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Event-Related Potentials Reveal the Effects of Aging on Meaning Selection and Revision

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Abstract

ERPs were recorded as older adults decided if a target word was related to a lateralized ambiguous or unambiguous prime; prime-target pairs were preceded by a related or unrelated context word. In an unrelated context, N400 facilitation effects differed from those seen in young adults (Meyer & Federmeier, 2007), with older adults showing priming for the dominant meaning (e.g., *BOOM-BANK-DEPOSIT*) on right visual field/left hemisphere (RVF/LH) trials and priming for the subordinate meaning (e.g., *BOOM-BANK-RIVER*) on LVF/RH trials. Higher-functioning older adults, especially those with better inhibition, were more likely to show bilateral activation of the dominant meaning and unilateral activation of the subordinate meaning, suggesting a retention of young-like activation. In a biasing context (e.g., *RIVER-BANK-DEPOSIT*), older adults selected the contextually-consistent meaning, but were less likely than young adults to revise their selection.

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Older adulthood has been associated with a general decline in cognitive functioning that includes reductions in capacities such as processing speed (Salthouse, 1996), attentional resources (Craik, 1983), inhibitory control (Hasher, Stoltzfus, Zacks, & Rypma, 1991), and both long-term and working memory (Park et al., 2002). Although verbal knowledge seems to be relatively spared across the lifespan (e.g., Park et al., 2002), these cognitive capacity changes affect the rapid use of that knowledge during on-line language processing. For example, older adults have difficulty inhibiting lexical competitors (Sommers & Danielson, 1999), making word recognition more difficult, and they show reduced abilities to use sentence context information to facilitate word processing (Federmeier, Van Petten, Schwartz, & Kutas, 2003) and predict upcoming semantic information (Cameli & Phillips, 2000; Federmeier, McLennan, De Ochoa, & Kutas, 2002).

Given the declines in attention, inhibition, and working memory that have been observed in older adulthood, one might predict that older adults would experience particular difficulty in the resolution of lexical ambiguity, which in young adults has been associated with working memory span and the ability to maintain multiple meanings (Miyake, Just, & Carpenter, 1994), as well as the ability to inhibit less frequent or contextually-inconsistent meanings (Gunter, Wagner, & Friederici, 2003). A deficit in ambiguity resolution would likely be

detrimental to daily language processing tasks, as many of the most frequent English words are ambiguous (Rodd, Gaskell, & Marslen-Wilson, 2004). However, studies that have used behavioral priming paradigms to investigate ambiguity resolution in older adulthood have yielded mixed results. On the one hand, a number of studies have found evidence that, within both neutral and biasing contexts, older adults select word meanings in a manner similar to young adults (e.g., Balota & Ducheck, 1991; Balota, Watson, Ducheck, & Ferraro, 1999; Hopkins, Kellas, and Paul, 1995; Paul, 1996). Some work with event-related brain potentials (ERPs) has even suggested that older adults show a greater sensitivity to context when processing ambiguous words, being more likely than younger adults to select the meaning of a homonym that is consistent with biasing information (Swaab, Brown, & Hagoort, 1998; 2003). In contrast to these findings, however, some behavioral evidence suggests that older adults have difficulty inhibiting meanings that are inconsistent with a biasing context (Faust, Balota, Ducheck, Gernsbacher, & Smith, 1997). Faust et al. asked older adults to perform a relatedness judgment task, in which they decided if a target word (e.g., *ace*) was related to a preceding sentence that contained a sentence-final ambiguous word or an unambiguous control word (e.g., *He dug with the spade* or *He dug with the shovel*). Compared to the unambiguous condition, at both short and long interstimulus intervals (ISIs) older adults' response times were slower when the sentence contained an ambiguous word. In young adults, the occurrence of this type of meaning interference effect at a long ISI has been linked to reading comprehension skill (Gernsbacher, Varner, & Faust, 1990). Thus, older adults, similar to young participants who are less-skilled readers, may have difficulty inhibiting the contextually-inconsistent meaning of a homonym.

Balota, Cortese, and Wenke (2001) have suggested that the discrepancy between the findings of Faust et al. (1997) and the studies cited above may be related to task demands. The task used by Faust and colleagues required an explicit comparison of the meaning of the target word and the biasing context, whereas the other studies involved either a naming task or silent reading. The priming effects observed in the latter tasks, therefore, may have reflected automatic spreading activation that originated with the biasing context, rather than controlled processes that may only be engaged when attention is explicitly drawn to meaning selection (Balota & Paul, 1996). The more controlled type of meaning selection process may be particularly affected by aging, whereas automatic spreading activation may be relatively more spared (cf. Hasher et al., 1991). In behavioral work that has utilized the visual half-field (VF) procedure to investigate hemispheric asymmetries, controlled semantic processing has often been associated with the left cerebral hemisphere (e.g., Beeman et al., 1994; Burgess & Simpson, 1988; Chiarello, 1985; Faust & Chiarello, 1998; Faust & Gernsbacher, 1996). Work involving fMRI has also pointed toward a role for the left hemisphere (LH) in semantic selection (e.g., Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). These findings thus suggest that aging may be associated with declines in left-hemisphere executive functions important for semantic selection.

The cognitive neuroscience literature on aging indeed points to changes in hemispheric dominance as a notable feature. Findings from neuroimaging studies have suggested that cognitive functions such as long-term memory, working memory, perception, and inhibitory control become less lateralized in older adulthood (see Cabeza, 2002; Greenwood, 2007). There are two general explanations for this decrease in lateralization: dedifferentiation and compensation. According to the dedifferentiation hypothesis (e.g., Baltes & Lindenberger, 1997), cognitive functions that were previously dependent on distinct, specialized resources begin to rely on a shared pool of resources in older adulthood. When applied to the phenomenon of reduced lateralization, the dedifferentiation hypothesis suggests that this pattern reflects a lack of specialization and a decline in functioning. On the other hand, according to the compensation hypothesis (Cabeza et al., 1997), the hemisphere that is not dominant for a specific cognitive process is recruited to compensate for age-related decline

in the functioning of the dominant hemisphere. In a source memory task, Cabeza, Anderson, Locantore, & McIntosh (2002) found support for the compensation hypothesis: high-performing older adults activated bilateral prefrontal cortex (PFC), whereas young adults and low-performing older adults activated the right PFC. Thus, low-performing older adults showed activation similar to that seen in young adults, but this activation was less effective. In contrast, among high-performing older adults the left PFC was apparently recruited to compensate for decline within the right PFC.

Similar to neuroimaging findings within the areas of memory, perception, and inhibitory control, event-related potential (ERP) studies have suggested that the laterality of language processing undergoes changes in older adulthood (Federmeier & Kutas, 1999; Federmeier et al., 2002). These studies found that older adults' ERP responses to unambiguous, auditorily-presented words in context were similar to those observed for younger adults when these stimuli were presented to the right hemisphere (RH) through the use of the visual half-field (VF) presentation procedure. In contrast, younger adults' ERP responses to the auditorily-presented words were similar to those observed when the stimuli were presented to the LH. These effect patterns were observed on the N400, a negative-going potential that peaks at approximately 400 ms following the onset of a meaningful stimulus (Kutas & Hillyard, 1980). N400 amplitudes are reduced in the presence of congruent contextual information, including that of a single word, and thus can be used as an index of semantic priming (see Kutas & Federmeier, 2001, for a review). Importantly, the N400 seems to reflect implicit, fairly automatic aspects of semantic processing, as N400 semantic priming effects can be seen with masking (Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002; Misra & Holcomb, 2003), during the attentional blink (Rolke, Heil, Streb, & Hennighausen, 2001), and even during coma and some stages of sleep (Brualla, Romero, Serrano, & Valdizan, 1998; Kotchoubey et al., 2005). These results thus suggest that not only controlled semantic processing but also automatic meaning activation may be changing with age, in conjunction with altered patterns of laterality. What remains unclear is whether such changes arise because of dedifferentiation or as a result of compensatory recruitment of RH processing resources in response to declines in specialized LH functions. Interestingly, Federmeier et al. (2002) found that older adults with higher verbal fluency scores were more likely to show the LH-biased pattern that was seen in younger adults. Thus, depending on the process under investigation, older adults with greater resources may demonstrate a pattern of hemispheric activation that is similar to that seen in young adults, suggesting a retention of young-like functional activation, or they may show a dissimilar pattern that likely reflects compensation for functional decline within the dominant hemisphere (e.g., Cabeza et al., 2002).

