on average, 44.1 (SD=15.8; range 11-76) words on the letter fluency (FAS) portion and 63.7 (SD=14.1; range 41-103) words on the category fluency portion. The average combined score of 107.8 (SD=27; range 63-171) is comparable to the performance of age and education matched samples (Tombaugh, Kozak, & Rees, 1999).

[2]In the reading span test, participants read aloud sets of unrelated sentences (progressing from 2 to 6 sentences in a set, with 5 sets at each span level), and were asked at the end of each set to report the last word of each sentence. Participants' performance on the reading span test was measured in terms of both span score (measured as the highest set size for which participants correctly recalled all items in 3 of the 5 total sets) and total number of words recalled. In the Hayling test, participants were required to complete sentences with, in a first phase (initiation), a word that was a reasonable completion and, in the second phase (suppression), a word that was incongruent in the context. For the letter fluency test (FAS), participants were instructed to orally generate words that began with the letters F, A, and S in three separate 1-minute periods. Finally, for the category fluency test, participants were instructed to generate words that belong to the categories of animals, fruits/vegetables, and first names within three separate 1- minute periods.

EEG recording and data analysis

The electroencephalogram (EEG) was recorded from twenty-six evenly-spaced silver/silver-chloride electrodes attached to an elastic cap (shown in Figure 1). All scalp electrodes were referenced on-line to the left mastoid and re-referenced off-line to the average of the right and the left mastoids. In addition, one electrode (referenced to the left mastoid) was placed on the left infraorbital ridge to monitor for vertical eye movements and blinks, and another two electrodes (referenced to one another) were placed on the outer canthus of each eye to monitor for horizontal eye movements. Electrode impedances were kept below 3kΩ. The continuous EEG was amplified through Sensorium amplifiers, using a bandpass filter of 0.02-100Hz and recorded to a hard disk at a sampling rate of 250Hz.

Epochs of EEG data were taken from 100 ms before stimulus onset to 920 ms after. Those containing artifacts from amplifier blocking, signal drift, eye movements, or muscle activity were rejected off-line before averaging, using thresholds selected for each participant through visual inspection of the data. Trials contaminated by eye blinks were corrected for 15 participants who had enough blinks to obtain a stable filter (Dale, 1994); for all other participants, trials with blink artifacts were excluded from analysis. Artifact rejection and blink correction were carried out using the same procedures as used in Lee & Federmeier (2009). Trial loss across all 24 participants averaged 13%, comparable to the 13% trial loss of the younger adults in Lee & Federmeier (2009). Artifact-free ERPs were averaged by stimulus type after subtraction of the 100 ms pre-stimulus baseline. Prior to statistical analyses, ERPs were digitally filtered with a bandpass of 0.2–20 Hz. To correct for violations of sphericity associated with repeated measures, the Huynh–Feldt adjustment to the degrees of freedom was applied for each analysis of variance (ANOVA). Consequently, for all F tests with more than 1 degree of freedom in the numerator, the corrected p value is reported. For all analyses, main effects of electrode and interactions with electrode sites are not reported unless they are of theoretical significance.

Results

Behavior

Word recognition task—Overall accuracy for the word recognition task was 98%, indicating that participants were reading the sentences attentively enough to remember individual words. Participants' performance was assessed using the discriminability index d'. Memory performance was better for words in congruent sentences than for words in syntactic prose: d' scores (and standard deviations) for probes from sentences containing ambiguous and unambiguous critical words were 2.87 (.25) and 2.87 (.19), respectively, in the congruent condition, and 2.69 (.41) and 2.69 (.32) in the syntactic prose condition. An omnibus analysis of variance (ANOVA) with two levels of Ending Word Type (sentences ending with unambiguous and ambiguous critical words) and two levels of Context (congruent sentences and syntactic prose) revealed a significant main effect of Context [$F(1,23)=7.72$; $p<.05$] but no significant main effect of Ending Word Type or interaction between the two factors.

Older adults' overall performance on the word recognition task was numerically slightly lower than the performance by young adults in our prior study (Lee & Federmeier, 2009). For young adults, d' scores (and standard deviations) for probes from sentences containing ambiguous and unambiguous critical words were 2.90 (.15) and 2.90 (.19), respectively, in the congruent condition, and 2.82 (.21) and 2.75 (.3) in the syntactic prose condition. An ANOVA with the between subject factor of Age (younger vs. older adults) and two levels of Ending Word Type (sentences ending with unambiguous and ambiguous critical words) and two levels of Context (congruent sentences and syntactic prose) showed a significant main

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effect of Context [F(1,46)=14.37, p<.001], but no reliable Age effect [F=2] or Ending Word Type [F<1]. The effect of Age did not interact with Context or Word Type.

