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Sounds, Words, Sentences: Age-Related Changes Across Levels of Language Processing

Kara D. Federmeier
University of Illinois at Urbana–Champaign

Cyma Van Petten
University of Arizona

Tanya J. Schwartz
Rehabilitation Hospital of the Pacific

Marta Kutas
University of California, San Diego

Age-related changes in sensory, lexical, and sentence processing were examined and compared using event-related potentials (ERPs) recorded as young and elderly participants listened to natural speech for comprehension. Lexically associated and unassociated word pairs were embedded in meaningful or syntactically legal but meaningless sentences. Early, general sensory, and attention-related responses (N1, P2) were delayed by about 25 ms for older participants, but later components indexing semantic processing (N400) were not delayed. There were no differences in the size, timing, or distribution of lexical associative effects for the two groups. In contrast, message-level context effects were delayed by more than 200 ms in the elderly group. The results support models that posit age-related changes primarily in higher order language processes.

The ability to comprehend language is clearly one of the most central to human life. The rapid and accurate appreciation of spoken (or signed) messages lies at the core of a person's ability to gain information from the environment, to perform everyday tasks, and to maintain normal social relations. And, although such comprehension often seems to proceed effortlessly, successful language comprehension is actually the result of a myriad of complex sensory and cognitive processes. The sensory stream must be analyzed, parsed into words, phrases, and clauses, and used to cue long-term semantic memory. At the same time, this information must be held and manipulated in working memory as the comprehender chooses between alternate meanings, establishes reference, builds up a message-level meaning representation, and calls up additional information from long-term memory for inference drawing as needed. Many, if not all, of these subprocesses are believed to be affected by changes that occur in the course of normal aging.

On the one hand, the underlying knowledge of words and their meanings—a core part of what is often referred to as *semantic memory*—seems to remain fairly stable (and may even be augmented) throughout adulthood (see review by Light, 1992). For example, older adults keep pace with, and sometimes even outperform, education-matched younger adults on standard vocabulary measures (Salthouse, 1993), suggesting that word-meaning information is well retained. Similarly, older adults are at least as accurate as younger ones at making speeded word/nonword judgments (lexical decision; e.g., Bowles & Poon, 1981, 1985; Howard, 1983). Furthermore, the nature and organization of this word-related information also seems to remain stable with age. When verbal abilities are matched, older adults generate word associations (Bowles, Williams, & Poon, 1983; Burke & Peters, 1986; Lovelace & Cooley, 1982; Scialfa & Margolis, 1986) and category exemplars (Howard, 1980) that are qualitatively similar to those of younger adults. Such associations are generally taken to reflect the strength of connections between items in semantic memory, suggesting that the organization of semantic information is similar for younger and older adults. Correspondingly, older adults' online performance, like that of younger adults, is facilitated in the presence of semantically related word information (semantic priming), as a function of associative strength (e.g., Balota & Duchek, 1988; Bowles, 1989; Burke, White, & Diaz, 1987; Howard, McAndrews, & Lasaga, 1981; Laver & Burke, 1993).

On the other hand, during real-time language processing this semantic information must be accessed and integrated at an extraordinary rate (i.e., ≥100 words/min for speech), and it is here that age-related changes become more apparent. Sensory thresholds increase with age, such that even the initial analysis of the sensory stream is likely to be delayed and/or more variable ("noisier") for older adults (see review by Olsho, Harkins, & Lenhardt, 1985, for auditory processing; see review by Kline & Schieber, 1985, for visual processing). Some data suggest that word recognition and/or lexical access may also be slowed or become more

Kara D. Federmeier, Department of Psychology, University of Illinois at Urbana–Champaign; Cyma Van Petten, Department of Psychology, University of Arizona; Tanya J. Schwartz, Department of Psychology, Rehabilitation Hospital of the Pacific, Honolulu, Hawaii; Marta Kutas, Department of Cognitive Science and Department of Neuroscience, University of California, San Diego.

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Correspondence concerning this article should be addressed to Marta Kutas, Department of Cognitive Science, University of California at San Diego, 9500 Gilman Drive, La Jolla, California 92093-0515. E-mail: mkutas@ucsd.edu

difficult with age (Balota & Duchek, 1988; Bowles & Poon, 1985), although other data argue against this (Bowles & Poon, 1981; Stern, Prather, Swinney, & Zurif, 1991). Perhaps in part because of slowed or noisier recognition processes, older adults seem to benefit more from contextual information. For example, whereas older adults show behavioral semantic priming effects that are qualitatively similar to those in younger adults, these facilitative effects seem to be somewhat larger in the older group (see meta-analyses by Laver & Burke, 1993; Myerson, Ferraro, Hale, & Lima, 1992). Furthermore, differences in semantic priming with age are seen in event-related brain potentials (ERP) studies looking at the N400, an electrophysiological component that has been closely linked to semantic processing (see review by Kutas & Federmeier, 2001; Kutas & Hillyard, 1980, 1984). The N400 is a central–posterior negativity, peaking around 400 ms, that is elicited in response to meaningful stimuli of all kinds (including spoken, signed, and written words). The neural generators of the N400 are not known in full, but an important part of the scalp-recorded activity seems to be coming from medial temporal lobe areas known to be important for long-term, semantic memory (McCarthy, Nobre, Bentin, & Spencer, 1995). The amplitude of the N400 is reduced when an item appears in a congruent context, be it a single word, a sentence, or a larger discourse. N400 responses have been found to decrease in amplitude and increase in latency with increasing age (Harbin, Marsh, & Harvey, 1984; Kutas & Iragui, 1998), and effects of semantic primes on the N400 are also delayed for older adults (Gunter, Jackson, & Mulder, 1998).

Whereas some data thus suggest that even early stages of word processing may be compromised during normal aging, more striking age-related changes are seen as tasks become more complex and demands on cognitive resources increase. For example, working memory spans have been found to decrease with age (Wingfield, Stine, Lahar, & Aberdeen, 1988), and such decreases in working memory capacity have been linked to age-related differences in various aspects of discourse processing (reviewed in Gunter, Jackson, & Mulder, 1995; Light & Albertson, 1993) and syntactic analysis (Kemper, 1986; Kemtes & Kemper, 1997; Kynette & Kemper, 1986; Light & Capps, 1986), although not all data support a strong link between verbal working memory span and age-related changes in language processing (e.g., Light & Anderson, 1985). In a different approach to working memory resources and aging, Hasher and Zacks (1988) argued that it is specifically the ability to inhibit irrelevant information that is compromised with age. Declines in inhibitory processing effectively reduce working memory capacity because inappropriate information is being maintained along with task-relevant information. In support of this, it has been found that older adults are more likely to maintain disconfirmed inferences (Hamm & Hasher, 1992; Hartman & Hasher, 1991); on the other hand, older adults do not seem to differ from younger ones in, for example, the time course with which they select appropriate meanings of words (Hopkins, Kellas, & Paul, 1995). Overall, though, several lines of research suggest that increased cognitive loads (of various kinds) may often disproportionately affect older adults' language comprehension.

In general, older adults' language processing seems to be most similar to that of younger adults when information is presented in a supportive context and when cognitive resources are not particularly taxed (e.g., Burke & Yee, 1984; Cohen & Faulkner, 1983; Madden, 1986, 1988). Even under such "ideal" circumstances, however, electrophysiological measures continue to reveal age-related differences. Decreases in N400 amplitude and increases in N400 peak latency have been found for words in sentence contexts in both the visual (Gunter, Jackson, & Mulder, 1992) and the auditory (Woodward, Ford, & Hammett, 1993) modalities. There have also been indications that older adults may achieve similar behavioral outcomes using different underlying processing strategies. For example, Hamberger, Friedman, Ritter, and Rosen (1995) found differences in the pattern of (visual) N400 responses in younger versus older participants to different types of sentence-final words in a sense-judgment task. Whereas younger participant's N400 responses were graded by both congruity with the sentence and semantic relatedness, older participant's N400 responses were facilitated only for the most expected completion. Hamberger et al. suggested that the older participants might have employed a different strategy for making the sense/nonsense classification, with any unexpected item classed as nonsensical.

Federmeier et al. (2002) also found age-related differences in the pattern of (auditory) N400 responses to words in sentence contexts (in addition to a general age-related reduction in N400 amplitude). In their study, participants listened for comprehension to sentence pairs (e.g., "They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of . . .") that ended with the expected completion ("palms"), an incongruent completion from the same semantic category ("pines"), or an incongruent completion outside the category ("tulips"). All participants elicited smaller N400s to congruent than to wholly incongruent completions. Young adults also elicited N400s of intermediate amplitude to incongruent words that came from the same semantic category, and this facilitation actually increased in more constraining contexts, counter to rated plausibility. This pattern suggests that young adults' sentence processing is predictive, such that the system actively prepares to process the semantic features of likely upcoming words. Older adults, however, showed much less overall facilitation for semantically related completions and did not show the constraint-based modulation observed with younger adults (although there were important individual differences), suggesting that predictive processing becomes less likely or less efficient with age. Thus, there seem to be age-related differences in online language comprehension even when word processing is supported by context and when processing demands are not particularly high.