The specific role of each cerebral hemisphere in lexical ambiguity resolution remains controversial. For example, behavioral VF studies involving neurologically-normal young participants have produced conflicting results within a neutral context, such as LH selection of the most frequent (dominant) meaning (Burgess & Simpson, 1988) or RH selection of the dominant meaning (Hasbrooke & Chiarello, 1998¹). Similarly, behavioral studies that have presented a biasing context to participants with unilateral brain injury have found a meaning selection deficit that is associated either with LH damage (e.g., Copland, Chenery, & Murdoch, 2002) or with RH damage (e.g., Klepousniotou & Baum, 2005; Tompkins, Baumgaertner, Lehman, & Fassbinder, 2000). Similar to the conflicting findings within the aging literature on ambiguity resolution, the disparity in findings across studies may arise because different materials and tasks differentially tap into more automatic or more controlled aspects of semantic selection. Because ERPs provide multiple, functionally-specific indices of processing, they can play an important role in elucidating the processes

¹At a 750 ms SOA, Hasbrooke and Chiarello (1998) found accuracy priming for the dominant meaning in the RH and accuracy priming for multiple meanings in the LH. Reaction time priming for the dominant meaning was found in both hemispheres.

involved in ambiguity resolution. More automatic aspects of meaning activation would be expected to manifest as changes in N400 amplitude. In contrast, more explicit and controlled selection processes have been associated with effects on the late positive complex (LPC), a positive-going potential that follows the N400. For example, Swaab and colleagues (1998) found that N400 facilitation² was absent following the presentation of a target word that was related to the contextually-inconsistent meaning of a homonym, indicating that biasing information initially suppressed activation of the inconsistent meaning. However, LPC responses to contextually-inconsistent targets were more positive than an unrelated baseline, suggesting that the suppressed meaning was eventually activated (or reactivated).

In a recent ERP study (Meyer & Federmeier, 2007), we used the VF procedure to investigate meaning selection and revision processes in young adults. Participants performed a relatedness judgment task, deciding if a lateralized prime was related to a centralized target word. On each trial, the lateralized ambiguous or unambiguous prime was preceded by a centrally-presented context word that could be biasing or neutral, and the prime was followed by the centrally-presented target, which could be related or unrelated to the prime. Thus, within an experiment, participants viewed discordant ambiguous triplets such as *RIVER-BANK-DEPOSIT* that involved subordinate-related context words and dominant-related targets; they also viewed concordant unambiguous triplets that involved weakly-related context words and strongly-related targets (e.g., *HANDLE-DOOR-WINDOW*) that were similar in associative strength to the context words and targets from the ambiguous triplets (see the top half of Table 1 for examples). In a second experiment, the context words and targets were exchanged in order to create an unambiguous condition involving strongly-related context words and weakly-related targets and an ambiguous condition involving dominant-related context words and subordinate-related targets (see the bottom half of Table 1 for examples). A condition in which both the context word and the target were unrelated to the prime (UU: unrelated context, unrelated target) served as a baseline and priming was assessed for targets in both a neutral context (UR: unrelated context, related target) and a biasing one (RR: related context, related target).³

In both experiments, N400 responses were more positive than baseline (facilitated) within each of the unambiguous conditions involving related targets (RR and UR). A different pattern occurred in the ambiguous conditions: when the context word was unrelated (UR condition), N400 facilitation occurred across experiments and visual fields, except when subordinate targets followed primes that were presented to the RH. These findings indicate that the hemispheres are differentially affected by meaning frequency when a biasing context is absent, with the LH maintaining dominant and subordinate meanings and the RH selecting the dominant meaning (cf. Hasbrooke & Chiarello, 1998). In either experiment, when discordant context information was presented (ambiguous RR condition), N400 facilitation was absent in both visual fields. This finding indicates that the contextually-biased meaning of the ambiguous word was selected within each hemisphere. Subsequent to the N400 time window, there was an increase in the LPC amplitude to these items, indicating that the inconsistent meaning was eventually recovered (cf. Swaab et al., 1998); this recovery occurred more quickly for dominant-related targets (cf. Duffy, Morris, & Rayner, 1988).

To examine how hemispheric specialization for ambiguity resolution changes with age across both automatic and controlled aspects of processing, in the current study, we utilized

²Facilitation occurs when the N400 or LPC amplitude is less negative than that measured in an unrelated baseline condition.

³The condition in which the context word was related to the prime but the target was unrelated (RU: related context, unrelated target) was included in the experiment to prevent the targets from being predictable, but was not of theoretical relevance and was not analyzed.

the materials and procedure from Meyer and Federmeier (2007) with neurologically-normal older adult participants. If older adults retain the ability to inhibit the contextually-inconsistent meaning of a homonym (Swaab et al., 1998), then N400 facilitation should occur in the neutral (UR) condition, but not the discordant (RR) condition. Of interest, then, would be whether older adults, like younger adults, can employ controlled meaning selection processes (indexed by the LPC) to bring online these previously suppressed meanings in the ambiguous RR condition. Alternatively, if older adults have difficulty inhibiting the inconsistent meaning (Faust et al., 1997; Gernsbacher et al., 1990), then one would expect N400 facilitation to occur in both related conditions (UR and RR).

Of particular interest will be changes in the pattern of asymmetry observed with age and whether any such changes are correlated with reduced performance (as predicted by dedifferentiation) or enhanced performance (as predicted by compensation) on relatedness judgment accuracy and/or on neuropsychological measures of cognitive functions that may be related to ambiguity resolution, such as inhibition (Gernsbacher et al., 1990), working memory (Miyake et al., 1994), and verbal fluency (cf. Federmeier et al., 2002). Whereas the findings from our study involving young adults (Meyer & Federmeier, 2007) indicate that dominant meanings are selected by both hemispheres but subordinate meanings only by the LH, a different pattern may occur in older adulthood. For example, consistent with findings of more distributed activation patterns with advancing age, especially under more difficult processing conditions, we might expect to see additional recruitment of the RH for processing of the subordinate meaning. If so, it will be of interest to assess whether this additional recruitment is associated positively (i.e., compensation; Cabeza et al., 2002) or negatively (i.e., dedifferentiation; Baltes & Lindenberger, 1997) with performance on the behavioral task or the neuropsychological measures. Furthermore, if such shifts occur, they may involve concomitant changes in the processing of the dominant meaning. For example, it is possible that with age there is an increasing tendency to split processing demands across the hemispheres (e.g., Banich & Brown, 2000), such that one hemisphere becomes specialized for dealing with the dominant meaning and the other the subordinate. If so, this would suggest that bilateral activation patterns in older adulthood may reflect a more complex redistribution of processing resources than just additional recruitment or activation.

