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Aging in context: Age-related changes in context use during language comprehension

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Abstract

Effects of normal aging on the use of sentence context information during language comprehension were examined by measuring younger and older adults' event-related potential (ERP) responses to congruent sentence-final words as a function of contextual constraint. Half of the sentence contexts were strongly constraining, rendering the target word very predictable, whereas the other half were weakly constraining. Both age groups elicited smaller N400 responses to target words in strongly than in weakly constrained contexts, but this effect was significantly smaller and later for older adults. Older adults with lower reading spans showed greater delays. Age-related changes were driven primarily by decreases in older adults' ability to make use of the richer information available from strongly constraining contexts to guide semantic processing, as word processing (N400s) in weak contexts was qualitatively and quantitatively similar in the two age groups.

Descriptors: Aging, Language, Sentence processing, Sentential constraint, Event-related potentials, N400

James Thurber is quoted as saying, "With sixty staring me in the face, I have developed inflammation of the sentence structure and definite hardening of the paragraphs" (New York Post, June 30, 1955). Indeed, normal aging is accompanied by a myriad of well-documented changes in cognitive processing, many of which could affect the ability to rapidly comprehend and/or fluidly express oneself. At the same time, language—in particular, verbal knowledge—has often been heralded as a part of cognition that appears particularly resistant to age-related decline (e.g., Park et al., 2002). Older adults seem to retain, and perhaps even augment, their store of word-related knowledge (Salthouse, 1993), and the organization of this information, as assessed off-line by word associations (e.g., Burke & Peters, 1986; Lovelace & Cooley, 1982; Scialfa & Margolis, 1986) or on-line by semantic priming (Burke, White, & Diaz, 1987; Laver & Burke, 1993), also seems to remain fairly stable with age.

Furthermore, like younger adults, older adults seem to be able to use the information available in language contexts to shape their on-line processing of words—to disambiguate word meanings (Balota & Duchek, 1991; Burke & Harrold, 1993; Hopkins, Kellas, & Paul, 1995), draw inferences (Burke & Yee, 1984; Light, Valencia-Laver, & Zavis, 1991), and aid word identification (Wingfield, Alexander, & Cavigelli, 1994). In many cases, the pattern of contextual facilitation on behavioral language and memory measures is very similar across age groups, despite main effects of discriminability, bias, and/or response time. For example, Stine-Morrow, Miller, and Nevin (1999) found that contextual constraint had similar facilitative effects on auditory lexical decisions for older and younger adults. Other findings suggest that older adults may actually be *more* sensitive to preceding context, particularly when input is speeded/degraded or processing resources are taxed (e.g., Madden, 1988; Stine & Wingfield, 1994; Stine-Morrow, Loveless, & Soederberg, 1996).

At the same time, measures of electrical brain activity (event-related potentials [ERPs]) during comprehension have fairly consistently found differences—generally interpreted as decrements—in older adults' ability to use sentence context information. These differences are seen in the timing, amplitude, and pattern of N400 responses to sentence final words during comprehension. The N400 is a negative-going potential between 300 and 500 ms that has been closely linked to the processing of meaningful stimuli (e.g., auditory and visual words, pictures) at the level of meaning. Its amplitude is reduced by the presence of prior congruent context information at the word, sentence, and/or discourse level (for a review, see Kutas & Federmeier, 2001). Older adults' N400s in both the visual and auditory modality are typically smaller and later than those observed in younger adults (Gunter, Jackson, & Mulder, 1992; Kutas & Iragui, 1998; Woodward, Ford, & Hammett, 1993). Furthermore, a number of studies have reported qualitative differences in sentence context effects on older adults' N400 responses.