Sentence recognition task—Overall accuracy for the sentence recognition task was 89%, again showing that participants were engaged during the task and were able to integrate the words and encode the sentences holistically. d' scores again revealed better memory performance for congruent sentences (2.43 (.42) and 2.20 (.57), respectively, for sentences ending with ambiguous and unambiguous critical words) than for syntactic prose (1.51 (.65) and 1.55 (.71)). Similar to the results of the word recognition task, an ANOVA with two levels of Ending Word Type and 2 levels of Context revealed a significant main effect of Context on d' scores [F(1,23)=33.51; p<.0001], but no main effect of Ending Word Type or interaction between the two factors.

Again, older adults' overall performance on the sentence recognition task was slightly lower than the performance by young adults in our prior study (Lee & Federmeier, 2009). For young adults, d' scores (and standard errors) for probes from sentences containing ambiguous and unambiguous critical words were 2.53 (.25) and 2.57 (.23), respectively, in the congruent condition, and 1.71 (.57) and 1.97 (.61) in the syntactic prose condition). An ANOVA with the between subject factor of Age (younger vs. older adults) and two levels of Ending Word Type (sentences ending with unambiguous and ambiguous critical words) and two levels of Context (congruent sentences and syntactic prose) showed a significant main effect of Age [F(1,46)=8.62, p<.01] in this case and, additionally, a significant main effect of Context [F(1,46)=90.86, p<.001]. The effect of Ending Word Type was again not reliable, and the effect of Age did not interact with Context or Word Type.

Summary—In summary, the behavioral data confirm that participants attentively read and integrated the words in the experimental sentences. The overall performance was lower than the performance of younger adults observed in Lee & Federmeier (2009), although the performance difference was only statistically significant for the delayed sentence recognition test. Despite the lower accuracy, these age-related differences did not seem to be modulated by context type. Importantly, akin to the young pattern, the addition of semantic constraints to syntactic ones appears to aid older adults' memory in both the short-term word-level memory test and the long-term sentence-level memory test, and did so similarly for sentences ending with NV-homographs and with unambiguous words.

ERPs

ERP responses to sentence-final NV-homographs and unambiguous words in the syntactic prose (left panel) and congruent (right panel) sentences are shown in Figure 2 at a representative sample of scalp channels across frontal and posterior regions. As in our prior study with young adults using the same design and materials, N400s to sentence final words in congruent versus syntactic prose sentences are globally reduced, due to facilitation from accumulated semantic constraints (e.g., Kutas & Hillyard, 1980;Lee & Federmeier, 2009;Van Petten & Kutas, 1991). Also replicating the young adult pattern, within congruent sentences N400 amplitudes are less reduced (more negative) for NV-homographs compared to matched unambiguous words. However, in the syntactic prose condition, older adults as a group did not show any systematic differences in the brain responses between the two word types; this is very different from the response pattern in young adults, who elicited a frontal sustained negativity to NV-homographs relative to unambiguous words.

In the following, we report analyses of the N400 effects (1) between all sentence final words across context types and (2) between NV-homographs and unambiguous words within congruent sentences, followed by analyses of the frontal negativity effect in the syntactic prose sentences.

N400 effects

Semantic context vs. syntactic context—A comparison of N400s elicited by final words in congruent sentences and syntactic prose sentences from this sample of older adults showed a very similar pattern to that demonstrated previously in younger adults (Lee & Federmeier, 2009; Van Petten & Kutas, 1991), with global reductions in congruent sentences relative to syntactic prose. An omnibus ANOVA with 2 levels of Context (congruent sentences and syntactic prose), 2 levels of Ambiguity (ambiguous and unambiguous words), and 11 levels of central/posterior Electrode Site (including MiCe, LMCe , RMCe, LDCe, RDCe, MiPa, LDPa, RDPa, MiOc, LMOc, and RMOc) was conducted on mean amplitudes between 250-500 ms (using the time window and electrode distribution most typical for characterizing N400 effects). The results revealed a main effect of Context [$F(1,23)=10.4$; $P<.005$], with more reduced (more positive) N400s in congruent sentences (mean amplitude 2.3 μV) than in syntactic prose (mean amplitude 1.3 μV), reflecting the build up of message-level semantic constraints in the congruent condition and its facilitatory effect on the processing of the sentence final words (shown more clearly in Fig. 3).

NV homographs vs. unambiguous words in congruent sentences—Similar to findings in younger adults (Lee & Federmeier, 2009), within congruent sentences, N400s to sentence-final homographs are more negative (less facilitated) than those elicited by unambiguous words. To measure this response difference, an analysis of variance (ANOVA) with 2 levels of Ambiguity (ambiguous and unambiguous words) and 11 levels of Electrode Site (posterior electrode sites, including MiCe, LMCe , RMCe, LDCe, RDCe, MiPa, LDPa, RDPa, MiOc, LMOc, and RMOc) was conducted on data within the time window of 250-500ms post stimulus onset. The results revealed a main effect of ambiguity [$F(1,23)=6.6$; $P<.05$].