Method

Participants

The final set of participants consisted of 40 native English speakers⁴, 20 run on the “dominant/strong target” version of the experiment (8 female), and 20 run on the “subordinate/weak target” version (9 female). Assignment to experiment version was random within gender. Participants were screened for neurological and psychiatric health, none were taking psychotropic medication, and none had early (< age 5) exposure to a second language. All participants had corrected visual acuity of 20/30 or better and reported that they could read the words presented on the monitor. All participants were right-handed according to the Edinburgh handedness inventory (Oldfield, 1971). The mean laterality quotient was 0.84 (range 0.24 to 1.0), with 1.0 indicating strong right-handedness and -1.0 indicating strong left-handedness. Eighteen participants (nine in each version) reported having immediate family members who were left-handed. The mean age of the participants was 65 in both versions of the experiment (range in dominant/strong target version = 60-80; range in subordinate/weak target version = 60-75). All participants had some college education, 68% had at least a bachelor's degree, and 48% had a graduate or professional

⁴A total of 60 participants were tested. 20 participants were excluded, typically because they were unable to maintain fixation during the 200 ms period when the lateralized prime was presented. A few participants were excluded due to excessive muscle movement artifacts.

degree. Participant groups from the dominant/strong and subordinate/weak target versions both had an average of 5 years of post-secondary education.

Neuropsychological Measures

The Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975) was used to screen participants for dementia (cutoff score = 24, $M = 28.8$, range 25-30). Three additional neuropsychological tests were administered to assess specific aspects of cognitive functioning: a modified version of the Hayling test, which measures response suppression/inhibition within highly-constraining sentences (Burgess & Shallice, 1996); the reading span test, which examines working memory capacity (Daneman & Carpenter, 1980); and the letter (FAS) and category (animals, fruits and vegetables, first names) components of the verbal fluency test (Benton & Hamsher, 1978).

The Hayling test consists of two subsections: response initiation, in which participants are asked to complete highly-constraining sentences with a word that fits the context (e.g., *He mailed the letter without a _____*); and response suppression, in which participants are asked to complete highly-constraining sentences with a word that is completely unrelated to the context. We utilized a modified version of the Hayling test, in which the same set of 35 sentences was used in the response initiation and suppression components of the test, rather than using two separate sets of 15 sentences. The sentences were taken from Bloom and Fischler (1980); 30 of these sentences are used in the standard version of the test. In all of the sentences, the most frequent completion had a cloze probability of .70 or greater. Responses were scored as correct or incorrect (i.e., we did not use the Burgess and Shallice [1996] method for rating errors according to their relatedness to the expected completion)⁵. The average number of correct items in the initiation and suppression subtests was 34.5 ($SD = .64$, range 32-35) and 23.9 ($SD = 8.84$, range 6-35), respectively. The number of correct responses in the suppression subtest was used as a measure of inhibition in the individual differences analyses.

The mean verbal fluency score (combined) was 109.5 ($SD = 23.06$, range 63-155). All participants had verbal fluency scores within the normal range for their age and educational level (Tombaugh, Kozak, & Rees, 1999). The mean reading set size was 2.6 ($SD = .81$, range 1.5-6), which is comparable to previous findings involving educated older adults (e.g., Federmeier & Kutas, 2005: $M = 2.4$). The average number of items recalled in the reading span test was 56.7 ($SD = 11.9$, range 34-79), or 64.4%. The number of items recalled was used as the measure of working memory in the individual differences analyses for this study (for a discussion of optimal scoring methods, see Friedman and Miyake, 2005).

There were strong positive correlations between performance on the three neuropsychological measures [Inhibition and Working Memory: $r(38) = .51$, $p < .01$; Inhibition and Verbal Fluency: $r(38) = .55$, $p < .001$; Working Memory and Verbal Fluency: $r(38) = .47$, $p < .01$]. Age was negatively, but non-significantly, correlated with each of these measures [Inhibition: $r(38) = -.27$, $p = .09$; Working Memory: $r(38) = -.26$, $p = .11$; Verbal Fluency: $r(38) = -.24$, $p = .14$]. Neither age nor any of the neuropsychological measures were significantly correlated with overall relatedness judgment performance; the largest correlation was with working memory, $r(38) = .25$, $p = .12$.

⁵Re-scoring according to the system devised by Burgess and Shallice (1996) showed that the significant correlations between Hayling suppression performance and priming were not affected by the scoring method.

Materials

The stimuli from Meyer and Federmeier (2007) were utilized. Stimulus characteristics are presented in Table 2. The stimulus set included 104 ambiguous and 104 unambiguous words. For each ambiguous word, one dominant-related and one subordinate-related word were selected (the mean dominant and subordinate meaning frequencies were 74% and 13%, respectively [Twilley, Dixon, Taylor, & Clark, 1994]). The mean association between primes and dominant-related words was 0.13, and that between primes and subordinate-related words was 0.03 (Nelson, McEvoy, & Schreiber, 1998). For each unambiguous word, one strongly-related word and one weakly-related word were also selected (mean associations of 0.14 and 0.05, respectively). Additionally, two unrelated words were selected for each ambiguous and unambiguous word. At least 75% of the words in each target condition had a noun meaning, approximately half had a verb meaning, and approximately 15% had an adjective meaning. The overall distribution of word types was similar across conditions.

Trials consisted of triplets containing a related or unrelated context word, the prime, which was lateralized to the left or right visual field, and the target. Context words and targets were unassociated in all conditions. We refer to the conditions as UU (unrelated context, unrelated target), UR (unrelated context, related target), and RR (related context, related target). Trials involving a related context word and an unrelated target (RU) were also included in the experiment to prevent the targets from being predictable, but these were omitted from statistical analyses because they were not of theoretical relevance for the current study.

To ensure sufficient critical trials in all conditions, two versions of the experiment were run. One group of participants viewed subordinate-related or unrelated context words and a dominant-related or unrelated target (e.g., *RIVER-BANK-DEPOSIT* if both the prime and the target were related; see the top half of Table 1). The parallel unambiguous trials involved the presentation of a weakly-related or unrelated context word and a strongly-related or unrelated target (e.g., *HANDLE-DOOR-WINDOW* if both the prime and the target were related). Note that “strong” is being used in a relative sense, as the association with the lateralized prime words is still fairly weak. A second group of participants were given the same materials in the reverse sequence, such that the dominant-related and strongly-related words occurred as the context and the subordinate-related and weakly-related words occurred as the targets (see the bottom half of Table 1; note that the same stimuli were used in the two experiments but different examples are provided in the bottom half of Table 1 to illustrate a wider range of the stimuli).

Sixteen total conditions were formed in each version of the experiment by crossing triplet type (ambiguous or unambiguous) with relatedness pattern (UU, UR, RU, or RR) and VF. Across eight stimulus lists per version, each ambiguous or unambiguous word appeared in all possible conditions. In order to increase the number of items per condition, each lateralized prime was presented an additional time in the second half of the experiment, in the opposite VF, with different context and target words (e.g., RR trials became UU trials, and RU trials became UR trials). There were then 26 items per condition and a total of 416 trials.

Procedure

Participants sat in a dimly-lit room, one meter from a computer screen. They were told that a series of three words would be presented on each trial, instructed to read each word without moving their eyes from a central fixation point, and informed that their primary task was to decide if the second and third words were related in meaning. Participants were also told

that the first word could be related to the second word and that reading the first word might aid perception of the rapidly-presented, lateralized second word. In addition, participants were informed that a recognition test involving the first words would occur between blocks.