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Several studies, for example, have found that younger, but *not* older, adults show facilitation (reduced N400 amplitudes) for unexpected, but semantically related, sentence endings (Cameli & Phillips, 2000; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Hamberger & Friedman, 1992). Federmeier et al. have argued that this age-related difference reflects a decline in older adults' ability to efficiently use context information to predict an expected word. Supporting this, they found that a small subset of older adults with high verbal fluency—that is, those who were readily able to produce words of a specified type (Benton & Hamsher, 1978)—did show the younglike N400 pattern. Although a few older adults thus appear to retain the ability to rapidly generate features of likely upcoming words, there seems to be a more general age-related decrement in the ability or tendency to use context to prepare for word processing. One source for such difficulty might be delays in older adults' ability to construct and use message-level meaning, and to maintain this representation while processing incoming information. For example, Federmeier, van Petten, Schwartz, and Kutas (2003) found that although older adults showed facilitation from word associations that was similar in timing and form to that observed in young adults, effects of message-level congruity on the N400 were delayed by more than 200 ms in the healthy older sample. Such quantitative shifts in processing speed could qualitatively change the impact of context information on word processing, if, for example, top-down information is substantially delayed and thus too late to affect the analysis of the bottom-up signal.

Thus, although behavioral studies have shown that older adults eventually extract and make use of sentence context information (and, in some cases, may even rely on it more than younger adults), studies looking at the fine-grained timing of such context effects have revealed striking age-related changes in when and how this happens. An important next step is to begin to delineate the source of those differences. Are older adults especially disadvantaged by weak or inconsistent contextual information, as might be predicted by theories that have emphasized age-related effects on inhibitory processing (Hasher & Zacks, 1988; see, e.g., Phillips & Lesperance, 2003)? Or are older adults less able to take advantage of the richer cues available in strongly constraining contexts, perhaps because of age-related slowing (Salthouse, 1985) in retrieving or integrating information or working memory limitations that impede their ability to rapidly build an integrated meaning representation (Stine & Wingfield, 1987)? To address these questions, we compared younger and older adults' ERP responses to congruent sentence endings as a function of the availability of constraining contextual information, examining in particular whether age-related changes are observed on target words in weakly or strongly constraining contexts or both. We also looked at individual differences in context use as a function of verbal and nonverbal fluency and working memory capacity.

Method

Materials

One hundred sixty strongly constraining sentence contexts and 160 weakly constraining sentence contexts were paired with the same set of 160 sentence-final target words. A small subset of the sentence contexts (8 strongly constraining and 49 weakly constraining) were taken from published sources that reported cloze probabilities[1] for sentences (Bloom & Fischler, 1980; Griffin & Bock, 1998; Rayner & Well, 1996; Sanocki & Oden, 1984). Cloze probabilities for the remaining sentences (taken from an unpublished set) were obtained across different sessions from a total of 40–80 University of California, San Diego (UCSD), undergraduate students. Student volunteers were asked to complete each sentence context with "the first word that comes to mind." Weakly constraining sentences from all sources were defined as those with no more than 40% agreement (range 16–40%) for the most common completion, whereas strongly constraining sentences from all sources were defined as sentences with at least 70% agreement (range 70–100%) for the most common completion. Mean sentence length (in number of words) was matched for strongly and weakly constraining contexts (for both, mean length = 13 words).

Table 1. *Example Stimuli (Target Words Underlined for Illustration)*

Strongly constraining
No one at the reunion recognized Dan because he had grown a beard.
He didn't worry about burglars because he kept two fierce dogs.
Marie would have been here but she never received the invitation.
The cold drink was served with a slice of lemon.
Every morning Susan braids her little girl's hair then helps her dress for school.
She pulled her head out from under the faucet and reached for a towel.
Weakly constraining
At the children's park next to the beach she saw a man with a beard.
They both have jobs, but they get some extra income by raising dogs.
He was so busy and overwhelmed that he forgot to respond to the invitation.
The only food left in the barren refrigerator was a moldy lemon.
He called early in the morning to arrange his monthly appointment at the school.
After politely standing in line at the hotel desk, the boy asked for another towel.

Strongly constraining sentence contexts were paired with the endings obtaining the highest cloze probability, and these same 160 words were then paired with the weakly constraining contexts to yield plausible, low cloze probability endings. Across the experiment, therefore, sentence-final target words in the two constraint conditions were perfectly matched for all lexical variables. Mean word length was five letters and mean word frequency was 118 (Francis & Kucera, 1982).

The strongly and weakly constraining sentences were then divided into halves and combined in two lists of 160 sentences each, such that the same target word was never repeated in a list. Within each list, sentence final targets in the two constraint conditions were matched for word length and word frequency. Table 1 gives examples of the stimuli.