To directly compare the brain responses from the older adults and younger adults reported in our previous study (Lee & Federmeier, 2009), an omnibus ANOVA with 2 levels of Age (young and older) as a between subjects factor, and 2 levels of Context (congruent sentences and syntactic prose), 2 levels of Ambiguity (ambiguous and unambiguous words), and 11 levels of central/posterior Electrode Site (including MiCe, LMCe , RMCe, LDCe, RDCe, MiPa, LDPa, RDPa, MiOc, LMOc, and RMOc) as within subject factors was conducted on mean amplitudes between 250-500 ms (using the time window and electrode distribution most typical for characterizing N400 effects). The results revealed a marginal main effect of Age [$F(1,46)=2.8$, $p=0.06$]. There was a significant main effect of Context [$F(1,46)=49.1$, $p<.0001$], which interacted with Age [$F(1,46)=9.8$, $p<.005$]. For both age groups, N400 responses were smaller (more positive) in congruent sentences than in syntactic prose sentences. This N400 attenuation in congruent contexts was reliable for both age groups [young: $F(1,23)=41.3$, $p<.0001$; older: $F(1,23)=10.4$, $p<.005$], although the N400 attenuation averaged across the 11 central/posterior electrode sites was larger overall for younger as compared with older adults [$t(46)=3.1$, $p<.005$]. There was also a significant main effect of Ambiguity [$F(1,46)=6.0$; $p<.05$], which interacted with Context [$F(1,46)=5.2$, $p<.05$]. Follow-up comparisons confirmed a greater ambiguity effect in congruent contexts than in syntactic prose [$t(47)=2.3$, $p<.05$], with the Ambiguity effect being significant in congruent sentences [$t(47)=3.0$, $p<.005$] but not in syntactic prose sentences [$t<1$]. The effect of Ambiguity did not interact with Age ($F=1$), or jointly with Age and Context ($F<1$).

Frontal negativity effects

Our prior study showed that when reading syntactic prose sentences, younger adults elicited sustained frontal negativity to NV-homographs in comparison to unambiguous words. This frontal negative effect started from about 200ms after stimulus onset to around 700ms. Such a frontal response difference, however, is not evident in the data from healthy older adults (Fig 2). To confirm this visual impression, mean amplitudes between 200 and 700 ms were subjected to an omnibus ANOVA with 2 levels of Ambiguity (ambiguous and unambiguous words), and 11 levels of Electrode sites (anterior electrode sites, including MiPf, LLPf, RLPf, LMPf, RMPf, LDFr, RDFr, LMFr, RMFr, LLFr, and RLFr). The results showed no significant main effect of Ambiguity [$F<1$].

To again directly compare the responses of older adults in this study with those of younger adults in Lee and Federmeier (2009), mean amplitudes were measured between 200 to 700 ms and were subjected to an omnibus ANOVA with 2 levels of Age (young and older) as a between subjects factor, and 2 levels of Ambiguity (ambiguous and unambiguous words), and 11 levels of Electrode site (anterior electrode sites, including MiPf, LLPf, RLPf, LMPf, RMPf, LDFr, RDFr, LMFr, RMFr, LLFr, and RLFr) as within subjects factors. The results showed a significant main effect of Age [$F(1,46)=8.9$, $p<.01$], a marginal effect of Ambiguity [$F(1,46)=2.7$, $p=.11$] and a marginal interaction between the two [$F(1,46)=2.3$, $p=.13$]. The interaction between the effect of Age and Ambiguity was significant in a slightly shorter time window between 200-60 [$F(1,46)=4.1$, $p<.05$] (as the effect in young adults tapered off toward the end of the time window). Follow-up comparisons showed that the effect of Ambiguity was significant only for young adults [$F(1,23)=7.1$, $p<.05$], but not older adults [$F<1$].

Figure 4 summarizes the data in isopotential voltage maps, showing comparisons with that obtained from younger adults in our previous study. Mean amplitude differences between ambiguous and unambiguous words during the time windows of interest (250-500ms for congruent sentences and 200-700ms for syntactic prose) are plotted separately for each age group. Both groups show clear differences in the N400 responses to ambiguous and unambiguous words with a typical central/posterior scalp distribution to sentence final words in congruent sentences. However, a clear contrast between groups is shown in the responses to sentence final words in syntactic prose condition, such that only younger adults show notable frontal negative effects.