On each trial, the context word was presented above the central fixation cross for 500 ms, with a 1000 ms stimulus onset asynchrony (SOA). The ambiguous or unambiguous prime was presented two degrees to the left or right of fixation for 200 ms, with a 1000 ms SOA. The target was then presented above the fixation cross for 500 ms. One second after the target's offset, a prompt ("??") appeared on the screen, indicating that participants should make a relatedness judgment response by pressing a "yes" or "no" button. For a given participant, each button was paired with the left or right hand; response/hand pairings were counterbalanced across participants.

There were eight blocks of trials and 52 trials per block. Between blocks, participants took a short break and were given a recognition memory test over a subset of the context words from the previous block, in order to ensure that participants attended to the context words. The experimental runtime was approximately 70 minutes, including a practice block and breaks.

EEG Recording and Analysis

The electroencephalogram (EEG) signal was recorded from 26 evenly-spaced silver/silver-chloride (Ag/AgCl) scalp electrodes (see Federmeier and Kutas, 1999, for a depiction of the electrode array). Eye movements were detected with a bipolar montage of electrodes placed on the outer canthus of each eye. Blinks were monitored with an electrode placed below the left eye. All data were sampled at 250 Hz and were bandpass filtered online from 0.02 to 100 Hz. Data were referenced online to the left mastoid and rereferenced offline to the algebraic mean of the left and right mastoids.

Trials containing eye movements or recording artifacts (signal drift or amplifier blocking) were rejected offline, using thresholds set for individual subjects based on visual inspection of the data. For target words, epochs containing blinks were either rejected, or corrected (Dale, 1994) when blinks occurred on a number of trials that was sufficient to develop a stable filter (blink correction was employed for 15 participants in the "dominant/strong target" version and 14 in the "subordinate/weak target" version). Due to an insufficient number of blinks within the epochs corresponding to the lateralized prime, correction was not employed for any subject within those epochs. To ensure that presentation of the prime remained lateralized (i.e., 2 degrees from fixation), trials that contained saccades that occurred during the 200 ms of stimulus presentation were marked, and both prime and target epochs were discarded for these trials. For ten participants from each version, data from lateralized prime epochs was not usable due to a high overall rejection rate, including trials in which participants did not execute a saccade during the presentation of the prime but did execute a slower saccade that contaminated the prime epoch. The overall average trial loss was 13.5% for the targets (20 participants in each version) and 16.1% for the lateralized primes (10 participants in each version). Thus, following artifact rejection there were 22.5 items per target condition and 43.6 items per prime condition, on average.

After artifact rejection, ERPs were computed for the epoch from 100 ms prior to stimulus onset to 950 ms after onset. Following subtraction of the 100 ms prestimulus baseline, averages were formed for each experimental condition. A digital bandpass filter of 0.2 to 20 Hz was implemented before analyses were performed. Supported by distributional analyses revealing a canonical distribution for both N400 and LPC effects, the same 10 central-posterior channels (Left and Right Medial Frontal, Left and Right Medial Central, Middle Central, Left and Right Dorsal Parietal, Middle Parietal, and Left and Right Medial

Occipital) used to assess effects in Meyer and Federmeier (2007) were used in the present study, to allow maximum comparability across younger and older adult participants.

Results

Behavior

Recognition Accuracy for Context Word—Mean A' was .76 ($SE = .01$)⁶ for the dominant/strong target version of the experiment and .77 ($SE = .01$) for the subordinate/weak target version. In both versions, therefore, participants clearly attended to the context words and were able to discriminate between these words and new words. Performance was comparable to that seen in young adults, who had mean A' values of .78 and .80 in the dominant/strong and subordinate/weak target versions, respectively.

Relatedness Judgment Accuracy—Due to the fact that a delayed response task was used, reaction time data were not analyzed. Accuracy data were submitted to a 2 (Visual Field) $\times$ 2 (Ambiguity) $\times$ 3 (Relatedness) analysis of variance (ANOVA). The Geisser-Greenhouse correction was employed when necessary.

Dominant/strong targets: For the dominant/strong target version of the experiment, there were main effects of VF [$F(1, 19) = 25.27, p < .001, MSE = .008$], Ambiguity [$F(1, 19) = 43.70, p < .001, MSE = .003$], and Relatedness [$F(1, 19) = 4.81, p < .05, MSE = .071$]. Accuracy was lower in the LVF/RH condition ($M = .79, SE = .02$) than in the RVF/LH condition ($M = .85, SE = .02$), which is consistent with the RVF/LH advantage for word recognition that is typically found in VF studies (e.g., Jordan, Patching, & Thomas, 2003). Lower accuracy occurred in the ambiguous condition ($M = .80, SE = .02$) compared to the unambiguous condition ($M = .84, SE = .02$), indicating that the task was more difficult when the prime had multiple meanings. Accuracy was also lower in the UR condition ($M = .78, SE = .03$) compared to both the RR ($M = .82, SE = .03$) and UU ($M = .87, SE = .02$) conditions [RR vs. UR: $t(19) = 3.0, p < .01$; UU vs. UR: $t(19) = 2.44, p < .05$; RR vs. UU: $t(19) = -1.66, p = .12$]. The lower accuracy for UR trials may have occurred because of the mismatch between the relatedness of the context word and target.

The main effects were moderated by significant VF $\times$ Relatedness [$F(2, 38) = 9.16, p < .01, MSE = .006$] and Ambiguity $\times$ Relatedness [$F(2, 38) = 3.71, p < .05, MSE = .004$] interaction effects. To explore these interactions, the effect of Relatedness was examined separately for each VF and Ambiguity condition. A similar pattern of Relatedness was seen in both the Ambiguous and Unambiguous conditions, with UR trials manifesting the lowest accuracy. However, this effect was significant in the Ambiguous condition [$F(2, 38) = 5.60, p < .05, MSE = .044$] but only marginal in the Unambiguous condition [$F(2, 38) = 3.60, p = .06, MSE = .029$]. When the data were examined separately by Visual Field, the same pattern of Relatedness (reduced accuracy for UR trials) was significant in the LVF/RH condition [$F(2, 38) = 7.55, p < .01, MSE = .05$] but not the RVF/LH condition [$F(2, 38) = 2.11, p = .15, MSE = .027$]. Thus, contextual support seemed to be more important for facilitating relatedness judgments on ambiguous than unambiguous trials, and the LH seemed to be less affected by the mismatch in the relatedness of the context word and target that occurred in the UR condition than did the RH.

Subordinate/weak targets: The main effects of VF [$F(1, 19) = 20.75, p < .001, MSE = .009$], Ambiguity [$F(1, 19) = 63.31, p < .001, MSE = .004$], and Relatedness [$F(1, 19) = 8.09, p < .01, MSE = .064$] were significant. Similar to the pattern with dominant/strong targets,

⁶ A' is a non-parametric measure of discriminability. Values range from 0 to 1, with 0.5 indicating chance performance.

accuracy was lower in the LVF/RH condition ($M = .77$, $SE = .02$) than in the RVF/LH condition ($M = .83$, $SE = .02$), and lower accuracy occurred in the ambiguous condition ($M = .77$, $SE = .02$) compared to the unambiguous condition ($M = .84$, $SE = .02$). However, with subordinate/weak targets, accuracy in both related conditions (RR: $M = .78$, $SE = .03$; UR: $M = .75$, $SE = .03$) was lower than in UU ($M = .88$, $SE = .02$): RR vs. UR: $t(19) = 1.39$, $p = .17$; UU vs. UR: $t(19) = 3.59$, $p < .01$; UU vs. RR: $t(19) = 2.46$, $p < .05$.