Participants

Twenty UCSD undergraduate volunteers (10 men and 10 women, 18–24 years of age, mean age 20) participated in the experiment for cash or class credit. Twenty older adults (10 men and 10 women, 60–76 years of age, mean age 67) were recruited from the local San Diego population using a newspaper announcement and were compensated for their participation with cash. All were

[1]The cloze probability for a given word in a given sentence context is defined as the proportion of individuals choosing to complete that particular context with that particular word (Taylor, 1953).

healthy, right-handed (as assessed by the Edinburgh Inventory; Oldfield, 1971), monolingual English speakers with normal or corrected-to-normal vision and no history of reading difficulties or neurological/psychiatric disorders. The older adults were on average more educated than the younger adults (12 of the older adults had completed college and 6 had advanced degrees). Ten participants from each age group were randomly assigned to each of the stimulus lists.

Procedure

Volunteers were tested in a single experimental session conducted in a soundproof, electrically shielded chamber. They were seated in a comfortable chair 40 in. in front of a monitor and instructed to read the stimulus sentences for comprehension.

The presentation of each sentence was preceded by a series of crosses (500 ms duration with a stimulus-onset asynchrony varying randomly between 1000 and 1500 ms) to orient the volunteer toward the center of the screen. Sentences were then presented one word at a time, each for a duration of 200 ms with a stimulus-onset asynchrony of 500 ms. Volunteers were asked not to blink or move their eyes during sentence presentation. The final, target word was followed by a blank screen for 4000 ms, after which the next sentence appeared automatically.

Volunteers were given a short break after every 20 sentences. At the conclusion of the recording session, participants were given a surprise recognition memory test over the sentence-final target words. The 160 sentence-final target words were mixed with 160 new words, not previously seen in any part of the experimental session. New words were matched for length, frequency, and part of speech (word category) with the target words. Participants were asked to circle all the words they remembered seeing in the experiment.

At the conclusion of the testing session, young adults were administered a short battery of neuropsychological tests that measured verbal fluency (letter and category; Benton & Hamsher, 1978), nonverbal fluency[2] (Ruff, Light, & Evans, 1987), and reading span (Daneman & Carpenter, 1980). Older adults returned for a second testing session in which they were administered these same tests as part of a larger neuropsychological battery. Across age groups, the two fluency measures showed a moderate positive correlation (0.64) with one another and were more weakly correlated with reading span (0.25 and 0.33 for verbal and nonverbal fluency, respectively). Mean verbal fluency (letter and category combined) was 123 (range: 101–161) for young participants and 110 (range: 75–145) for older participants. Mean nonverbal fluency was 117 (range: 91–155) for young participants and 77 (range: 43–112) for older participants. Mean reading span was 2.8 (range 2–5) for young participants and 2.4 (range 1–3) for older participants. All measures showed a negative correlation with age, greatest for nonverbal fluency (verbal fluency: – 0.30; nonverbal fluency: – 0.76; reading span: – 0.25).

EEG Recording Parameters

The electroencephalogram (EEG) was recorded from 26 geodesically arranged tin electrodes embedded in an Electro-cap

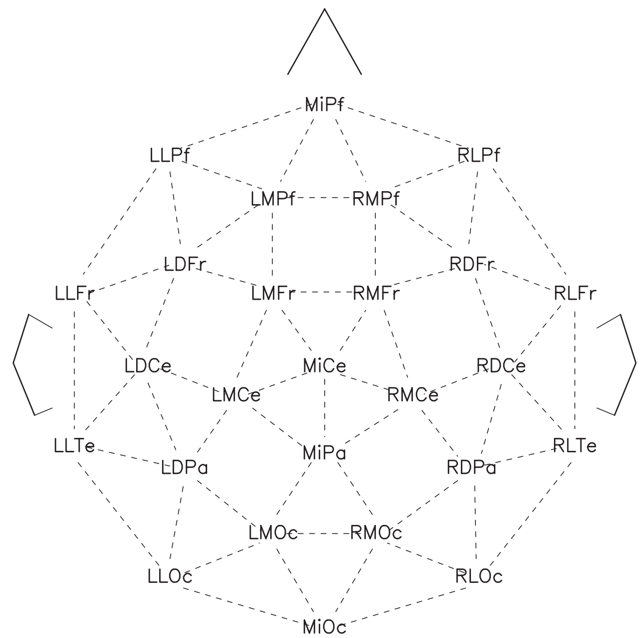

Figure 1. Schematic of the 26-electrode array used in the experiment.