Individual differences analyses

Past work has revealed that even when group-level effect patterns differ as a function of age, subpopulations of older adults can continue to show young-like effect patterns. Therefore, to examine the possibility that some older adults elicited the frontal negative effect associated with effortful ambiguity resolution, the size of the frontal effect, measured as the mean amplitude difference of the response to NV-homographs and unambiguous words between 200 and 700 ms over the 11 frontal electrodes, was regressed against the neuropsychological measures of working memory, response suppression, letter fluency, and category fluency. The results showed that the size of the frontal negativity effect significantly correlated with the number of words generated on the letter fluency test (FAS) ($r=-.43$, $p<.05$) (Figure 5), but not any other individual difference measure (reading span, both span score and total number of words recalled; Hayling test, both initiation and suppression phases; and category verbal fluency). In addition, the number of words generated on the letter fluency test did <u>not</u> correlate with the size of N400 effects in congruent sentences, measured as the mean amplitude difference of the responses to NV-homographs and unambiguous words between 250 and 500 ms over the 11 posterior electrodes ($p=.6$), indicating that the correlation

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between FAS scores and the frontal negativity effect is specific rather than a marker of general waveform characteristics across people.

Motivated by this finding, we looked at group averages based on a median split of participants' letter fluency. Higher-functioning older adults (4 females and 8 males) produced 55.8 words on average (SD=12.1; range 76-43), whereas lower-functioning older adults (8 females and 4 males) produced 32.4 (SD=8.9; range 43-11) words. ERP responses to sentence-final words in congruent and syntactic prose sentences from these two subsets of older adults as well as younger adults (Lee & Federmeier, 2009) are shown side-by-side in Figure 6. All three groups showed very similar N400 patterns to sentence final words in congruent sentences (with smaller N400s in congruent than in syntactic prose sentences overall, and, within congruent sentences, more N400 reduction to unambiguous than ambiguous words). In contrast, only younger adults and older adults with higher verbal fluency scores showed a clear sustained frontal negativity to homographs in syntactic prose sentences.

An ANOVA with the between subjects factor of Group (higher vs. lower verbal fluency) and within subjects factors of two levels of Ambiguity (ambiguous and unambiguous words) and 11 levels of anterior Electrode Site conducted on mean amplitudes in the syntactic prose condition between 200-700 ms showed no significant main effects of Ambiguity or Group [$Fs<1$] but a significant Group by Ambiguity interaction [$F(1,22)=11.0$, $p<.005$]. Follow-up comparisons showed that only the higher verbal fluency group displayed a reliable young-like frontal negativity to ambiguous relative to unambiguous words [$F(1,11)=9.1$; $p<.05$] (respective mean amplitudes for unambiguous and ambiguous words: 1.3 μV and 0.4 μV). The lower verbal fluency group did not show such effect; instead, responses to ambiguous words were actually marginally more positive than responses to unambiguous words (respective mean amplitudes for unambiguous and ambiguous words: 0.9 μV and 1.7 μV, [$F(1,11)=3.8$; $p=.08$]).

Discussion

Lexical ambiguity resolution has often been treated as arising through a single mechanism. However, our prior work (Lee & Federmeier, 2009), buttressed by neuroimaging findings (Gennari, MacDonald, Postle, & Seidenberg, 2007; Ihara, Hayakawa, Wei, Munetsuna, & Fujimaki, 2007; Rodd, Davis, & Johnsrude, 2005; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007), indicates that multiple neural mechanisms are involved in ambiguity resolution, and that the nature of the information provided by different types of context is important for determining when and how these mechanisms are recruited. The current study was designed to examine whether normal aging imposes differential effects on these subsystems, and, more specifically, to test the hypothesis that the more controlled, top-down, frontal mechanisms important for resolving ambiguity under difficult selection conditions would be more affected by advancing age than the mechanisms used to resolve ambiguity in the presence of biasing semantic supports.

In the case when constraining semantic information allows for the build-up of semantic feature information, word processing is highly facilitated, as shown by the prominent N400 reduction for sentence final words in congruent sentences as compared with syntactic prose sentences. Under those conditions, multiple meanings of ambiguous words still do seem to become transiently activated in some cases, as shown in the larger N400s to NV-homographs than the cloze-probability matched unambiguous words in both older and younger adults. Our data from young adults showed that this N400 ambiguity effect was driven by cases in which the context information picked out a homograph's subordinate sense, and thus seemed to reflect residual activation of dominant meaning features. The