Because the Ambiguity $\times$ Relatedness interaction was also significant, the effect of Relatedness was examined separately for each ambiguity condition. The effect of Relatedness was significant in the ambiguous condition [$F(2, 38) = 10.06$, $p < .01$, $MSE = .036$], which showed the overall pattern of higher accuracy of UU compared to either UR or RR trials. The effect of Relatedness was also significant in the unambiguous condition [$F(2, 38) = 4.56$, $p < .05$, $MSE = .030$]. However, in this case the pattern of effects was similar to that seen in the dominant/strong target version of the experiment, with the lowest accuracy in the UR condition. Thus, while related context words generally facilitated “yes” responses relative to unrelated context words, they selectively failed to do so when the target word was associated with a subordinate meaning of the ambiguous homonym.

Summary: Similar to the pattern seen in young adults, for dominant/strong targets older adults were less accurate in the UR condition, compared to both the RR and UU conditions, likely due to the discrepancy between the relatedness of the context word and target. However, older adults showed a hemispheric asymmetry in this sensitivity, which was not seen for younger adults, in that the RH was more affected by the mismatch between context and target. For subordinate targets, both young and older adults were more accurate in the UU condition, compared to both UR and RR. For young adults, weakly-related targets patterned like subordinate targets, but for older adults, the strongly-related context words seemed to facilitate relatedness judgments for the weakly-related targets. Compared to that seen for young adults, overall accuracy for older adults was lower in the dominant/strong target version [Young: $M = .88$, $SE = .02$; Older: $M = .82$, $SE = .02$; $t(38) = 2.11$, $p < .05$], but was comparable in the subordinate/weak version [Young: $M = .81$, $SE = .01$; Older: $M = .80$, $SE = .02$; $t(38) = .15$, $p = .88$].

Event-Related Potentials

Whereas the N400 component peaked at 390 ms in our study involving young adults (Meyer and Federmeier, 2007), for older adults the N400 peaked at 459 ms (note that a delay in the N400 component is commonly seen with age; e.g., Kutas and Iragui, 1998). Therefore, in the current study we selected a later time window (350-550 ms) in which to examine the amplitude of N400 effects in each condition. The subsequent time window of 550-950 ms was used to examine the amplitude of LPC effects. These time windows were utilized in both the lateralized prime and target epochs.

Prime Epoch—As can be seen in Figure 1, the N100 response to lateralized primes was larger at contralateral channels, indicating that the VF manipulation was successful.

Within the prime epoch, mean amplitude data from each time window were subjected to a 2 (Visual Field) $\times$ 2 (Ambiguity) $\times$ 2 (Relatedness: Related vs. Unrelated) ANOVA.

Dominant/strong target version: In the dominant/strong target version of the experiment, priming reflects facilitation from subordinate or weakly related context words onto the ambiguous or unambiguous prime words (see the left side of Figure 2). The main effect of Relatedness was significant in the N400 window [$F(1, 9) = 28.78$, $p < .001$, $MSE = 5.65$] and was marginal in the LPC window [$F(1, 9) = 4.50$, $p = .06$, $MSE = 11.59$], with more

positivity in the related context condition. There were no interactions with the main effect of Relatedness.

Subordinate/weak target version: In the subordinate/weak target version of the experiment, priming reflects facilitation from dominant or strongly related context words onto the ambiguous or unambiguous prime words (see the right side of Figure 2). The main effect of Relatedness was significant in both time windows [N400: $F(1, 9) = 16.55, p < .01, MSE = 6.44$; LPC: $F(1, 9) = 6.20, p < .05, MSE = 22.62$]. In each window, primes that followed a related context word were more positive. In the LPC window, there was a significant $VF \times Relatedness$ interaction, $F(1, 9) = 6.97, p < .05, MSE = 3.40$. For the RVF, the effect of Relatedness was significant, $F(1, 9) = 7.57, p < .05, MSE = 9.20$, with greater positivity for related primes. This effect was not significant in the LVF, $F(1, 9) = 3.20, p = .11, MSE = 3.80$.

Summary: Patterns of facilitation on the N400 revealed that, consistent with the pattern seen for young participants, both hemispheres of older adults are sensitive to strong and weak associations and to both the dominant and subordinate meanings of ambiguous homonyms. However, the pattern of LPC priming effects suggests that the controlled selection of dominant- and strongly-related meanings is weaker in the RH, compared to the LH (with neither hemisphere showing a strong tendency for controlled selection of subordinate- and weakly-related meanings).

Target Epoch—The data from the target epoch are presented in Figure 3. A 2 (Visual Field) $\times 2$ (Ambiguity) $\times 3$ (Relatedness: Related-Related [RR] vs. Unrelated-Related [UR] vs. Unrelated-Unrelated [UU]) ANOVA was used to assess priming effects in both the N400 and LPC time windows. The Geisser-Greenhouse correction was employed when necessary.

Dominant/strong targets: The main effect of Relatedness was significant in the N400 and LPC windows [N400: $F(2, 38) = 11.46, p < .001, MSE = 10.47$; LPC: $F(2, 38) = 8.98, p < .001, MSE = 24.07$]. In both windows, the UR condition was more positive than UU, whereas RR was not significantly different from UU. Thus, in a neutral context (UR), target processing was facilitated by the lateralized primes, but significant priming did not occur in a related context (RR). The main effect of Ambiguity was significant in the N400 [$F(1, 19) = 6.98, p < .05, MSE = 14.91$] and LPC [$F(1, 19) = 7.26, p < .05, MSE = 15.63$] windows. In both cases, there was more negativity in the ambiguous condition, suggesting that processing of the target was facilitated when the prime was unambiguous. There were no significant interaction effects in either time window.

To more fully explore the pattern of priming effects within the target epoch, planned comparisons examined the effects of Ambiguity and Relatedness within each VF. In each time window, unambiguous and ambiguous UR and RR conditions were compared to the appropriate UU baseline. The results of these comparisons are presented in Table 3. In a neutral context (UR condition), priming following RVF/LH presentation was significant for both strongly-related unambiguous and dominant-related ambiguous targets in both time windows (priming effects from the UR condition are shown in Figure 4). In contrast, priming following LVF/RH presentation was weaker overall and only marginally significant for unambiguous targets in both time windows. However, with a more restricted set of parieto-occipital electrodes (Left and Right Dorsal Parietal, Left and Right Medial Occipital), priming for unambiguous targets was significant in both windows [N400: $t(19) = 2.22, p < .05$; LPC: $t(19) = 2.71, p < .05$]. There was no priming in the N400 time window for dominant-related ambiguous targets. In the LPC time window, the effect was marginal overall and just reliable for the more restricted set of electrodes, $t(19) = 2.06, p = .05$. In a biasing context (RR condition), there was no priming for dominant-related targets in either

visual field in any time window. For unambiguous targets, priming was limited to the RVF/LH condition in the LPC time window.

Subordinate/weak targets: The main effect of Relatedness was significant in both time windows [N400: $F(2, 38) = 11.14, p < .001, MSE = 20.21$; LPC: $F(2, 38) = 12.13, p < .001, MSE = 18.93$]. In both, UR was more positive than UU, whereas RR did not show facilitation relative to UU. The main effect of Ambiguity was significant in the LPC window [$F(1, 19) = 4.96, p < .05, MSE = 5.37$], with greater negativity in the ambiguous condition. No interaction effects were significant.

The results of the planned comparisons are presented in Table 4. Again, in each time window, unambiguous and ambiguous UR and RR conditions were compared to the appropriate UU baseline. In a neutral context (UR condition), facilitation for subordinate-related ambiguous targets after LVF/RH presentation began in the N400 window and continued throughout the epoch, whereas facilitation for the corresponding weakly-related unambiguous targets was not significant for this same visual field condition until the LPC time window. Following RVF/LH presentation, priming for both ambiguous and unambiguous UR targets became significant only in the LPC time window. Facilitation for targets in a biasing context (RR) was significant only for unambiguous targets in the LPC time window, and only after RVF/LH presentation.