(Figure 1), referenced to the left mastoid. Blinks and eye movements were monitored via electrodes placed on the outer canthus (left electrode serving as reference) and infraorbital ridge of each eye (referenced to the left mastoid). Electrode impedances were kept below 5 KΩ. EEG was processed through Grass amplifiers set at a bandpass of 0.01–100 Hz. EEG was continuously digitized at 250 Hz and stored on hard disk for later analysis.

Data Analysis

Data were re-referenced off-line to the algebraic average of the left and right mastoids. Trials contaminated by eye movements, blinks, excessive muscle activity, or amplifier blocking were rejected off-line before averaging; approximately 15% of trials in each condition were lost due to such artifacts (14% for young and 17% for old; $F[1,38] = 0.58$, $p = .45$). ERPs were computed for epochs extending from 100 ms before stimulus onset to 920 ms after stimulus onset. Averages of artifact-free ERP trials were calculated for target words in the two constraint conditions (strongly constraining and weakly constraining) after subtraction of the 100-ms prestimulus baseline. All p values are reported after epsilon correction (Huynh–Felt) for repeated measures with greater than one degree of freedom.

Results

Behavior

Young adults correctly recognized 38% of the target words that had originally appeared in strongly constraining sentences and 39% of those that had appeared in weakly constraining sentences. Their false alarm rate was 4%. Older adults correctly recognized 35% of the target words that had appeared in the strongly constraining sentences and 33% of those that had appeared in weakly constraining sentences. Their false alarm rate was 10%. Hit rates were subjected to an omnibus analysis of variance (ANOVA) on two levels of Age Group (younger adults and older adults) and two levels of Constraint (targets from strongly constrained sentences and targets from weakly constrained sentences).

[2]In this nonverbal fluency measure, the participant's task is to draw as many unique designs as possible within 60 s by connecting five dots arranged in a square work area. Analogous to the different letters in verbal fluency tests, the five-dot stimulus configurations are different in three parts of the test. In another two parts, distractors are added to the dot configurations.