Several classes of models have been put forward to explain age-related change in language processing. Generalized slowing models assume that older and younger adults process information in a qualitatively similar fashion, but due to global neurobiological changes (e.g., slowed neural transmission times, increased noise, weakened connections), older adults take longer than younger ones to process information at each stage (Cerella, 1985, 1990; Myerson, Hale, Wagstaff, & Poon, 1990; Salthouse, 1988). Differences in the magnitude of age-related change for verbal and nonverbal tasks (Lima, Hale, & Myerson, 1991) have led some to modify this hypothesis to apply only within a given processing domain (e.g., language). In contrast to generalized (or domain-specific) slowing, another set of models focused instead on the reduced availability of specific higher-order, cognitive processing resources with age. As already discussed, age-related changes in working memory function (e.g., Stine & Wingfield, 1987) and in inhibitory processing (Hasher & Zacks, 1988) have been put forward as explanations for aging effects on specific aspects of language processing. Crucially, such capacity models assume that age-related processing differences will be differentially observed across tasks/levels of processing, as a function of the extent to which the critical resource is tapped. Finally, there is the possibility that younger and older adults process language input in a qualitatively different fashion—whether as a conscious strategy choice or as an unconscious compensatory mechanism.

Data for and against all of these types of models have been put forward (see reviews by Light, 1991, and Perfect & Maylor, 2000); all remain viable candidates as explanations for age-related differences. Critical to evaluating such models is an understanding of the nature and degree of aging effects at various stages within a complex cognitive process like language comprehension. Are age-related changes ubiquitous across processing stages (as generalized models assume) or limited to higher-order aspects of processing? Do they arise only when resources are taxed (as in capacity models) or are they pervasive? Are the differences qualitative (indicative of a strategy change) or quantitative? Answering these questions has proven difficult, in part, because different types of materials and different kinds of tasks have generally been used to examine different aspects of processing. Ideally, one would like to examine age-related changes at multiple levels using a single set of materials and single task within the same set of participants.

To that end, in this experiment we record ERPs as younger and older individuals listen to sentences for comprehension. Because of the continuous nature and high temporal resolution of ERPs, we can examine processing as it unfolds in real time, from early sensory stages to higher-order, cognitive processing. In addition, our sentences are designed to allow for the simultaneous examination of lower-level lexical processing (i.e., effects of association) and higher-level context effects. At the message level, we use sentences that are either congruent (e.g., “She fixed the sticky drawer so that it opened and closed easily”) or syntactically legal but anomalous (e.g., “She occupied the tall pellet so that it opened and closed easily”). Half of each type of sentence context contains a lexically associated pair (e.g., “opened” and “closed” in this example), whereas the other half contains no strong lexical associates. A given sentence-intermediate critical word (e.g., “closed”), therefore, may be supported by lexical associative constraints, by message-level constraints, by both, or by neither. As already outlined, N400 amplitudes have been shown to be sensitive to both lexically based context information (such as word association) and message-level semantic constraints established at the sentence or discourse level. Thus, by examining the strength of the facilitation (i.e., N400 amplitude reduction) afforded by lexical and message-level cues—and the time course of any such effects—we can uncover whether the influences of lexical and sentence-level context information on word processing change with age, and, if so, to what extent. These effects can also be differentiated by their sensitivity to distance (number of words intervening between the critical pair), as lexical effects tend to dissipate with increased separation between associates (e.g., Foss, 1982; Simpson, Peterson, Casteel, & Burgess, 1989), whereas sentential effects build as successive words add increasing message-level constraints (e.g., Van Petten & Kutas, 1990). Generalized slowing models tend to predict age-related changes in all aspects of functioning, whereas models positing a loss of specific, higher-order resources tend to predict changes in message-level processing accompanied by relatively preserved lexical associative effects.

Other parts of the sentence can also be measured to examine changes in sensory and attentional processing (that might be correlated with changes in lexical or semantic processing) and to look further at message-level context effects. Auditory stimuli of all kinds elicit a characteristic set of sensory components, including a negative deflection at approximately 100-ms poststimulus onset (N1), followed by a positive deflection at approximately 200 ms (P2). These deflections can be seen over both frontal and posterior sites, although with somewhat different timing and response characteristics. The frontal part of the N1, for example, occurs earlier and has been linked to auditory cortex activity, whereas the posterior part of the N1 has been linked to activity in auditory association cortex in the superior temporal gyrus (e.g., Liegeois-Chauvel, Musolino, Badier, Marquis, & Chauvel, 1994). Both N1 and P2 amplitudes are modulated by physical characteristics of stimuli and attention, with larger amplitudes for stimuli within the focus of attention. We will examine these components at the sentence-initial word, before they become refractory (due to continuous auditory stimulation as the sentence unfolds), looking for nonspecific age-related delays in sensory and attentional processing. These sentence-initial words will also elicit an N400, and we will therefore also measure its latency to determine whether any delays in earlier, sensory components will carry over to the processes that the N400 indexes (i.e., the access and integration of semantic information). We also will measure N400 responses to sentence-final words as an additional means of assessing age-related changes in message-level semantic processing. In congruent sentences, N400 amplitudes decrease with word position as message-level constraints build (Van Petten & Kutas, 1990). One can thus use N400 responses to the final words of congruent and anomalous sentences as a measure of sensitivity to message-level context; insofar as participants are using the ongoing context to build the message-level representation, N400 amplitude should be smaller at the end of congruent than anomalous sentences. Across this set of measures, therefore, we can compare sensory, lexical, and message-level processing by younger and older adults within a single, ecologically valid paradigm, with the aim of determining the type and extent of age-related changes in language comprehension.

Method

Materials

Stimulus materials consisted of auditory versions of the sentences originally used by Van Petten (1993) to examine lexical and sentential context effects during reading. Four types of sentences were used, each containing a critical pair of words (see Table 1 for examples).

A total of 120 congruent associated (CA) sentences contained a lexically associated word pair embedded within a syntactically and semantically congruent sentence. Both words in the pair occurred in sentence-intermediate positions, and the distance between the words varied, with 59 close pairs (0–1 intervening word) and 61 distant pairs (2–14 intervening words, $M = 4.8$). A corresponding set of 120 congruent unassociated (CU) sentences contained a lexically unassociated critical pair. Sentences were matched in length to the CA ones and the critical pairs were matched for word class, word frequency (Francis & Kučera, 1982), word length, sen-

Table 1
Examples of the Four Sentence Types (Critical Words Underscored)

Sentence type	Example
Congruent associated	
Near pair	She fixed the sticky drawer so that it opened and closed easily.
Distant pair	After taking his wallet, they waved a gun and threatened to shoot him if he reported it.
Congruent unassociated	
Near pair	As soon as they reached the sand he stopped to take off his shoes.
Distant pair	The mill worker caught his hand in a piece of machinery and was immediately rushed to the hospital.
Anomalous associated	
Near pair	She occupied the tall pellet so that it opened and closed easily.
Distant pair	After trying his Chinese they irritated a gun and expected to shoot him if he clipped it.
Anomalous unassociated	
Near pair	As soon as they decided the sand he stopped to break off his name.
Distant pair	The young shoes took their promotion in a discussion of machinery and were immediately rushed to the aliens.

tence position, and the number and class of words intervening between the pair. Congruent sentences of both types were written to minimize lexical association among noncritical words and between noncritical and critical words. Thus, the second word of a CU pair would be subject to message-level constraints, but not to lexical association.

Anomalous Associated (AA) and Anomalous Unassociated (AU) sentences (120 each) were derived from the corresponding congruent sentences by replacing all of the open class words in that sentence, except the critical pair, with words from other sentences. These sentences were thus syntactically legal but semantically anomalous, and contained the same critical word pairs in the same positions with the same number and class of intervening words. The second critical word in AA sentences would thus be subject to lexical association without message-level constraints. In contrast, second words in AU sentences are subject to neither lexical nor message-level constraints, and, as expected, Van Petten (1993) found no difference in the ERP response to first and second critical words in these contexts. The AU condition can thus be regarded as a neutral or baseline condition.

Sentences ranged between 8 and 22 words in length ($M = 14.2$). They were recorded as natural speech by an adult male volunteer and then digitized with "Wave for Windows." Combined visual and auditory inspection was used to determine word onset for sentence-initial words, sentence-final words, and both words of each critical pair. Sentences were divided into two lists, made up of half of the stimuli (60) from each condition (CA, CU, AA, AU). Critical word pairs were not repeated within a list. Sentences were randomized once within each list and then presented in the same order to all participants.