Summary: In a neutral (UR) context, the LH showed N400 and LPC facilitation for both the dominant meanings of homonyms and the strong associates of unambiguous words. Priming for subordinate meanings of homonyms and weak associates of unambiguous words, however, was delayed in the LH until the LPC time window. Thus, for the LH, associative strength was predictive of the timing and strength of priming effects, and this did not differ across ambiguous and unambiguous words. The RH, instead, showed a very different pattern of effects. For ambiguous words, only the subordinate meaning showed priming in the N400 time window, whereas the dominant meaning did not differ from the unrelated baseline until the LPC time window and then only at a restricted set of electrodes. For unambiguous words, priming for strong associates was seen on the N400 and LPC, but only at a restricted set of electrodes. Priming for weak associates was seen on the LPC but not the N400. The RH thus showed a dissociation between associative strength and meaning dominance, showing the earliest and most robust priming effects for secondary meanings of ambiguous words.

In a biasing context, LPC facilitation indicated that the LH eventually selected both strongly- and weakly-related meanings in the unambiguous condition. Neither hemisphere selected dominant or subordinate meanings of ambiguous words preceded by discordant context information.

Individual Differences—In order to examine the effects of individual differences within the target epoch, we computed correlations between the priming effect for each critical condition and the following individual difference measures: Hayling response suppression/inhibition, reading span (number of items recalled), verbal fluency, and overall relatedness judgment performance. The individual difference measures were also correlated with a variable representing hemispheric asymmetry, which was formed by subtracting the LVF/RH priming effect from the RVF/LH priming effect and taking the absolute value.⁷ Thus, this variable represents the degree to which one hemisphere is activated without corresponding activation of the contralateral hemisphere. Negative correlations with this

⁷Forty-eight correlations were computed within each time window. Because these analyses were somewhat exploratory in nature, the results should be interpreted with caution.

variable indicate more symmetrical priming. Relatedness judgment was uncorrelated with any priming effect, and thus will not be discussed further.

Dominant/strong targets: Higher levels of inhibition were generally associated with more symmetrical priming effects. This was true for both N400 and LPC responses to strong associates of unambiguous words in a neutral (UR) context [$r(18) = -.53, p < .05$; $r(18) = -.77, p < .01$, respectively] as well as for LPC responses to these same items in a biasing context, $r(18) = -.58, p < .01$. N400 responses to dominant associates of ambiguous words in a neutral (UR) context were also more symmetrical in those with higher inhibition scores [$r(18) = -.45, p < .05$], and higher inhibition predicted reduced RVF/LH N400 priming of dominant targets in the neutral (UR) context, $r(18) = -.50, p < .05$. Thus, when targets were presented in a neutral (UR) context, older adults with poorer inhibition showed initial priming of the dominant meaning that was limited to the RVF/LH, whereas those with better inhibition distributed priming for the dominant meaning across the two hemispheres.

Higher working memory was predictive of larger LVF/RH N400 priming effects for dominant targets presented in a neutral (UR) context [$r(18) = .45, p < .05$; a similar pattern was marginal on the LPC, $r(18) = .42, p = .06$]. Higher verbal fluency (along with higher inhibition) was associated with more symmetrical LPC priming of strong associates in a neutral (UR) context, $r(18) = -.51, p < .05$.

Subordinate/weak targets: Very different from the pattern seen for dominant associates, for subordinate associates in a neutral (UR) context, higher inhibition was associated with *reduced* symmetry in N400 priming, $r(18) = .52, p < .05$; this same pattern was also predicted by higher working memory span, $r(18) = .46, p < .05$. Interestingly, for weak associates (which did not show significant overall N400 priming in either hemisphere), there was a marginal tendency for higher inhibition (and memory span) to be associated with *increased* symmetry, similar to the pattern seen for dominant/strong targets [Inhibition: $r(18) = -.41, p = .07$; Working Memory: $r(18) = -.38, p = .10$]. Higher verbal fluency predicted larger RVF/LH N400 priming effects to these weakly associated words in a neutral (UR) context, $r(18) = .52, p < .05$.

Finally, higher inhibition predicted LVF/RH N400 priming of weakly associated targets in a biasing context, $r(18) = .45, p < .05$. A similar, although marginal, pattern was seen for subordinate-associated targets in a biasing context [$r(18) = .38, p = .10$], and this pattern continued into the LPC time window, $r(18) = .37, p = .10$. Higher verbal fluency also predicted greater LVF/RH LPC priming for subordinate-associated targets in a biasing context, $r(18) = .44, p = .05$.

Summary: Individual differences in inhibition, as assessed by the Hayling test, explained a number of data patterns, but had different effects as a function of both associative strength and meaning dominance. For dominant and strong associates, higher inhibition predicted more bilateral priming, and a similar (though not statistically significant) pattern was observed for weak associates. In contrast, for subordinate associates, higher inhibition was associated with the tendency to activate a single hemisphere.

Higher working memory span affected the processing of ambiguous words in a neutral (UR) context, predicting more LVF/RH priming of dominant associates and more asymmetric priming of subordinate associates. Verbal fluency predicted LPC priming in some conditions.

General Discussion

In order to explore hemispheric asymmetries in meaning selection and revision in older adulthood, we presented a biasing or neutral context word, a lateralized ambiguous or unambiguous prime, and a related or unrelated target. Participants decided if the target word was related to the lateralized prime. In the prime epoch, N400 facilitation effects indicated that processing was facilitated within both VFs by context words that were related to weak and strong associations, and by context words related to subordinate and dominant meanings. These findings are consistent with those obtained for young adults (Meyer and Federmeier, 2007), and are also consistent with the literature showing normal, but somewhat smaller and later semantic priming effects in older adulthood (e.g., Gunter, Jackson, & Mulder, 1998; Kutas and Iragui, 1998). During the LPC window of the prime epoch, facilitation from dominant- and strongly-related information was weaker in the RH compared to the LH, suggesting that more controlled processing is not focused on strongly-related information within the RH (cf. Beeman et al., 1994).

Within the target epoch, the pattern of N400 facilitation effects across visual fields/hemispheres was different from the findings obtained in our parallel study conducted with young adults (Meyer and Federmeier, 2007). More specifically, in a neutral (UR) context, young adults showed evidence of dominant meaning activation in both hemispheres, whereas the N400 results indicate that older adults initially selected this meaning within the LH but not the RH. More strikingly, for the subordinate meaning, young adults showed N400 facilitation within the LH, whereas older adults demonstrated N400 priming of this meaning in the RH. Thus, with increasing age there is a shift from left to right in the hemisphere that appears to be specialized for the activation and initial selection of the subordinate meaning. The overall pattern suggests that a division of labor may be occurring in older adulthood, with each hemisphere focusing on a distinct meaning. Thus, rather than becoming more dedifferentiated (e.g., Baltes and Lindenberger, 1997), the hemispheres appear to become more specialized.

When individual differences are taken into account, correlations between the neuropsychological measures and the N400 facilitation effects suggest that bilateral selection of dominant- and strongly-related meanings is associated with higher functioning older adults, contrary to the predictions of the dedifferentiation hypothesis (cf. Cabeza et al., 2002; Reuter-Lorenz et al., 2000). In a neutral (UR) context, participants with greater processing resources, as evidenced by better inhibition (or verbal fluency, in the case of LPC priming for strong associates), showed more symmetrical activation across the hemispheres. Additionally, for dominant-related targets, participants with a greater working memory span showed a larger priming effect in the RH. This bilateral selection pattern that is seen in higher-functioning older adults is similar to the pattern seen in young adults, suggesting a retention of young-like functional activation.