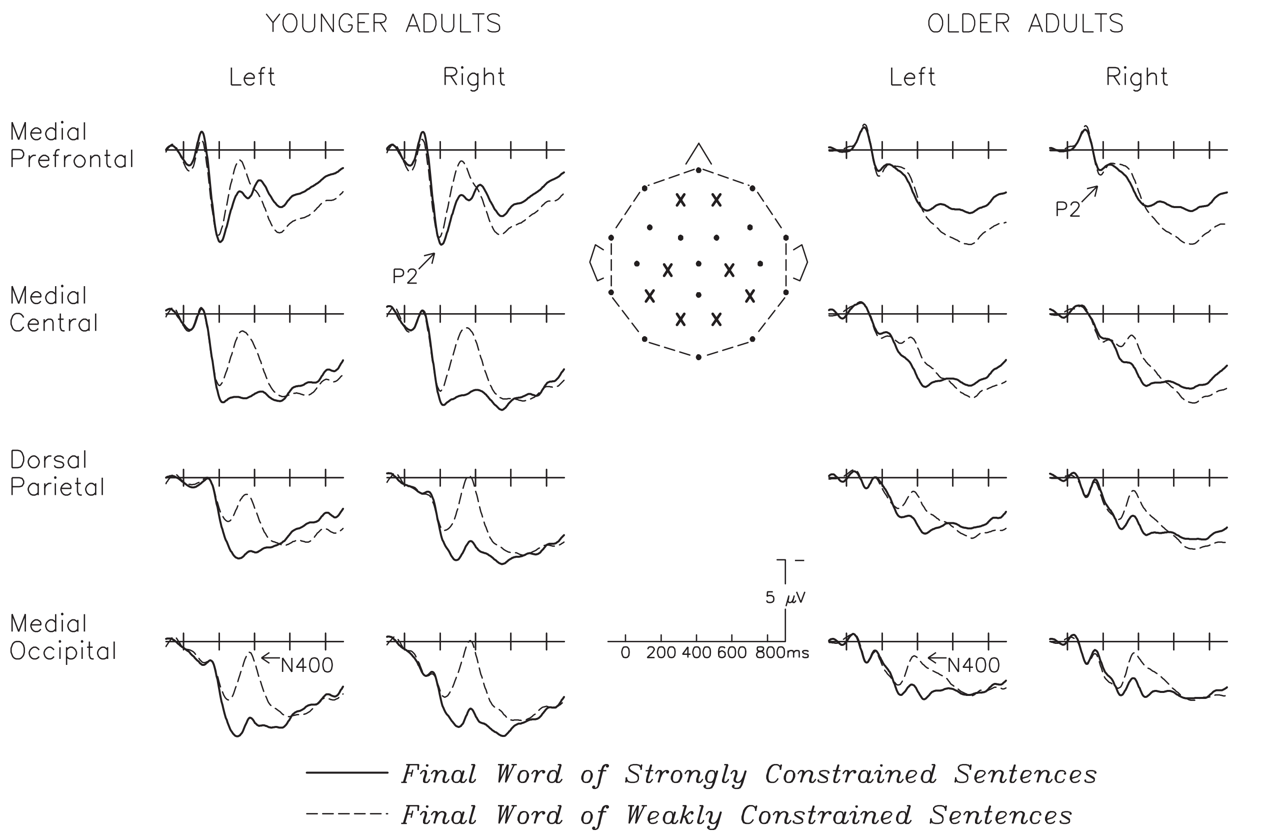

Figure 2. Younger adults' (left) and older adults' (right) grand average ERPs to strongly and weakly constrained sentence-final words at eight channels over left and right medial prefrontal, medial central, dorsal parietal, and medial occipital scalp sites. The small head illustrates the 26 channel positions with the depicted sites marked.

Neither factor had a significant influence on the hit rates (Age Group, $F[1,38] = 0.60$, $p = .44$; Constraint, $F[1,38] = 0.00$, $p = .98$). False alarm rates, however, were larger for older than for younger adults, $F(1,38) = 4.34$, $p < .05$. Older adults thus had a reduced ability to discriminate old items from new ones (young adults average $d' = 1.46$; older adults average $d' = 0.87$), irrespective of contextual constraint.

ERPs

Figure 2 shows younger and older adults' grand average ERPs to sentence final targets in the two constraint conditions at a representative sample of electrode sites. Early components in all groups and conditions include, at posterior sites, a positivity peaking around 110 ms (P1), a negativity peaking around 180 ms (N1), and a positivity peaking around 280 ms (P2), and, at frontal sites, a negativity peaking around 120 ms (N1) and a positivity peaking around 200 ms (P2). Consistent with prior observations (e.g., Kemmer, Coulson, De Ochoa, & Kutas, 2004), this frontal P2 is strikingly diminished for the older adults; the functional and neural significance of this difference remains unknown. Early components are followed, in the strongly constrained condition, by a broad, late positivity, largest over medial central and posterior sites, and, in the weakly constrained condition, by a negativity peaking around 400 ms (N400), also largest over medial central and posterior sites. In this condition, the N400 is followed by an extended, late positivity, which is of an amplitude similar to that observed for the strongly constrained condition over central posterior sites and which is larger than that observed for the strongly constrained condition over medial frontal sites.