Participants

Twenty young (7 men, 13 women; 18–28 years old, $M = 22$) and 20 elderly (10 men, 10 women; 57–79 years old, $M = 72$) native English-speaking volunteers were recruited from the local area and paid for their participation. All of the young participants were right-handed (Oldfield, 1971; 6 reported left-handed family members). Nineteen of the elderly participants were right-handed (7 reported left-handed family members), and 1 was left-handed. All participants were in good health and none had a history of psychiatric or neurological disorders. Both young and elderly participants had 12 to 20 years of education ($M = 15$ years).

All participants reported their hearing to be normal. As additional insurance that differences in hearing ability would not confound the experimental effects, each participant's hearing was tested at the beginning of the first session. Tones of varied frequency (113, 200, and 2000 Hz) were randomly presented to each participant via speakers and the decibel level was increased until a threshold of 50% detection accuracy was determined. The sound level for the experiment was then set at 50 dB above this threshold. Mean overall threshold did not differ between young and elderly participants, $F(1, 38) = 0.90$, $p = .35$. Four elderly participants showed possible indications of some high-frequency hearing loss, as they had thresholds for the 2000 Hz stimuli that were higher than the thresholds for these stimuli obtained for any of the young participants in the sample.

Procedure

Each participant was tested in two sessions (each approximately 2 hr), spaced at least 1 week apart. Order of presentation of the two stimulus lists was counterbalanced across participants. Participants were seated 3 ft (0.9 m) in front of a computer monitor with speakers to either side of the monitor. They were asked to focus their eyes on a central fixation circle while listening to the experimental sentences for comprehension.[1] Sentences were presented with a 5.8-s intersentence interval. A 20-sentence practice trial preceded the experimental trials, and participants were given a rest period after every 20 sentences.

The participants' task was to listen carefully to each sentence and to judge whether or not it made sense. Participants indicated their sense judgment at the end of each sentence with a button press. They were instructed to be as accurate as possible, but were not asked to respond quickly. Assignment of the left or right hand to represent *yes* or *no* was counterbalanced across participants.

Electrophysiological Recording

The electroencephalogram (EEG) was recorded from 15 tin electrodes embedded in an Electro-Cap. Scalp sites included International 10-20 System locations over the frontal (Fz), central (Cz), and parietal (Pz) midline and lateral pairs of electrodes over frontal (F7, F8), temporal (T5, T6), and occipital (O1, O2) areas. Three additional pairs of electrodes were used: a frontal pair (Bl, Br) placed midway between F7, F8 and T3, T4 (approximately over Broca's area and its right-hemisphere homologue), a temporoparietal pair (Wl, Wr) placed 30% of the interaural distance laterally and 12.5% of the inion–nasion distance posterior to Cz (approximately over Wernicke's area and its right-hemisphere homologue), and a central pair (L41, R41) placed 33% lateral to Cz (approximately over primary auditory cortex). Electrodes were referenced online to the left mastoid and re-referenced off-line to the average of the left and right mastoids. Eye movements and blinks were monitored via an electrode placed below the infraorbital ridge of the right eye and a bipolar recording from electrodes placed on the outer canthus of each eye.

The EEG was amplified through Nicolet amplifiers (bandpass = 0.02–100 Hz), continuously digitized at 167 Hz, and stored on hard disk for subsequent analysis. Trials contaminated with eye movements, muscle activity, or amplifier-blocking artifacts were rejected off-line prior to averaging. Eye blinks were rejected when these were rare, or, in the data of 8 young and 8 elderly participants where they were more frequent, were

[1] Participants were asked to keep their eyes open during the experiment because involuntary eye movements increase when the eyes are kept closed.

corrected using a spatial filter algorithm developed by Dale (1994). For young participants, an average of 5% of the trials was lost to artifacts across the various conditions. Elderly participants had more difficulty inhibiting horizontal eye movements, and therefore more artifacts (an average of 10%) were lost across conditions for this group. ERPs were bandpass filtered from 0.1 to 8 Hz prior to statistical analyses.

Results

Response Accuracy

The goal of the behavioral sense-judgment task was to ensure that participants remained focused on the meaning of the sentences throughout the experiment. Responses were to be given at the end of each sentence, well beyond the point (generally within only a few words) that it would first have been possible to determine whether or not the sentences made sense. Participants were therefore instructed to respond accurately, not quickly, and reaction times were not analyzed. Overall, as expected, accuracy to classify the sentences as sensible or not sensible was very high (M = 98.8%), indicating that participants were attending to meaning. Accuracy data were subjected to an omnibus analysis of variance (ANOVA) with group (young vs. elderly) as the between-subjects variable, and sentence type (congruent vs. anomalous) and lexical association (associated vs. unassociated; here referring to the prior presence or absence of a strongly lexically associated pair) as within-subjects variables.

The main effect of group was not significant, although there was a marginal trend, $F(1, 38) = 3.96$, $p = .07$, for more accurate responding by elderly (M = 99.1%) than by young (M = 98.5%) participants. There were significant main effects of both sentence type, $F(1, 38) = 12.04$, $p < .01$, and lexical association, $F(1, 38) = 25.83$, $p < .001$, with more accurate responses to congruent (99.2%) than to anomalous (98.3%) sentences (i.e., participants were more accurate to respond "sensible" than to respond "not sensible") and to sentences with a lexical associate (99.1%) than those without (98.4%). These main effects were modulated by an interaction between sentence type and lexical association, $F(1, 38) = 29.15$, $p < .001$. Association did not affect accuracy of responses in congruent sentences (99.2% with an associated pair vs. 99.3% without), but did affect responses to incongruent sentences (99.0% with an associated pair vs. 97.6% without). There were no interactions of any of these effects with group. As expected, therefore, participants found these judgments relatively easy, and older participants were no less (and perhaps slightly more) accurate than younger ones.

ERPs to Sentence-Initial Words

ERP responses to sentence-initial words were first examined to look for age-related changes in the size and/or time course of the N1, P2, and N400 components. Figure 1 shows these responses for young and elderly participants at a representative subset of the analyzed channels over frontal, central, and posterior scalp locations. Responses over all channels in both groups were characterized by a negativity peaking around 100 ms (N1), followed by a positivity peaking around 225 ms (P2). As discussed previously, the N1 and P2 have been linked to nonlanguage-specific processing in primary and secondary auditory areas; age-related differences in these components would thus indicate general changes in

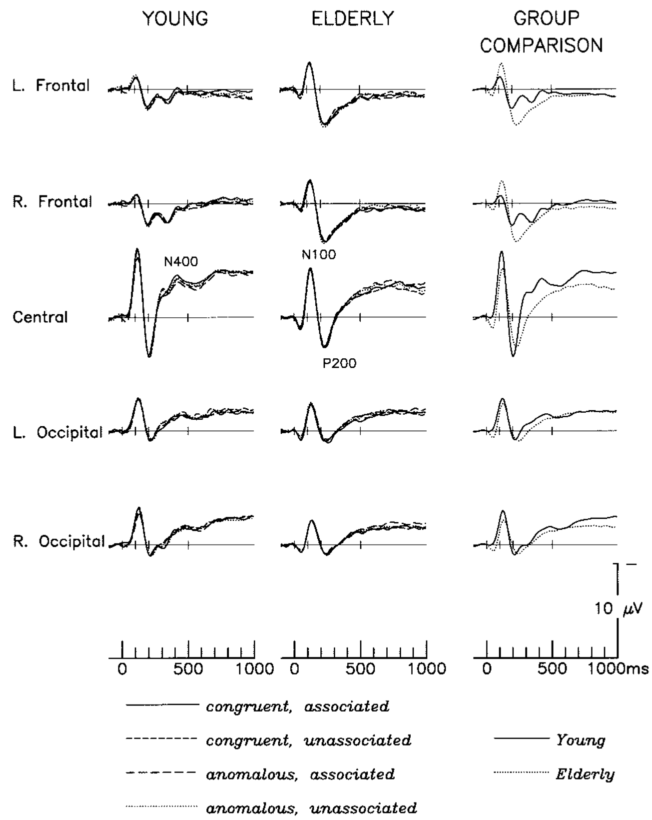

Figure 1. Sentence-initial words. Plotted are the ERP responses to sentence-initial words at five representative electrodes: two frontal (F7, F8), a central (Cz), and two occipital (O1, O2) channels. Negative is plotted up in this and all subsequent plots. The first two columns show first-word ERPs for young and elderly participants, respectively, across the four experimental conditions. The two groups' responses (collapsed across conditions) are overlaid in the third column. Aging was associated with both delays and distributional changes in early sensory components (N1, P2). L = Left; R = Right.

sensory and/or attentional processing. These sensory components are then followed in both groups by a sustained negativity, which includes the N400. By examining the N400 response at this point, before lexical and message-level context information is available, one can determine whether changes observed on the earlier components carry over to affect access to semantic memory.