Inhibition was not only associated with symmetrical priming of the dominant meaning, it was also negatively correlated with the magnitude of priming for the dominant meaning within the LH. These findings suggest that lower performance on the suppression component of the Hayling test is related to a tendency for greater LH activation of strongly-related information – such as the expected completion of the highly-constraining sentences used in the Hayling procedure, which must be inhibited in order to provide a correct, unrelated response. In work that has examined the effects of context-based expectancy on semantic processing in the cerebral hemispheres, processing within the LH has been linked to a capacity for the top-down prediction of upcoming language input, whereas processing in the RH seems to be bottom-up and integrative rather than predictive (see Federmeier, 2007, for a review). Thus, reliance on LH processing would be likely to hinder the inhibition of

expected words. Bilateral activation has been associated with inhibition in previous work involving the Hayling test and young participants (Nathaniel-James, Fletcher, & Frith, 1997). Whereas both response initiation (providing a contextually-consistent response) and response suppression involved activation in both hemispheres, suppression involved a reduction in left middle temporal and left inferior frontal activation compared to initiation, resulting in a more symmetrical activation pattern across the hemispheres.

In contrast, the RH has been associated with a more flexible use of context (e.g., Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Coulson and Williams, 2005; Meyer and Federmeier, 2008), and this flexibility could facilitate the generation of words that are unrelated to the expected sentence completion. Strikingly, higher functioning older adults – specifically, those with better inhibition and higher working memory spans – were more likely to show *asymmetrical* priming for subordinate associates. Similar to young adults, therefore, higher-functioning older adults demonstrate bilateral activation of the dominant meaning, as well as both strong and weak associations, but show unilateral activation of the subordinate meaning. In young adults, this unilateral activation was in the LH (Meyer and Federmeier, 2007). In older adults, however, better inhibition was significantly correlated with RH priming of weakly-related information within a strongly-related context and marginally correlated with RH priming of subordinate meanings within a dominant-related context (cf. Meyer and Federmeier, 2007, 2008). Thus, selection of the subordinate meaning in older adulthood may be more efficient when processing resources are allocated to a single hemisphere, especially the RH.

The results from the present study, therefore, suggest that the pattern of hemispheric recruitment in older age is more complex than that predicted for dedifferentiation (i.e., more bilateral recruitment for older adults with fewer processing resources; e.g., Baltes and Lindenberger, 1997) or compensation (i.e., more bilateral recruitment for older adults with more processing resources; e.g., Cabeza et al., 2002; Reuter-Lorenz et al., 2000) alone. Instead, higher functioning older adults show a pattern of dynamic recruitment of hemispheric processing resources more similar to young adults, but with some age-specific differences. When processing is relatively easy (as when accessing the meaning of an unambiguous word or selecting the dominant meaning of a homonym), higher-resource older adults, like young participants, show bilateral patterns of recruitment, whereas lower-resource older adults show more limited recruitment of the LH. Bilateral activation may facilitate semantic access when context information is less available, but may also serve to preserve flexibility of processing, affording a better balance between the LH's tendency to use top-down constraints to strongly activate expected information and the RH's ability to deal with less predictable inputs. For the more difficult selection of the subordinate meaning of a homonym, however, higher-resource older adult and young adult participants tended to use a single hemisphere, whereas lower-resource older participants showed more bilateral patterns of recruitment. Younger adults activate subordinate meanings with the LH, whereas older adults show a shift toward activating subordinate meanings in the RH, perhaps to minimize conflict with activation of the dominant meaning. Older adults with better inhibition seem to successfully lateralize activation for the subordinate meaning, whereas those with a poorer ability to inhibit show bilateral activation patterns. Thus, the efficacy of bilateral activation seems to be dependent on factors such as meaning frequency that might, in turn, relate to tradeoffs between the role of activation and suppression in optimizing semantic access.

Balancing activation and suppression is also critical for the effective use of context information, which, in this experiment, could be discordant with the target (pointing to a different meaning sense of the ambiguous prime) or concordant (pointing to the same meaning sense of the unambiguous prime). When the context and target words were

discordant (ambiguous RR condition), older adults showed strong sensitivity to context. Across experiments, both N400 and LPC facilitation effects were absent in this condition, indicating that the contextually-consistent meaning was selected, and this selection was not revised when the inconsistent target word was presented. Although the N400 effects were consistent with the pattern seen in young adults (Meyer and Federmeier, 2007), young adults demonstrated a meaning revision effect in the LPC window, with more positivity compared to the unrelated (UU) baseline. Thus, older adults are capable of selecting the meaning that is consistent with context (Klepousniotou & Baum, 2005; Swaab et al., 1998; cf. Faust et al., 1997; Gernsbacher et al., 1990), but they are less likely than young adults to revise this interpretation when faced with conflicting information. The lack of revision may result from a failure to recover the unselected meaning after it has been suppressed or inhibited (Gernsbacher, Robertson, & Werner, 2001; Simpson and Adamopoulos, 2001). Some work with young adults has pointed to a similar pattern of slower or absent revision in individuals with a lower working memory capacity (Gunter et al., 2003), and all but two of the older participants from the current study would fall into the low-span category used by Gunter and colleagues. Thus, the overall absence of a meaning revision effect for ambiguous words in older adulthood may be related to an age-related decrease in working memory capacity (e.g., Park et al., 2002). Consistent with Gunter et al.'s (2003) finding that higher-resource participants were better able to revise their initial interpretation of ambiguous words when conflicting information was encountered, older adults in the present study with higher verbal fluency and better inhibition showed more evidence for revision-based LPC priming in the LVF/RH when subordinate-associated targets were presented following dominant-associated context words.

In some circumstances, older adults were actually more sensitive to context than young adults (Meyer and Federmeier, 2007; see also Stine-Morrow, Loveless, & Soederberg, 1996, and Swaab et al., 1998, 2003), failing to show N400 facilitation even in the concordant, biased context (unambiguous RR) condition. Context and target words in this condition were related to the same basic meaning sense of the prime, but may have highlighted different features of it (for example, the type of *chair* associated with a *couch* might be different from that associated with a *desk*). Whereas younger adults showed robust N400 and LPC priming in both hemispheres in the unambiguous RR conditions, in older adults LPC priming was limited to the LH (both strongly- and weakly-associated meanings). Thus, the LH is capable of meaning revision in older adulthood, although such revision may be limited to situations in which the conflicting sources of information do not point to disparate meanings. Older adults with better inhibitory control showed a tendency for more symmetrical LPC activation patterns for strongly-related targets in a weakly-biased context, again more similar to the pattern seen in young subjects. These findings of greater contextual sensitivity stand in contrast with evidence that older adults are less sensitive to sentence context information (e.g., Cameli and Phillips, 2000; Federmeier and Kutas, 2005). The increased demands on working memory that exist within a sentence processing task may be the cause of the discrepancy between such findings and those of the current set of studies, which involved a word triplet design. In support of this argument, Federmeier and Kutas (2005) found that the facilitating effect of a strongly-constraining context was more similar in young and higher-span older adults than in young and lower-span older adults.