P2 amplitude. Because of the striking age-related changes observed on the frontal P2 response, we measured the amplitude of the largest positive peak between 150 and 250 ms at the 11 frontal channels (MiPf, LLPf, RLPf, LMPf, RMPf, LLFr, RLFr, LDFr, RDFR, LMFr, RMFr) for the sentence-final target words. An omnibus ANOVA on two levels of Age Group, two levels of Constraint, and 11 levels of Electrode revealed a significant effect of Age Group, $F(1,38) = 17.7$, $p < .001$, with smaller amplitude P2 responses in older adults (2.85 μV) compared with younger adults (5.74 μV).[3] There was no effect of Constraint, $F(1,38) = 0.38$, $p = .54$, and there were no interactions of Constraint with Age or Electrode. The same analysis done on sentence *initial* words revealed no effect of Age Group, $F(1,38) = 1.35$, $p = .25$, with a trend for larger positivities in older adults (4.66 μV vs. 3.50 μV for young). The group difference was apparent, however, by the second word of the sentence (older adults: 1.77 μV; younger adults: 5.25 μV; Age Group, $F[1,38] = 21.65$, $p < .001$). Figure 3 shows the pattern.

[3]This effect interacted with Electrode, $F(10,380) = 9.5$, $p < .001$, and follow-up analyses using eight frontal electrode sites (LLPf, RLPf, LMPf, RMPf, LLFr, RLFr, LMFr, RMFr) and including Hemisphere and Laterality as ANOVA factors revealed that P2 responses were larger over medial than lateral electrode sites in both age groups, $F(1,19) = 31.58$, $p < .001$ and $F(1,19) = 20.74$, $p < .001$, for younger and older adults, respectively, but were also larger over right than left hemisphere scalp sites for younger adults, $F(1,19) = 6.02$, $p = .02$, but not for older adults, $F(1,19) = 1.11$, $p = .31$.

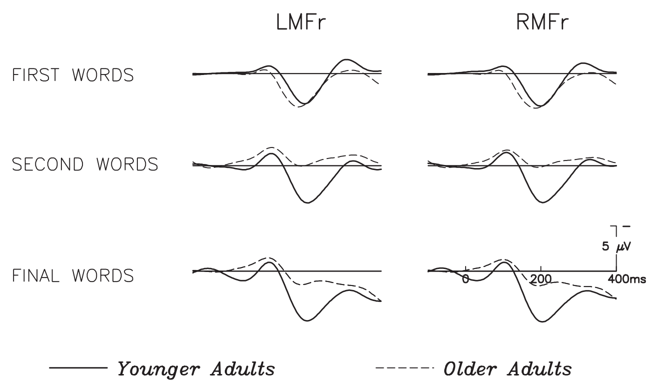

Figure 3. Younger and older adults' P2 responses to (1) the first word of the sentence, (2) the second word of the sentence, and (3) the final word of the sentence (collapsed across constraint), overlapped at left and right medial frontal channels. Although responses were of similar amplitude across the two age groups for the sentence-initial word, responses at the second word and thereafter were significantly smaller for older adults.

N400 amplitude. Mean amplitude measures were taken from 300 to 500 ms and subjected to an omnibus ANOVA on two levels of Age Group (younger and older adults), two levels of Constraint (strongly and weakly constrained targets), and 26 levels of Electrode. There was no main effect of Age Group, $F(1,38) = 0.40$, $p = .53$, but there was a main effect of Constraint, $F(1,38) = 35.88$, $p < .001$, that was modulated by an Age Group × Constraint interaction, $F(1,28) = 4.25$, $p < .05$. Planned comparisons revealed that the effect of Constraint was significant for both age groups, with larger N400 responses to targets in weakly than in strongly constrained contexts (Younger Adults: 1.72µV vs. 3.22 µV, $F[1,19] = 24.42$, $p < .001$; Older Adults: 1.76 µV vs. 2.5 µV, $F[1,19] = 11.47$, $p < .01$); however, constraint effects were larger for younger than for older adults. This age-related difference seemed to be driven by responses to the strongly constrained targets, with greater positivity (smaller N400 responses) over medial central and posterior electrode sites for the younger than the older adults (strongly constrained contexts: Age Group × Electrode interaction, $F[25,950] = 4.19$, $p < .01$, $\varepsilon = .13$); responses to the weakly constrained targets did not reliably differ between the age groups at any electrode sites (weakly constrained contexts: Age Group, $F[1,18] = 0.01$, $p = .93$; Age Group × Electrode interaction, $F[25,950] = 0.88$, $p = .47$, $\varepsilon = .15$). Figure 4 shows the pattern. Note that, although there was a preceding age-related difference in the size of the P2 response, that difference did not interact with constraint and thus cannot explain the Age Group × Constraint interaction observed on the N400 amplitudes.