N400 has been linked to neural processes that dynamically construct meaning from stimulus-driven and context-driven activations (Federmeier & Laszlo, 2009; Kutas & Federmeier, In press). Because N400 modulations have been observed under several experimental conditions wherein awareness is limited (Brualla, Romero, Serrano, & Valdizan, 1998; Deacon, Hewitt, Yang, & Nagata, 2000; Misra & Holcomb, 2003; Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998), it has been taken to be a reflection of more implicit and obligatory aspects of the initial access to long term memory. This interpretation is bolstered by the fact that the temporal lobe, shown to be an important part of the N400's distributed neural source (Elger et al., 1997; Halgren, Baudena, Heit, Clarke, Marinkovic, Chauvel et al., 1994; Halgren, Baudena, Heit, Clarke, Marinkovic, & Clarke, 1994; McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1994; Van Petten & Luka, 2006), has been viewed as the storage site for long-term semantic knowledge accessed during the bottom-up processing of meaningful stimuli (Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Thompson-Schill, D'Esposito, & Kan, 1999). Enhanced temporal lobe activation has also been found to lexically ambiguous stimuli in some imaging studies, and has been interpreted as reflecting lexico-semantic processing or semantic integration (Gennari, MacDonald, Postle, & Seidenberg, 2007; Rodd, Davis, & Johnsrude, 2005) or consequences of semantic mismatch (Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007).

Therefore, the N400 patterns observed within congruent contexts suggest that, in the case of lexical ambiguity, pre-activation of semantic features associated with the contextually-appropriate interpretation renders a sufficiently robust and stable activation state within the more stimulus-driven semantic processing mechanism, such that even when the meaning features of the contextually-irrelevant dominant sense of the homographs are automatically activated to some degree upon the apprehension of the word form of the homograph, the ambiguity can still be resolved without the need for recruiting additional selection-related resources. The current data suggest that these more automatic mechanisms of ambiguity resolution are preserved in older adults. Critically, if older adults were less effective at dealing with semantic conflict of this nature, we might have expected to find that they recruit additional processing resources (not recruited by the young) to help obtain an appropriate interpretation. However, they did not show such a response pattern. These results thus suggest that the same, relatively automatic processes that seem to allow the semantic system to settle down to a single interpretation of an ambiguous word when preceding semantic constraints are available continue to function well with advancing age.

However, as predicted, notable age-related differences are observed when constraining semantic contextual support is lacking and meaning selection is difficult. In this case, younger adults elicit a sustained frontal negativity to NV-homographs, which has been replicated across a wide range of semantically impoverished contexts (Federmeier, Segal, Lombrozo, & Kutas, 2000; Hagoort & Brown, 1994; Lee & Federmeier, 2006, 2009). The precise functional role of the frontal negativity effect is not yet completely understood. However, imaging and neuropsychological data jointly point to a functional link between this effect and selection-related activity mediated by frontal brain areas. Activation in the left inferior frontal gyrus has been reported across conditions in which ambiguous words occurred without much prior disambiguating semantic information (Gennari, MacDonald, Postle, & Seidenberg, 2007; Ihara, Hayakawa, Wei, Munetsuna, & Fujimaki, 2007; Rodd, Davis, & Johnsrude, 2005; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007). Neuropsychological data have also linked frontal lobe damage to deficits in semantic tasks related to resolving ambiguity or selecting relevant representations among competitors (Metzler, 2001; Randolph, Braun, Goldberg, & Chase, 1993; Robinson, Blair, & Cipolotti, 1998; Swaab, Brown, & Hagoort, 1998; Thompson-Schill et al., 1998). These findings are further bolstered by results of imaging studies using more general memory or judgment-related tasks, which have linked frontal areas, especially in the left hemisphere, to the selection of task-relevant representations among irrelevant competing ones (Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Gennari, MacDonald, Postle, & Seidenberg, 2007; Mason, Just, Keller, & Carpenter, 2003; Stowe, Paans, Wijers, & Zwarts, 2004; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997).

This body of literature thus suggests that the frontal negativity that is elicited by NV-homographs in semantically impoverished contexts may index a frontally-mediated selection-related mechanism recruited to aid difficult lexical ambiguity resolution. In view of the aging literature showing disproportional effects of aging on processes that are more controlled, as opposed to more stimulus-driven, and more frontally-mediated, as opposed to arising from other brain regions, it seems likely that these mechanisms might become less available with advancing age. Indeed, in contrast to the similar effect patterns obtained in younger and older adults for lexical ambiguity resolution in the presence of semantically constraining information, there was a clear age-related disparity in the brain activity elicited by sentence-final ambiguous words when semantic support for resolving the ambiguity is lacking. Older adults as a group did not elicit the frontal negativity to NV-homographs – and, in fact, did not manifest any differences between the ambiguous and unambiguous words in the syntactic prose condition. This pattern is consistent with Dagerman et al.'s (2006) observation of less effective on-line ambiguity resolution in older adults when semantic contextual support was not available. More generally, the pattern of aging effects we observe across the two context types provides a reconciliation of the disparate patterns that have been observed across the literature looking at age effects on ambiguity resolution (Balota & Duchek, 1991; Dagerman, MacDonald, & Harm, 2006; Hopkins, Kellas, & Paul, 1995; Meyer & Federmeier, 2010; Swaab, Brown, & Hagoort, 1998), in showing that when age-related differences will be observed depends on the nature of the context information available to support ambiguity resolution.