Peak amplitude measures (collapsed across conditions) were taken from 0–150 ms (N1) and 150–300 ms (P2) over seven frontal (Fz, F7, F8, Bl, Br, L41, R41) and eight posterior (Cz, Pz, T5, T6, Wl, Wr, O1, O2) electrode channels. We examine the frontal and posterior aspects of the N1 and P2 separately because they have slightly different time courses and have been linked to different brain areas and different processes. Peak amplitude measures were also taken from 300–500 ms over the eight posterior channels where N400 responses are typically most prominent. These measures were subjected to an omnibus ANOVA with two levels of group (young vs. elderly; between-subjects variable) and seven or eight levels of electrode (within-subjects variable); note that p values in this and all subsequent analyses are reported after Hyunh–Felt correction for repeated measures with more than 1 degree of freedom.

Young participants had larger N1 responses over the back of the head (−4.0 vs. −2.8 μV), $F(1, 38) = 6.59$, $p = .01$. In contrast, N1 amplitudes did not differ over frontal sites, $F(1, 38) = 1.73$, $p = .20$, with the tendency now going in the opposite direction (smaller responses from young participants: −2.4 vs. −3.2 μV). P2 amplitudes did not differ between the groups over the back of the head (1.2 and 0.8 μV), $F(1, 38) = 0.51$, $p = .48$. There was a marginal trend for the young participants to have smaller frontal P2 responses (3.1 vs. 4.0 μV), $F(1, 38) = 3.18$, $p = .08$, particularly over the most anterior sites: group by electrode interaction, $F(6, 228) = 4.23$, $p < .01$. N400 amplitudes were reduced for elderly (−1.2 μV) as compared with young (−1.9 μV) participants over central channels where N400 effects are typically more prominent, $F(7, 266) = 3.76$, $p = .03$.

Peak latency measures were also taken from 0–150 ms (N1) and 150–300 ms (P2) at the midline frontal channel (Fz) and the midline posterior channel (Pz) and from 300–500 ms (N400) at the midline posterior channel. These measures were subjected to an omnibus ANOVA with two levels of group (young vs. elderly). Whereas the latency of the posterior (Pz) N1 response did not differ between the groups (120 and 124 ms for young and elderly, respectively), $F(1, 38) = 1.09$, $p = .30$, all other sensory component measures were delayed in the elderly relative to the young participants. Average peak N1 latency at Fz was 110 ms for the young group and 124 ms for the elderly group, $F(1, 38) = 4.75$, $p = .04$. Average peak P2 latencies for young and elderly participants were 213 and 236 ms posteriorly, $F(1, 38) = 10.82$, $p < .01$, and 216 and 239 ms frontally, $F(1, 38) = 9.57$, $p < .01$. Peak latency in the N400 time window, however, did not differ between the two groups (411 vs. 412 ms for young and elderly groups, respectively), $F(1, 38) = 0.86$, $p = .36$.

Overall, analyses on sentence-initial words revealed some age-related changes in sensory processing. The distribution of N1 and P2 effects became more frontally shifted with age, and the peak latencies of these components were delayed in the older group by about 25 ms. Although N400 amplitudes were also decreased overall with age, the peak latency delays observed for the sensory components were not carried into the N400 region.

Sentence-Final Words

N400 responses to sentence-final words were measured in order to look at the buildup of message-level semantic constraints over the course of the sentence, as described previously. Figure 2 shows these responses across sentence types (CA, CU, AA, AU) for young and elderly participants at a representative subset of posterior electrodes. Both groups display negativity between 200 and roughly 600 ms (N400) that is greater for final words in the anomalous than in the congruent sentences (although this pattern is reversed for the elderly participants over frontal, particularly right frontal, sites). This negativity is followed in both groups by a positivity, which, in the young, is more pronounced for the anomalous than the congruent condition. The functional significance of this late positive complex (LPC) is not yet clear. To look at age-related differences in the effects of context on sentence processing, we compared mean amplitude and peak latency of the N400 and mean amplitude of the late positive complex (LPC) across the four conditions in the two groups.

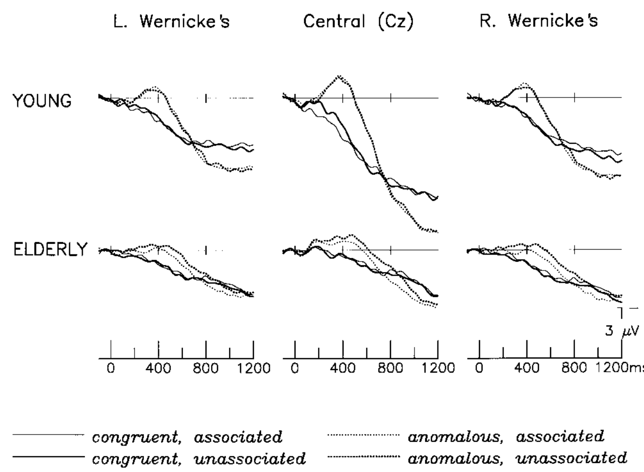

Figure 2. Sentence-final words. Plotted are the ERP responses to sentence-final words for the four experimental conditions at three representative medial–central channels where N400 effects are typically prominent. These are a subset of the channels used for statistical analyses. Both groups showed larger N400 responses to words in anomalous as compared with congruent sentences. This difference was larger for young participants, but did not alter in timing as a function of age. Young participants also showed a late positivity to words in anomalous contexts that was not observed for elderly participants. L = Left; R = Right.

To examine N400 responses to the final words, we measured mean amplitudes between 200 and 500 ms at the eight more posterior channels, and we subjected them to an omnibus ANOVA with two levels of group (young vs. elderly), two levels of sentence type (congruent vs. anomalous), two levels of lexical association (associated vs. unassociated, here referring to the prior presence or absence in the sentence of a strongly lexically associated pair), and eight levels of electrode. Although there was no main effect of group (overall amplitude 0.0 vs. −0.1 μV for young and elderly, respectively), $F(1, 38) = 1.14$, $p = .29$, there was a main effect of sentence type, $F(1, 38) = 92.11$, $p < .001$, and a group by sentence type interaction, $F(1, 38) = 15.88$, $p < .001$. Both groups showed more negativity to sentence-final words in anomalous than in congruent sentences. However, young participants' responses to the two sentence types were more differentiated: They had more negative responses than did elderly participants to the anomalous sentence endings (−0.63 vs. −0.42 μV) and more positive responses to the congruent sentence endings (0.68 vs. 0.12 μV). These differences were most prominent at more medial sites, where N400 effects are typically larger: sentence type by electrode interaction, $F(7, 266) = 17.77$, $p < .001$; group by sentence type by electrode interaction, $F(7, 266) = 6.85$, $p < .001$.[2] Peak latency of the N400 was compared across groups (at electrode Pz) using the two anomalous sentence conditions. Peak N400 latency was

[2] There was also a trend toward more negative responses to sentence-final targets in conditions that contained an unassociated pair relative to those with an associated pair: marginal main effect of lexical association, $F(1, 38) = 2.85$, $p = .10$, particularly for anomalous sentences in the elderly group; marginal group by sentence type by lexical association interaction, $F(1, 38) = 2.39$, $p = .13$.

Table 2
Analysis of Variance Outcomes for Factorial Analysis at Five Time Windows (all Electrode Sites)

		Time window (ms)				
Source	*df*	0–200	200–400	400–600	600–800	800–1,000
Sentence Type	1, 38			*	*	*
Sentence × Electrode	14, 532		*	**	**	**
Lexical association	1, 38			**	**	*
Lexical × Electrode	14, 532	*	**	**	**	$p = .06$
Sentence × Lexical	1, 38					*
Sentence × Lexical × Electrode	14, 532				**	**
Group	1, 38				$p = .09$	$p = .07$
Group × Sentence	1, 38	*				
Group × Sentence × Electrode	14, 532	**	**			
Group × Lexical	1, 38	*				
Group × Lexical × Electrode	14, 532		*			
Group × Sentence × Lexical	1, 38					
Group × Sentence × Lexical × Electrode	14, 532			*	**	

* $p < .05$. ** $p < .01$.

370 ms for the young and 368 ms for the elderly participants; these latencies did not differ, $F(1, 38) = 0.01$, $p = .93$.