Our results are thus consistent with behavioral work suggesting that the influence of biasing context information on automatic aspects of meaning activation is similar for older and younger adults (e.g., Balota and Duchek, 1991; Balota et al., 1999; Hopkins et al., 1995; Paul, 1996). Indeed, the results from the concordant condition suggest that older adults may actually constrain the set of meaning features they activate as a function of context even more than do younger adults (cf. Swaab et al., 1998; 2003). At the same time, however, our results also support the hypothesis that controlled meaning selection and revision processes

are compromised by age (cf. Faust et al., 1997; Gernsbacher et al., 1990). Older adults showed LPC priming to targets in concordant contexts only in the LH, whereas younger adults showed LPC priming in these conditions in both hemispheres. In discordant contexts, where younger adults again showed LPC priming in both hemispheres, older adults as a group showed no evidence of meaning revision. Higher functioning older adults showed a greater tendency for LPC priming than did lower functioning older adults, but only for subordinate targets. Interestingly, this pattern was seen only for the RH, providing additional evidence that the processing of subordinate meanings becomes increasingly right-lateralized with age.

In conclusion, then, consistent with general patterns observed in the literature on the cognitive neuroscience of aging (e.g., Cabeza, 2002; Greenwood, 2007), older adults showed a different pattern of hemispheric specialization from that seen in younger adults during meaning activation and revision. In particular, whereas young adults initially activated both dominant and subordinate (and strongly and weakly associated) information with the LH, older adults tended to distribute their processing across the two hemispheres. However, in the current study, this tendency for older adults to use both hemispheres was not a simple matter of dedifferentiation or compensation. Older adults with more processing resources showed bilateral processing of dominant (and unambiguous) information, but this does not seem to be the kind of “overactivation” that has been linked to compensation (e.g., Cabeza et al., 2002; Reuter-Lorenz et al., 2000), since young participants showed the same pattern. These higher functioning older adults then became more lateralized for the processing of subordinate information. In contrast, older adults with fewer processing resources showed a more focal, LH activation pattern in response to the dominant meaning, but showed a bilateral activation pattern for the subordinate meaning. Thus, bilateral activation patterns were linked to both higher *and* lower levels of functioning across conditions. Both groups of older adults were highly sensitive to context, using biasing context information to initially select the meaning of the ambiguous prime and even to constrain meaning activation for unambiguous words. However, consistent with the literature suggesting that aging negatively impacts executive processes (e.g., Craik, 1983; Hasher et al., 1991), older adults were less likely than younger adults to employ controlled processing to revise their initial meaning selections.

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Figure 1. Effect of Visual Field of prime presentation, by experiment version, at lateral occipital channels. The N100 was larger for primes presented in the contralateral visual field.

Figure 2.
Effect of Relatedness during the prime epoch, by experiment version, at a representative channel. Shading indicates a facilitation effect.

Figure 3. Effect of Relatedness during the target epoch, by Ambiguity condition, at a representative channel. Lighter shading indicates a facilitation effect in one context condition (UR or RR), while darker shading indicates that a facilitation effect is present in both context conditions.

Figure 4. Priming effects for the neutral (UR) condition during the target epoch. Bars represent standard error. Asterisks denote significant priming effects.

Table 1

Example Triplets

Experiment 1		
Condition	Ambiguous (Subordinate-Dominant)	Unambiguous (Weak-Strong)
Unrelated-Related (UR)	BOOM-BANK-DEPOSIT	SCRIPT-CHAIR-DESK
Related-Related (RR)	RIVER-BANK-DEPOSIT	COUCH-CHAIR-DESK
Unrelated-Unrelated (UU)	BOOM-BANK-NEW	SCRIPT-CHAIR-SINISTER
Related-Unrelated (RU)	RIVER-BANK-NEW	COUCH-CHAIR-SINISTER
Experiment 2		
Condition	Ambiguous (Dominant-Subordinate)	Unambiguous (Strong-Weak)
Unrelated-Related (UR)	SHUTTER-RULER-KING	FATE-DOOR-HANDLE
Related-Related (RR)	MEASURE-RULER-KING	WINDOW-DOOR-HANDLE
Unrelated-Unrelated (UU)	SHUTTER-RULER-BAIT	FATE-DOOR-WASP
Related-Unrelated (RU)	MEASURE-RULER-BAIT	WINDOW-DOOR-WASP

Table 2

Mean Stimulus Characteristics

Stimulus Type	Ambiguous					
	Concreteness	Imageability	Length	Syllables	Morphemes	Frequency
Prime	505 (86)	518 (67)	4.4 (1.0)	1.2 (.4)	1.0 (.2)	9.8 (1.5)
Dominant Related	507 (96)	542 (84)	5.2 (1.5)	1.5 (.7)	1.2 (.4)	9.1 (1.9)
Subordinate Related	508 (103)	519 (91)	5.7 (1.8)	1.7 (.7)	1.3 (.5)	9.1 (1.7)
Unrelated Context	495 (108)	503 (94)	5.6 (1.4)	1.7 (.6)	1.3 (.5)	8.9 (2.0)
Unrelated Target	463 (115)	487 (100)	5.1 (1.3)	1.5 (.6)	1.1 (.4)	8.9 (2.0)
						3422 (1700)
						3372 (1561)
						3414 (1528)
						4030 (1825)
						3691 (1797)
Stimulus Type	Unambiguous					
	Concreteness	Imageability	Length	Syllables	Morphemes	Frequency
Prime	514 (108)	551 (78)	4.8 (1.2)	1.3 (.5)	1.0 (.2)	10.3 (1.2)
Strongly Related	510 (103)	530 (77)	5.0 (1.3)	1.5 (.7)	1.1 (.3)	9.4 (1.5)
Weakly Related	502 (114)	525 (91)	5.1 (1.4)	1.4 (.6)	1.2 (.4)	9.6 (1.5)
Unrelated Context	478 (122)	499 (90)	5.5 (1.3)	1.6 (.7)	1.2 (.4)	9.0 (1.7)
Unrelated Target	495 (110)	516 (86)	5.7 (1.3)	1.7 (.7)	1.3 (.5)	8.8 (1.5)
						3222 (1739)
						3455 (1552)
						3665 (1594)
						3620 (1608)
						3853 (1637)

Standard deviations are in parentheses. *Orthographic N* refers to orthographic neighborhood. Concreteness and imageability ratings were obtained from Coltheart (1981); log frequency data are from Lund and Burgess (1996); values for other variables were obtained from Balota et al. (2007).

Table 3

Planned Comparisons (UU baseline), Dominant/Strong Targets

	Ambiguous				Unambiguous			
	RVF/LH		LVF/RH		RVF/LH		LVF/RH	
	<i>t</i> (19)	<i>p</i>	η^2	<i>t</i> (19)	<i>p</i>	η^2	<i>t</i> (19)	<i>p</i>
N400								
UR	3.00	<.01	.32	.59	.56	.02	3.45	<.01
							1.76	.09
RR	-.40	.70	.01	-1.16	.26	.07	1.32	.20
							.82	.42
LPC								
UR	3.34	<.01	.37	1.73	.10	.14	3.76	<.01
							1.68	.11
RR	1.04	.31	.05	.24	.81	.00	2.57	<.05
							.14	.89

UU = Unrelated context, Unrelated target; UR = Unrelated context, Related target; RR = Related context, Related target

Table 4

Planned Comparisons (UU baseline), Subordinate/Weak Targets

	Ambiguous				Unambiguous			
	RVF/LH		LVF/RH		RVF/LH		LVF/RH	
	<i>t</i> (19)	<i>p</i>	η^2	<i>t</i> (19)	<i>p</i>	η^2	<i>t</i> (19)	<i>p</i>
N400								
UR	1.65	.12	.13	2.11	<.05	.19	1.46	.16
RR	-.82	.42	.03	-1.90	.07	.16	.14	.88
LPC								
UR	3.38	<.01	.38	2.99	<.01	.32	3.45	<.01
RR	.10	.93	.00	-.10	.93	.00	2.22	<.05

UU = Unrelated context1, Unrelated target; UR = Unrelated context, Related target; RR = Related context, Related target