However, the absence of frontal negativity we observed in our sample of older adults is modulated by individual differences in participants' scores on the FAS (letter verbal fluency) test, such that older adults with higher FAS scores maintained a young-like effect pattern. Verbal fluency has also been associated with more young-like patterns of language processing in other domains (and on other ERP components). Federmeier et al. (2002;in press), for example, found that although older adults were overall less likely to recruit top-down processes that afford prediction during sentence comprehension, those older adults with higher verbal fluency scores showed young-like patterns of brain responses. Verbal fluency tests require participants to rapidly generate words in response to a given constraint/cue in a short time period. Because of its demand on active search, efficient organization of verbal retrieval, self-monitoring and inhibition of responses (e.g. to avoid repetition), etc., verbal fluency has been commonly used to assess executive (dys)function (e.g., Parker & Crawford, 1992;Phillips, 1997). The letter fluency (FAS) test, in particular, has been related to frontal lobe functions (e.g., Henry & Crawford, 2004;Stuss & Levine, 2002). The correlation observed in our current study thus strengthens the hypothesized link between frontally-mediated executive processes and the sustained anterior negative ERP effects we have characterized in association with ambiguity resolution when semantic constraints are not available (Federmeier, Segal, Lombrozo, & Kutas, 2000; Lee & Federmeier, 2006,2009). Although more research is needed to delineate the precise nature of the processes reflected in the frontal negativity and its neurobiological source(s), the pattern observed in this study is consistent with other findings in the aging literature suggesting that frontal lobe functions are more prone to age-related deterioration.

In sum, healthy aging is accompanied by anatomical changes in the brain that are more prominent in frontal regions than in others. Such biological deterioration may affect the availability of frontal resources that have been shown to be important in lexical ambiguity resolution under more effortful conditions. Indeed, our data showed that older adults were less likely to show neural effects associated with demanding meaning selection, which in turn have been linked to behavioral consequences (Dagerman, MacDonald, & Harm, 2006). However, this overall tendency toward decline does not seem inevitable, as a subset of older adults who scored higher on the FAS test, indicative of more preserved frontal lobe functions and/or better frontal lobe connectivity, did retain young-like abilities. Our results thus suggest that, overall, older adults may become more dependent on the availability of semantic context information to successfully rapidly resolve lexical ambiguities. Given that lexical ambiguity is prevalent in language – and that semantic constraints will not always be available – these results further suggest that interventions that can improve the function of or connectivity to and from frontal lobe areas may be quite valuable for enhancing and preserving language comprehension success, by aiding the orchestration of the multiple neurocognitive resources required for ambiguity resolution in a manner appropriate to the varying constraints provided by context.

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Appendix

Examples sentences ending with noun/verb homographs (a: congruent sentences; b: corresponding syntactic prose sentences)

1. (a) He was excited about Sunday’s football game, but seeing his team lose was painful to watch.

   (b) He was proven about something’s bottom court, but seeing his class turn was light to watch.

2. (a) Balancing a tray of wine glasses, the waitress hoped that she would not trip.

   (b) Balancing a station of family parents, the brain learned that she would not trip.

3. (a) None of the berries looked very appetizing, so the man didn’t know which to pick.

   (b) None of the soldiers got very new, so the car didn’t get which to pick.

4. (a) As the ball flew toward the girl’s head, her friend told her to duck.

   (b) As the animal went toward the artifact’s body, her resident told her to duck.

5. (a) To treat my tooth cavity, the dentist will first have to drill.

   (b) To make my room job, the coach will first have to drill.

6. (a) During the medieval castle tour, the man learned that the strongest part is the keep.

   (b) During the painful hook time, the flat knew that the best movie is the keep.

7. (a) You can usually find the registration desk of a hotel in the lobby.

   (b) You can usually install the math student of a day in the lobby.

8. (a) He really liked the magazine and couldn't wait for the next issue.

(b) He really asked the height and couldn't stay for the first issue.

9. (a) My grandpa said he hadn't played that game since he was a kid.

(b) My board said he hadn't called that volcano since he was a kid.

10. (a) He said the long, graceful bird was called a swallow.

(b) He realized the young, English life was assigned a swallow.

Example sentences ending with unambiguous words (a: congruent sentences; b: corresponding syntactic prose sentences)

1. (a) This question asks for an individual's opinion, so the responses will vary.

(b) This room looks for a drivers' homework, so the swordsmen will vary.

2. (a) He was so tense, his coach told him he had to relax.

(b) He was so ancient, his tower taught him he had to relax.