The same analysis was applied to the mean LPC response, measured between 600–1200 ms at the eight posterior channels. There was a main effect of group, $F(1, 38) = 23.19$, $p < .001$, a main effect of sentence type, $F(1, 38) = 13.88$, $p < .001$, and a group by sentence type interaction, $F(1, 38) = 4.83$, $p = .03$. Overall, young participants displayed more positive responses in this time window (3.1 μV) than did elderly participants (1.1 μV), and responses were more positive in anomalous (2.4 μV) than in congruent (1.8 μV) sentence contexts [particularly over more medial sites: sentence type by electrode interaction, $F(7, 266) = 3.70$, $p < .01$]. However, whereas responses in the elderly group were fairly similar as a function of sentence type (1.20 and 0.99 μV in anomalous and congruent, respectively), responses in the young group were more positive in anomalous (3.56 μV) than in congruent (2.71 μV) sentence contexts. There was also a significant sentence type by association interaction, $F(1, 38) = 6.13$, $p = .02$. For congruent sentences, more positive responses were elicited following an unassociated pair, whereas for anomalous sentences, more positive responses were elicited following an associated pair.

In summary, N400 responses to sentence-final words revealed that both young and elderly participants are sensitive to message-level context effects, as both groups had increased N400 responses to the final word of anomalous versus congruent sentences. N400 effects were smaller overall in the elderly group, but peak latency of the N400 was not prolonged with age. Young adults manifested an additional ERP effect of context in the form of increased LPC to final words in anomalous as compared with congruent sentence contexts. Elderly adults, in contrast, did not show LPC differences as a function of sentence type.

Critical Pairs

To compare the effects of lexical and sentential context information on word processing in the two age groups, the ERP response to the second word of the critical word pairs was analyzed in 200-ms time windows from 0- to 1,000-ms poststimulus onset. In each time window (0–200 ms, 200–400 ms, 400–600 ms, 600–800 ms, 800–1,000 ms), data were subjected to an omnibus ANOVA with two levels of group (young vs. elderly), two levels of sentence type (congruent vs. anomalous), two levels of lexical association (associated vs. unassociated), and 15 levels of electrode (see Table 2 for the results). Effects of lexical association were apparent over at least some electrode sites from the earliest time window and continued throughout the epoch. Effects of sentence type began slightly later (although sentence type interacted with group in the earliest time window) and also continued throughout the epoch. Group interacted with both effects in some form beginning in the earliest time window and continuing through 800 ms.

Planned comparisons (as in Van Petten, Weckerly, McIsaac, & Kutas, 1997) were then conducted to reveal the nature and timing of lexical and sentential context effects, respectively, as a function of age group. Recall that critical words may be subject to lexical influences alone (AA), to message-level effects alone (CU), to both types of contextual effects (CA), or to neither (AU; baseline condition). Comparisons were done for all time windows in which a significant interaction of group with experimental variables was observed in the factorial analysis (0–200 ms, 200–400 ms, 400–600 ms, 600–800 ms). These comparisons were first conducted on all critical pairs and then as a function of distance between the prime and target words.

Lexical context effects. The effects of lexical context were examined by comparing the response to the second critical words in anomalous sentences as a function of whether or not they were preceded by a lexical associate.[3] Figure 3 shows these responses at a representative subset of electrodes. In both groups, critical words

[3] Note that the analogous comparison within congruent sentence contexts is more difficult to interpret because it is not possible to unambiguously disentangle the contribution of lexical context from the contribution of message-level effects (which could differ between CA and CU sentences; Van Petten, 1993).

preceded by a lexical associate elicited less negative responses over posterior channels beginning in the first 200 ms and continuing throughout the epoch. Mean amplitude responses were examined in 200-ms time windows from 0–800 ms, using an omnibus ANOVA with two levels of group (young vs. elderly), two levels of lexical association (associated vs. unassociated), and eight levels of electrode (eight posterior channels). Lexical association affected the ERP response in all (marginally in one) time windows: 0–200 ms, $F(1, 38) = 4.71$, $p = .04$; 200–400 ms, $F(1, 38) = 3.09$, $p = .09$; 400–600 ms, $F(1, 38) = 20.24$, $p < .001$; 600–800 ms, $F(1, 38) = 27.60$, $p < .001$. However, there were no interactions with group in any time window, suggesting that the effects of lexical context are statistically similar in size and timing for elderly as for young participants.

Figure 4 plots the lexical context effect as a function of the distance between the words in the critical pairs: Close pairs were separated by fewer than two words whereas distant pairs were separated by an average of five intervening words. As was true for visual word reading in Van Petten et al. (1997), effects of lexical context are more evident for close than for distant pairs; this holds for both age groups. Because overall effects were qualitatively similar across all time windows, these were combined and mean amplitude responses from 0–800 ms were subjected to an omnibus ANOVA on two levels of group (young vs. elderly), two levels of distance (close vs. distant pairs), two levels of lexical association (associated vs. unassociated), and eight levels of electrode. Although there was no main effect of distance, $F(1, 38) = 1.04$, $p = .32$, there was a main effect of association, $F(1, 38) = 16.16$, $p < .001$, and a distance by association interaction, $F(1, 38) = 19.21$, $p < .001$. Group did not interact with any variable. Planned comparisons within each age group revealed that for both groups lexical context effects were significant for close pairs [young (0.76 μV difference), $F(1, 19) = 16.35$, $p < .001$, and elderly (0.77 μV difference), $F(1, 19) = 14.48$, $p < .01$] but not for distant pairs [young (0.25 μV difference), $F(1, 19) = 1.52$, $p = .23$, and elderly (0.07 μV difference), $F(1, 19) = 0.21$, $p = .65$].

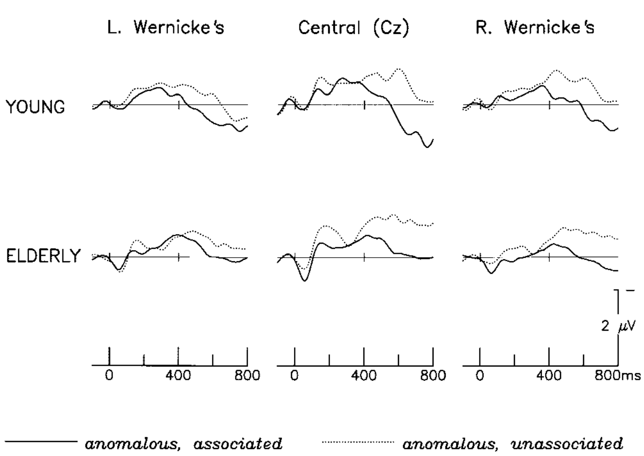

Figure 3. Lexical context effects. Plotted, at three representative channels, are the responses (in anomalous contexts) to lexically associated and unassociated second words in the critical word pairs. Both groups showed reduced N400 responses to associated words beginning in the first 200 ms after word presentation and continuing through 800 ms. These lexical context effects did not differ in size, timing, or distribution as a function of age. L = Left; R = Right.

Figure 4. Lexical context effects as a function of distance. Shown is a bar plot of the mean amplitude difference (0–800 ms) in the ERP response (across the eight posterior channels) to unassociated and associated words, as a function of their proximity in the (anomalous) sentences. A larger bar indicates a larger N400 reduction as a function of lexical association. For both young and elderly participants, significant N400 effects of lexical association were observed only within close pairs (0–1 intervening words) and not within distant pairs (>1 intervening word).

Sentential context effects. The effects of sentence context were examined by comparing the response to first and second critical words when these were embedded in meaningful (congruent) contexts (both CA and CU) as opposed to syntactically legal but meaningless (anomalous) contexts (both AA and AU), collapsed across association. The buildup of message-level constraints should result in a larger difference between first and second critical words in congruent as compared with anomalous sentences (in other words, a congruency by word position interaction). Previous studies with these materials have found that first–second word comparisons yield similar patterns of results as comparing second critical words directly across conditions (Van Petten, 1993; Van Petten et al., 1997); however, comparing trajectories within conditions is more robust to possible confounds from generalized slow potential differences across sentence types or groups. Figure 5 shows these comparisons for the two groups at a representative subset of electrodes; they are somewhat broader in distribution than the lexical level effects, encompassing more frontal (particularly right frontal) electrode sites. Effects were examined in 200-ms time windows from 0–800 ms, using an omnibus ANOVA with two levels of group (young vs. elderly), two levels of sentence type (congruent vs. anomalous), two levels of word position (first critical word vs. second critical word), and 15 levels of electrode, followed by planned comparisons.

Between 0–200 ms there were effects of both sentence type, $F(1, 38) = 7.47$, $p < .01$, and word position (at some electrode sites), $F(14, 532) = 5.64$, $p < .001$, with more positive responses in anomalous than in congruent sentences, and more positive responses to second than to first critical words. These effects were modulated by a group by sentence type by electrode interaction, $F(14, 532) = 2.99$, $p < .05$ (elderly participants showing greater overall positivity in anomalous sentences), and a marginal group by sentence type by word position by electrode interaction, $F(14, 532) = 2.24$, $p = .07$. Follow-up comparisons revealed no word position effects for the elderly group in either anomalous (word

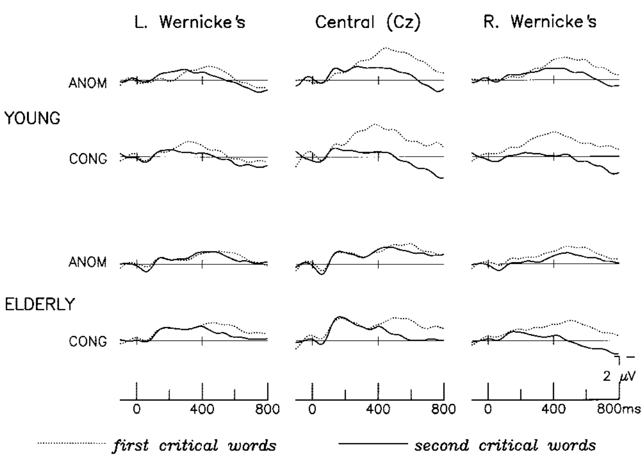

Figure 5. Sentential context effects. Plotted, at three representative channels, are the responses to first and second critical words in anomalous (ANOM) and congruent (CONG) sentence contexts (collapsed across association). Whereas both groups showed some N400 reduction to second critical words in anomalous sentences, both groups also showed an augmented effect in congruent sentences, indicative of the buildup of sentence message-level information. These effects, however, began within the first 200–400 ms for young participants, but not until after 400 ms for elderly participants. L = Left; R = Right.

position difference of 0.07 μV), $F(1, 19) = 1.56$, $p = .23$, or congruent (difference of 0.03 μV), $F(1, 19) = 0.24$, $p = .63$, sentence contexts. For the young group, there were no word position effects in anomalous sentences (word position difference of −0.06 μV), $F(1, 19) = 0.72$, $p = .41$, but there were differences over some electrode sites in congruent sentences, $F(14, 266) = 5.40$, $p < .001$, with responses more positive to second critical words. To examine this effect as a function of pair distance, an omnibus ANOVA was run with two levels of distance (close vs. distant pairs), two levels of word position (first critical word vs. second critical word) and 15 levels of electrode. Distance and word position interacted, $F(1, 19) = 6.26$, $p < .05$: Responses were more positive to second than to first critical words in close pairs (word position difference of 0.27 μV), $F(1, 19) = 7.48$, $p < .05$, but did not differ in far pairs (−0.04 μV), $F(1, 19) = 0.16$, $p = .70$. Figure 6 plots the distance effects.

The same pattern of effects continued in the 200- to 400-ms time window. There was a main effect of word position, $F(1, 38) = 6.59$, $p < .05$ (more positive responses to second than to first critical words), and a group by sentence type by electrode interaction, $F(14, 532) = 3.89$, $p < .01$ (elderly participants continuing to show an increased positivity in anomalous sentences). These were modulated by a sentence type by word position interaction, $F(1, 38) = 6.03$, $p < .05$, and a marginal group by sentence type by word position interaction, $F(1, 38) = 3.48$, $p = .07$. Planned comparisons again revealed no word position effects for the elderly group in either anomalous (word position difference of 0.03 μV), $F(1, 19) = 0.22$, $p = .64$, or congruent (0.08 μV), $F(1, 19) = 0.76$, $p = .40$, sentences. For young participants, there were again no effects of word position in anomalous sentences (0.02 μV), $F(1, 19) = 0.03$, $p = .86$, but there were effects in congruent sentences (0.42 μV), $F(1, 19) = 16.46$, $p < .001$, with more positive responses to second than to first critical words. Again, an analysis of the influence of pair distance on this effect revealed a distance by word position interaction, $F(1, 19) = 16.03$, $p < .001$, with a word position difference only within close pairs (word position difference of 0.71 μV), $F(1, 19) = 28.53$, $p < .001$, and not distant pairs (0.11 μV), $F(1, 19) = 0.72$, $p = .41$.

Effect patterns changed in the 400- to 600-ms time window. There was again a main effect of word position, $F(1, 38) = 24.78$, $p < .001$, and an effect of sentence type at some electrodes, $F(14, 532) = 7.18$, $p < .001$, which showed the same interaction with group as in previous time windows, $F(14, 532) = 3.63$, $p < .01$. Sentence type and word position interacted at some electrode sites, $F(14, 532) = 3.80$, $p < .01$, but this effect did not interact with group. For both groups, responses were more positive to second critical words within both sentence types, with a larger difference in the congruent sentences (−0.60 μV for first critical words and −0.14 μV for second critical words) than in the anomalous (−0.61 μV vs. −0.35 μV). For anomalous sentences, an analysis of group (young vs. elderly), distance (close vs. distant pairs), word position (first vs. second critical words), and electrode revealed a group by distance interaction, $F(1, 19) = 3.98$, $p = .05$, with more positive responses overall to critical words in close than in distant pairs for the young participants. The word position difference, however, was not influenced by distance between the pairs, $F(1, 38) = 0.05$, $p = .82$, and there were no interactions of this effect with group. For congruent sentences there was a distance by word position interaction, $F(1, 38) = 8.20$, $p < .01$, with larger response differences between first and second critical words in close pairs (−0.60 vs. 0.05 μV), $F(1, 38) = 28.41$, $p < .001$, than in distant pairs (−0.60 vs. −0.34 μV), $F(1, 38) = 7.46$, $p < .01$. There were no effects of group.

A very similar pattern of effects was found in the 600- to 800-ms time window. There was a main effect of word position, $F(1, 38) = 28.81$, $p < .001$, and an effect of sentence type at some electrode sites, $F(14, 532) = 9.79$, $p < .001$ (the group by sentence type by electrode interaction observed in previous time windows was marginal in this window). These effects interacted, $F(1, 38) = 4.19$, $p < .05$, but again did not interact with group. For both groups, responses were again more positive to second critical words within both sentence types, with a larger difference in congruent sentences (−0.38 μV vs. 0.18 μV) than in anomalous ones (−0.36 μV vs. −0.06 μV). As in the previous time window, for anomalous sentences, this word position difference was not influenced by distance between the pairs, $F(1, 38) = 0.00$, $p = .95$, although there was the same group by distance interaction, $F(14, 532) = 2.42$, $p < .05$, as in the previous time window. In this time window, there also was no distance by word position interaction for the congruent sentences, $F(1, 38) = 1.69$, $p = .20$, with effect sizes now somewhat larger for distant as compared with close pairs.

Thus, young participants showed message-level context effects (differences as a function of word position in congruent, but not anomalous, sentences) over some electrode sites in the first 200 ms after stimulus onset, and this effect increased and was sustained between 200–800 ms. Elderly participants, in contrast, did not show differential word position effects until 400 ms, after which time their response pattern did not differ statistically from that of young participants. In contrast to prior visual studies using these materials with young participants, which found that message-level