3. (a) The book that she wanted was one that is very difficult to obtain.

(b) The ice that she watched was one that is very obvious to obtain.

4. (a) When the babysitter arrived, my parents told my little brother to behave.

(b) When the time went, my muscles warned my boring collection to behave.

5. (a) I hate rewarding him with attention, but my brother's annoying behavior can be impossible to ignore.

(b) I hate taking him with ship, but my parents' nervous dentist can be serial to ignore.

6. (a) According to the school paper, this year the club only had one new member.

(b) According to the popcorn tool, this month the tape only had one nervous member.

7. (a) After she lost her assignment and failed the test, she was in a bad mood.

(b) After she received her turkey and built the graduation, she was in an impossible mood.

8. (a) The idea hadn't been proven, but it was a good theory.

(b) The kitchen hadn't been found, but it was a sore theory.

9. (a) People said that the older man was a much better athlete in his youth.

(b) Clothes thought that the bigger thing was a much older lot in his youth.

10. (a) When he went to court he swore to tell the truth.

(b) When he wanted to ring he decided to wear the truth.

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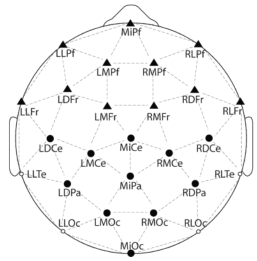

Figure 1.
Shown are the locations and abbreviations of the 26 scalp electrodes, as seen from the top of the head (with the front of the head at the top of the figure). The first two letters of the channel abbreviations describe channel positions in terms of laterality—LL (left lateral), LD (left dorsal), LM (left medial), Mi (midline), RM (right medial), RD (right dorsal), RL (right lateral). The last two letters of the channel abbreviations describe channel positions in terms of anteriority—Pf (prefrontal), Fr (frontal), Ce (central), Te (temporal), Pa (parietal), Oc (occipital). Frontal electrodes are represented as triangles and central/posterior electrodes are represented as circles. MiPf, MiCe, and MiOc correspond to Fpz, Cz, and Oz, respectively, in the 10/20 System. The electrodes used for statistical analysis are shown using filled-in shapes.

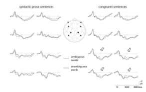

Figure 2.

Grand average ERPs to ambiguous words (dashed line) and unambiguous words (solid line) are plotted separately for syntactic prose sentences (left panel) and congruent sentences (right panel) at 8 representative electrode sites (LLPf, RLPf, LDFr,RDFr, LMCe, RMCe, LDPa, and RDPa). Positions of the plotted sites are indicated by filled circles on the center head diagram (nose at top). Negative is plotted up for this and all following figures. Replicating the pattern previously observed for younger adults, older adults showed reduced N400 responses in congruent as compared with syntactic prose sentences, and less facilitation for NV-homographs than for unambiguous words (marked with arrows). Responses in the syntactic prose condition, however, were quite different in older adults. Whereas younger adults elicited a sustained frontal negativity to NV-homographs relative to unambiguous words, older adults as a group did not show any systematic ERP differences between the two word types.

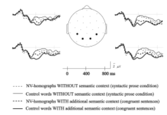

Figure 3.

Grand average ERPs to ambiguous words and unambiguous words in syntactic prose sentences and congruent sentences are overlaid at 4 representative central/posterior electrode sites (LDPa, RDPa, LMOc, and RMOc) to highlight the influence of semantic constraints on the N400. Similar to younger adults' data pattern, N400 amplitudes to both ambiguous and unambiguous words are highly attenuated (made more positive) in the presence of semantic constraints, although this attenuation is greater for unambiguous than ambiguous targets in cloze-probability matched sentence contexts.

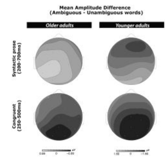

Figure 4.
Mean amplitude differences shown as isopotential voltage maps for older adults in this study (left) and younger adults in Lee & Federmeier (2009) (right). The maps show distributions viewed from the top of the head for brain responses in the syntactic prose sentences in the 200-700 ms time window (top) and in the congruent sentences in the 250-500 ms time window (bottom). Both groups show N400 response differences with a typical central/posterior scalp distribution to sentence final words in congruent sentences. However, a clear contrast between groups is shown in the responses to sentence final words in the syntactic prose condition, such that only younger adults elicit a notable frontal negative effect.