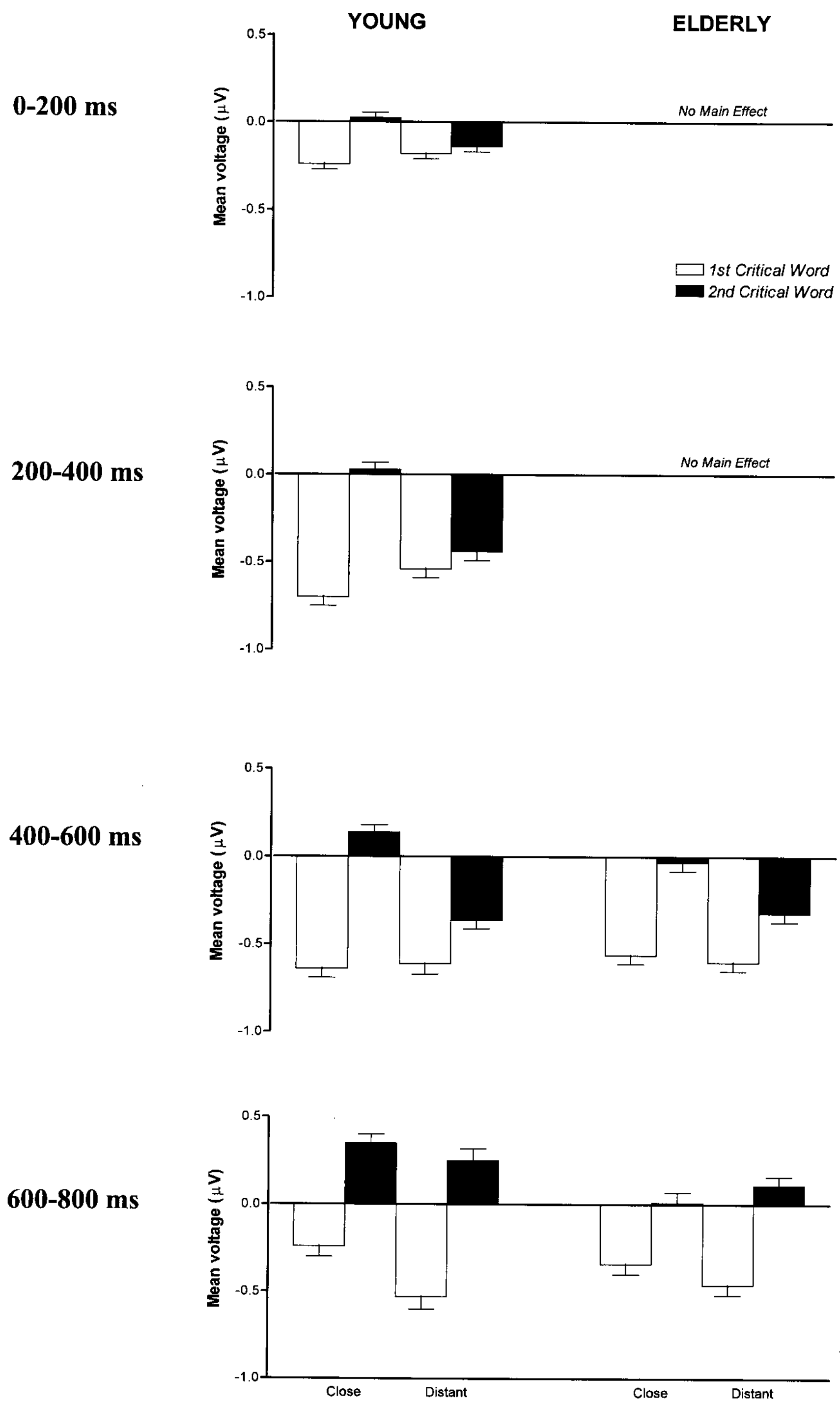

Figure 6. Lexical context effects as a function of distance. Shown are bar plots for each analysis time window of mean amplitude ERP responses (across the eight posterior channels) to first and second critical words in congruent sentences, as a function of their proximity. Elderly participants did not show significant sentential context effects within the first 400 ms. Young participants did show sentential effects in the first two time windows; as seen here, these effects were significant only within close pairs (one or no intervening words). Both groups showed similar sentential effects after 400 ms. These effects were larger in close than in distant pairs between 400–600 ms and did not differ statistically (but were slightly larger for distant pairs) between 600–800 ms.

effects increased with distance (Van Petten, 1993; Van Petten et al., 1997), for auditory presentation we observed message-level effects exclusively or more prominently within close pairs for all but the latest time window.[4]

Summary. Lexical context effects were evident beginning in the first 200 ms after stimulus presentation and continued through 800 ms, with more negative responses to the second word of unassociated than of lexically associated word pairs embedded in anomalous sentence contexts. These effects primarily arose from pairs in which the lexically associated words were immediately adjacent to one another or separated by a single word (close pairs). Age did not seem to affect the size or timing of these lexical context effects. In contrast, aging did alter message-level context effects. Young adults showed a larger word position effect (increased positivity to first as compared with second critical words) in congruent than anomalous sentences beginning in the first 200 ms after stimulus presentation and continuing through 800 ms. Sentence context effects were seen earlier (0–400 ms) for close pairs than for distant pairs (after 400 ms). Elderly adults, in contrast, did not show this pattern of message-level effects until after 400 ms.

Discussion

In this experiment, we recorded ERPs as young and elderly participants listened for comprehension to sentences that contained different types of context information: lexical, sentential (message-level), both, or neither. In so doing, we were able to examine and compare age-related changes in language processing at multiple levels: from sensory analysis, through lexical retrieval, to the construction of message-level meaning. By making comparisons within the same participants, using one set of materials and a single, ecologically valid task paradigm, we can begin to pinpoint the loci of age-related changes in language processing; whether, for example, they are a straightforward function of general slowing (or other changes) that begin even at the level of sensory processing, or whether, instead, they primarily arise at higher levels of analysis.

We did indeed observe age-related changes on sensory components of the ERP, measured at the onset of the first word of the sentence. These changes began on the N1 component (0–150 ms), which was smaller over the back of the head for older adults (perhaps reflecting a frontal shift in distribution with age), and, over frontal sites, was also delayed by about 15 ms. Prior studies in the visual modality have not reported age-related delays for the (visual) N1 (Gunter et al., 1992, 1998). One other ERP study using auditory presentation also did not observe effects of age on the N1 (Woodward et al., 1993). However, in that study measurements were made on the sentence-final word, opening up the possibility that contextual information from the preceding sentence mitigated the age-related changes in sensory processing that we found here at the sentence-initial word. At least at the beginning of an auditory sentence, however, it seems that fairly early aspects of sensory analysis are slightly slowed with normal aging. These delays continued into the time window of the P2 (150–300 ms), where we observed peak latency differences on the order of 25 ms between young and elderly adults over both the front and the back of the head. There was again a tendency for older adults' responses to show a frontal shift in distribution as well. Distributional changes in the ERP typically reflect some change in the number, location, or orientation of the underlying neural generators. Thus, distributional changes as a function of age may indicate changes in the neural resources subserving a particular process, or may result from more general anatomical changes, such as sulcal widening, that affect the orientation of the (same) set of generators. Prior studies in both the visual (Gunter et al., 1992) and auditory (Woodward et al., 1993) modalities have also observed age-related P2 delays (on the order of 15–20 ms with fast presentation in the visual modality) as well as amplitude reductions, at least for some experimental conditions. Aging thus seems to change those aspects of auditory sensory processing and attentional allocation indexed by the N1 and P2, with slower and smaller (or distributionally shifted) ERP responses in the older adults.

Strikingly, however, in this study delays on general, sensory components did not carry over to later "cognitive" components, such as the N400. Whether measured on the sentence-initial or sentence-final word, N400 peak latencies did not differ between older and younger adults. Contrary to predictions from general slowing, then, we do not find a monotonic function for latency changes across processing stages/time. Prior visual studies all have observed delays in N400 latency with age (Gunter et al., 1992, 1998; Harbin et al., 1984; Kutas & Iragui, 1998). Woodward et al. (1993) used an auditory sentence paradigm and also found N400 delays in their older participants. However, in their study the target word was presented after an artificial delay in the speech stream. Using natural, connected speech, as in this study, Federmeier et al. (2002) found no changes in N400 latency with age. Thus, it seems that semantic processing (as indexed by the N400) need not be delayed for words that are embedded in connected speech and thus supported by normal coarticulatory and intonational information. In contrast to some hypotheses regarding age-related slowing, therefore, delays at early levels of analysis need not directly carry over to higher levels of analyses, at least when words are presented in a natural speech context.

Whereas N400 latencies were not affected by age, the magnitude of the N400 (difference between anomalous and congruent sentence endings) was significantly reduced in older as compared with younger participants; this concurs with the findings of all previous ERP studies (Federmeier et al., 2002; Gunter et al., 1992, 1998; Hamberger et al., 1995; Kutas & Iragui, 1998; Woodward et al., 1993). However, the pattern of sentence-final N400 responses across conditions did not change with age. Both groups had larger N400 responses to the final word of anomalous as compared with congruent sentences, and both groups showed little effect of lexical association at the final word (with a tendency for older adults to show a small facilitative effect of association in anomalous sentence contexts). Thus, as is true for younger adults, older adults' brain waves are influenced by the buildup of message-level information over the course of a congruent (as compared with anomalous) sentence context. Indeed, we have previously found this effect even for elderly participants with probable Alzheimer's

[4] Direct comparisons of second critical words across the sentence types yielded the same overall pattern as first–second word comparisons, with differences between words in congruent and anomalous sentences beginning at least 200 ms earlier for the young participants than for the elderly, and with earlier message-level effects in close than in distant pairs.

disease (Schwartz, Federmeier, Van Petten, Salmon, & Kutas, 2003).

Young participants also continued to show condition-related effects in the 600- to 1,200-ms time window, with overall more positive responses to final words in anomalous sentence contexts (larger LPC) and a crossover interaction of association (AA > AU ≫ CU > CA). In contrast, elderly participants had much smaller LPC responses overall and their responses in this time window were not modulated by either congruency or association. The LPC has been linked to processes associated with explicit/effortful memory (e.g., Juottonen, Revonsuo, & Lang, 1996; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, Kutas, & McIsaac, 1995; Stuss, Picton, & Cerri, 1988; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). No explicit retrieval of information was required by the behavioral task we employed; however, it is nonetheless possible that participants might have come to consciously appreciate particular relationships between words in the sentences, such as the presence or absence of a strongly associated word pair. If this is the case, then the age-related difference in LPC pattern that we found may indicate that young participants are more likely to take note of such patterns (or are more successful at doing so) explicitly. The pattern we observed here for older adults—with relatively preserved N400 response patterns but little or no LPC effects—may thus represent another instance of the now well-documented dissociation between aging effects on semantic memory as opposed to explicit recognition/recall (Burke et al., 1987; Howard, 1983; Howard, Fry, & Brune, 1991; Madden, 1986).

Of central interest in this study were ERP responses to the midsentence critical words in the two age groups. Critical words could be subject to no context (anomalous unassociated), to lexical association only (anomalous associated), to sentence message-level constraints only (congruent unassociated), or to both lexical and sentential context (congruent associated). Responses of younger adults to the critical words largely replicate what was found previously using visual presentation of these same materials (Van Petten, 1993; Van Petten et al., 1997). Lexical context alone decreased the N400 response beginning in the first 200 ms after stimulus onset and continuing through 800 ms. This effect was modulated by distance between the words in the critical pairs: Lexical context effects were significant when words were adjacent or separated by one intervening word, but were not significant when words were more distant from one another. Lexical effects thus tend to dissipate with distance between the associates, as has been observed in many behavioral studies as well (Foss, 1982; Simpson et al., 1989).

Older adults' responses to lexical association within the context of otherwise semantically anomalous (though syntactically well-formed) sentences were identical in size, timing, and distribution to those of younger participants. As was true for younger adults, lexical effects began within the first 200 ms after stimulus presentation and continued through 800 ms. These effects were driven by responses to close pairs, with no significant effects observed to distant pairs.[5] These results suggest that the mechanism subserving lexical association effects—be it spreading activation or some other process—remains relatively intact with normal aging. Although we cannot rule out the possibility of small temporal delays (e.g., on the order of what was observed for sensory processing) in the onset of lexical association effects, it would seem that lexical processing is not substantially delayed or altered in the course of normal aging. This was also the conclusion reached in several behavioral studies (e.g., Bowles & Poon, 1981; Stern et al., 1991), although at least one study found weakened lexical priming in older adults with short stimulus onset asynchronies (Howard, Shaw, & Heisey, 1986). Behavioral studies have, however, observed that older adults tend to show more behavioral priming than do younger adults (Laver & Burke, 1993; Myerson et al., 1992), and a prior ERP study of semantic priming found overall diminished ERP effects in older adults (Gunter et al., 1998). In all of these cases, lexical association was studied out of context; to our knowledge this is the first study to look at aging effects on lexical priming in syntactic prose. In such a context, we do not find evidence to suggest that effect sizes are either augmented or reduced in older as compared with younger adults. This lack of an age-related effect on lexical associative priming is consistent with the body of evidence for preserved semantic memory with age (e.g., Light, 1992), and suggests further that lexical associative effects on the N400 may arise fairly directly from the organization of semantic memory (e.g., Federmeier & Kutas, 1999).

In addition to the early effects of lexical association, younger adults began to show effects of sentence message-level context information within the first 200 ms of word processing (although these effects were more limited in their spatial distribution over the scalp in the 0- to 200-ms window than in later time windows). For younger adults then, message-level effects begin around the same time as, or are perhaps only slightly delayed relative to, lexical level effects. This is consistent with the observation that lexical and sentential level context effects are additive in their influence on the N400 when these materials are presented visually (Kutas, 1993; Van Petten, 1993; Van Petten et al., 1997). However, the pattern of message-level context effects as a function of distance was different for auditory presentation in this study from that previously observed with visual presentation of the same materials (Van Petten, 1993; Van Petten et al., 1997). With visual presentation, message-level effects were significant for distant pairs but not for close pairs. This was the expected result, as (visual) N400 amplitudes decrease with word position as message-level constraints build (Van Petten & Kutas, 1990), and the second word of distant pairs occurs slightly later, on average, in the sentence. With auditory presentation, however, young participants showed the earliest effects for the close pairs. It was not until after 600-ms postcritical word onset that approximately equivalent word position effects were observed in close and distant pairs (with effects in distant pairs now slightly—though not significantly—larger). Although further work is needed to explore this modality difference in more detail, a likely starting point for such investigations might be the different information afforded by the auditory signal, in particular, the prosodic cues that, among other things, help delineate grammatical units and highlight information structure. Such information may have its greatest impact within close word pairs that are more likely to be within the same grammatical and/or prosodic unit.

[5] In this study, the distance manipulation was relatively coarse. It is possible that age-related differences would emerge for a more fine-grained analysis of the distant items. Zurif, Swinney, Prather, Wingfield, and Brownell (1995), for example, observed that older adults are more sensitive to distance when processing syntactic dependency relations.

Elderly participants, like young ones, showed word position effects that were greater for congruent than for anomalous sentence contexts. This message-level effect, however, was clearly delayed for the older group. Significant N400 reductions with message-level contextual information began only between 400–600 ms, more than 200 ms later than the same effect in the young. For the time windows (400–800 ms), in which both groups showed message-level effects, these did not differ in their size, distribution, or sensitivity to word pair distance. Thus, it would seem that elderly individuals are ultimately affected in a similar manner by message-level constraints, but with a delay of several hundred milliseconds. It is potentially interesting to compare these results with those obtained in the visual modality for young participants as a function of working memory span. Lexical context effects were unaffected by memory span, but readers with low (as opposed to medium or high) working memory spans failed to show sentential context effects on the N400 when words were presented fairly rapidly (Van Petten et al., 1997). Reduced working memory span thus also affected message-level integration more than lexical processing. However, it is noteworthy that, whereas low-span young readers failed to show sentential effects in any time window, older listeners in this study did show effects, albeit delayed in time.

Overall, then, the picture that emerges from this study is one in which aging has more serious consequences for higher-order language processes (e.g., those involved in the construction of message-level meaning) than for lower-order ones (e.g., those involved in processing of lexical associative relationships). Whereas age-related delays on sensory processing components were observed, these did not carry over to the peak latency of the N400 component itself and were not associated with changes in the effect of lexical association on the timing or amplitude of the N400 effect. Furthermore, delays in the availability/use of message-level context information were much greater than could be predicted from the delays in sensory processing alone. Inconsistent with theories based on general (or even domain-based) slowing, then, we find that different subcomponents of cognitive processing (within the same task) are differentially affected by age, and that higher-level processing difficulties are not easily explained as deriving from (or even building upon) similar difficulties with lower-level processing. Instead, we find age-related changes in message-level processing in the face of apparently preserved lexical level effects, and, crucially, this dissociation of the effects of the two information types not only occurs within the same materials, task, and individuals, but also is observed on the same electrophysiological response, the N400.

This pattern, in which higher levels of analysis are substantially affected by aging, whereas lower-level processes are affected very little, if at all, is more consistent with capacity-limitation-based accounts of age-related change (although slowing need not be ruled out as an explanatory factor within such accounts; e.g., Salthouse, 1985). In this experiment, the observed age-related change was a quantitative shift in the timing with which message-level information impacted semantic analysis (as indexed by the N400), and the underlying cause for such a shift remains unclear. Whereas the data are not inconsistent with models in which age-related differences in language processing are presumed to be driven by either resource limitations (e.g., working memory capacity) or by changes in processing capabilities (e.g., inhibition), it is important to note that the age-related differences we found were observed during a minimally demanding task (listening for comprehension) and for everyday sentences that were not designed to be syntactically complex, to make high demands on working memory resources, or to require inhibition or reanalysis. Thus the ERP data suggest that, whatever their cause, age-related changes may be fairly pervasive, and can emerge even without unusually high demands for particular cognitive resources.

The fact that the scalp distribution of the message-level N400 effect did not change across the age groups suggests that older adults eventually engage similar processes and brain areas. Of course, however, quantitative differences in the timing with which information becomes available can lead to qualitative processing differences downstream. For example, slowed buildup of message-level constraints could make predictive processing less efficient, and thus fundamentally change the mechanism by which message-level information comes to affect processing in older as compared with younger adults (e.g., Federmeier et al., 2002).

In general, then, the results of this study underscore the difficulty of separating the influences of slowing, resource/capacity limitations, and processing-strategy differences on age-related changes in cognitive behavior; indeed, all may contribute to some extent to processing differences over the life span (see also, e.g., Light, 1991). We hope that these results also highlight the utility of psychophysiological measures for examining and comparing age-related changes in multiple subcomponents of a complex cognitive task within the same set of individuals. Using ERPs, we found that age-related changes in the comprehension of natural, connected speech are most manifest for processing at the message level. Older adults had a similar electrophysiological effect of contextual congruency from that observed in younger adults, but with a delayed onset of several hundred milliseconds. Lower level processing (both sensory analysis and lexical level processing), in contrast, did not seem to be subject to such striking age-related delays or changes. These data thus cohere with behavioral results suggesting that comprehension differences between older and younger adults do not derive directly from changes in peripheral processing, sensory analysis, or lexical access, but arise, primarily, at the level in which individual words are put together to yield sentence or discourse-level meaning.

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