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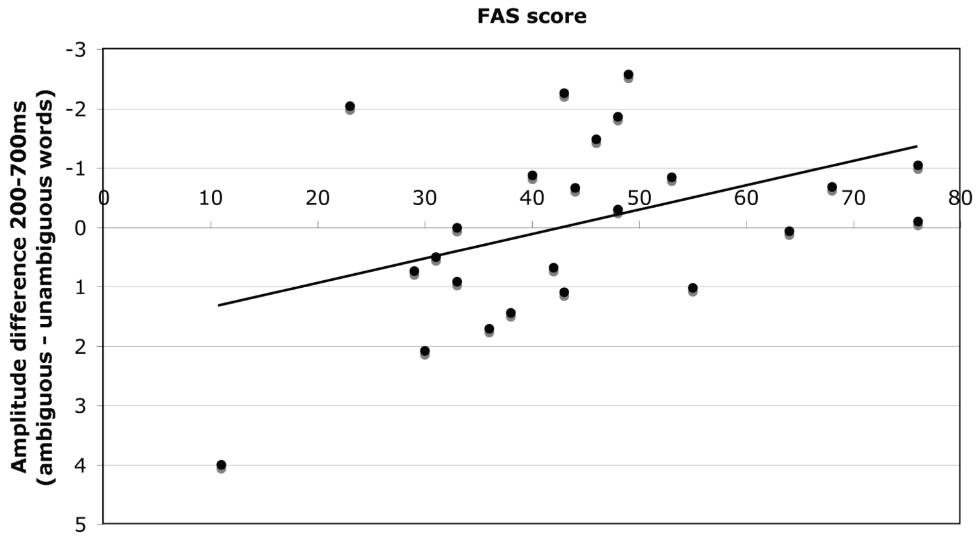

Figure 5.
Older adults' FAS scores (number of words produced that fit the cue) are plotted on the X axis against the mean amplitude difference (200-700 ms post-stimulus onset over the 11 frontal channels) between responses to ambiguous and unambiguous words in syntactic prose sentences on the Y axis (negativity is plotted up). The scatter plot shows that better FAS performance is associated with greater amount of frontal negativity elicited by the older adults.

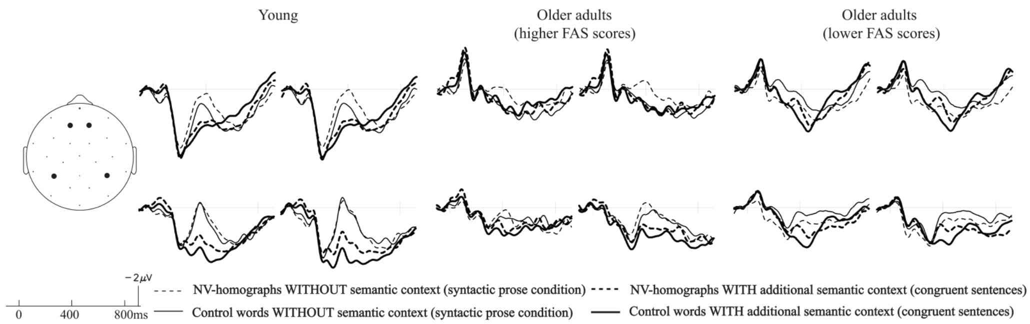

Figure 6.
Grand average ERPs to ambiguous (e.g. 'the season/to season'; dashed line) and unambiguous words (e.g. 'the drama/to teach; solid line) in syntactic prose sentences are plotted at 4 representative electrode sites (LMPf, RMPf, LDPa, and RDPa) for three participant groups: younger adults in our previous study (Lee & Federmeier, 2009), older adults with higher letter fluency scores, and older adults with lower letter fluency scores. All three groups showed very similar responses to N400 response patterns, with more N400 attenuation for sentence final words in congruent sentences compared to syntactic prose sentences, and, within congruent sentences, more attenuation for unambiguous as compared with ambiguous words. However, for syntactic prose sentences, only younger adults and older adults with higher letter fluency scores elicit a relative negativity to ambiguous compared to unambiguous words over frontal channels, between about 200 and 700 ms post-stimulus-onset.

Table 1

Mean values (with standard deviations in parentheses) of lexical features of the two word types (NV-homographs and unambiguous words).

	NV-homographs	Unambiguous words
	'the season'/'to season'	**'the drama'/'to teach'**
Log frequency	1.56 (0.58)	1.58 (0.51)
Word length	4.8 (1.3)	5.2 (1.1)
Concreteness (1=very abstract; 7=very concrete)	4.7 (1.0)	4.7 (1.0)
Semantic distinctiveness (1=very different; 7=very similar)	2.7 (0.8)	N/A

Table 2

Mean values (with standard deviations in parentheses) of sentential features of congruent sentences ending with the two word types (NV-homographs and unambiguous words).

	NV-homographs	Unambiguous words
	'the season'/'to season'	**'the drama'/'to teach'**
Sentence Length	14.6 (3.6)	13.9 (3.1)
Plausibility (1=least plausible; 7=most plausible)	6.5 (0.5)	6.6 (0.3)
Cloze probability	50% (35%)	50% (32%)