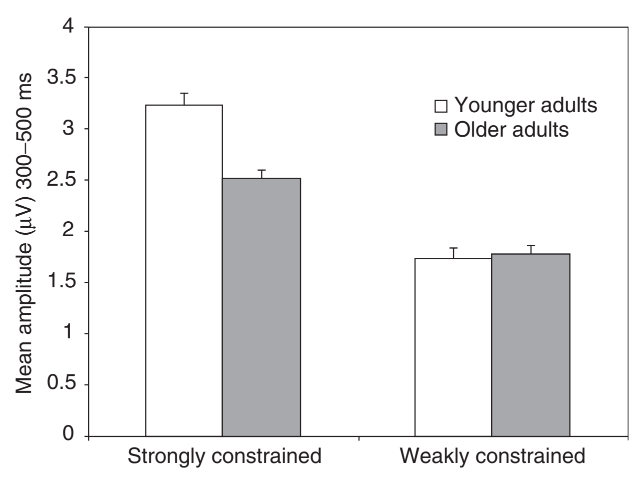

Figure 4. Mean amplitude responses (all channels) between 300 and 500 ms (N400) to strongly and weakly constrained target words for the two age groups. Whereas younger and older adults elicited N400s of similar mean amplitude to targets in weakly constrained contexts, advancing age was associated with a reduced positivity to targets in strongly constrained contexts.

N400 latency. Difference waves were created by taking a point by point subtraction of the ERP response to strongly constrained targets from the ERP response to weakly constrained targets (Figure 5). The latency of the peak difference between 300 and 500 ms was measured at the eight posterior central sites where N400 effects are typically largest (LMce, RMCe, MiCe, MiPa, LDCe, RDCe, LDPa, RDPa). The peak latency of the N400 constraint effect was delayed in older adults relative to younger adults (408 ms vs. 358 ms, respectively; $F[1,38] = 13.68$, $p < .001$). An even more striking delay was observed in the onset latency of the N400 constraint effect, measured as the time point at which the mean amplitude difference reached 15% of its peak value: 330 ms in older adults compared with 225 ms in young adults, $F(1,38) = 23.64$, $p < .001$. However, there was no significant age-related delay in the peak latency of the N400 *component* elicited by the weakly constrained targets between 300 and 500 ms (Age, $F[1,38] = 1.17$, $p = .29$; Age × Electrode, $F[7,266] = 0.80$, $p = .59$), suggesting that the source of the delay in the constraint effect arose from differential buildup of the positivity to the strongly constrained targets.[4]

Individual Differences

To assess the sources of variability that might help to explain age-related differences in N400 effect size and amplitude, we examined the relationship between the neuropsychological data obtained for each participant (verbal fluency, nonverbal fluency, and reading span) and the ERP measures of interest, using multivariate linear regression with a partial correlation analysis. N400 effect size (measured on the difference wave at all channels) and latency (measured on the difference wave at MiPa) were regressed against the three neuropsychological measures and age. Correlations across age groups were swamped by the main effect of age on N400 effect size and latency, as already described; therefore, to look at factors modulating the within-group variability, regression analyses were done for each age group separately.

For young adults, N400 effect size was uncorrelated overall with these factors, $F(4,15) = 1.45$, $p = .27$, and was not predicted independently by any neuropsychological measure or by age. N400 effect latency was similarity uncorrelated with the factors as a group, $F(4,15) = 0.67$; $p = .62$, and not predicted by any factor independently.

For older adults, N400 effect size was not significantly associated with age or the neuropsychological measures as a group, $F(4,15) = 0.36$; $p = .84$, and was not independently correlated with any factor. However, N400 effect latency was significantly correlated with the measures as a set, $r^2 = .49$, $F(4,15) = 3.56$, $p < .05$. Both age, $t(15) = 2.11$, $p = .05$, and reading span,

[4]Because little N400 activity was observed to the strongly constrained targets in either group, it was not possible to measure peak latencies for these items.

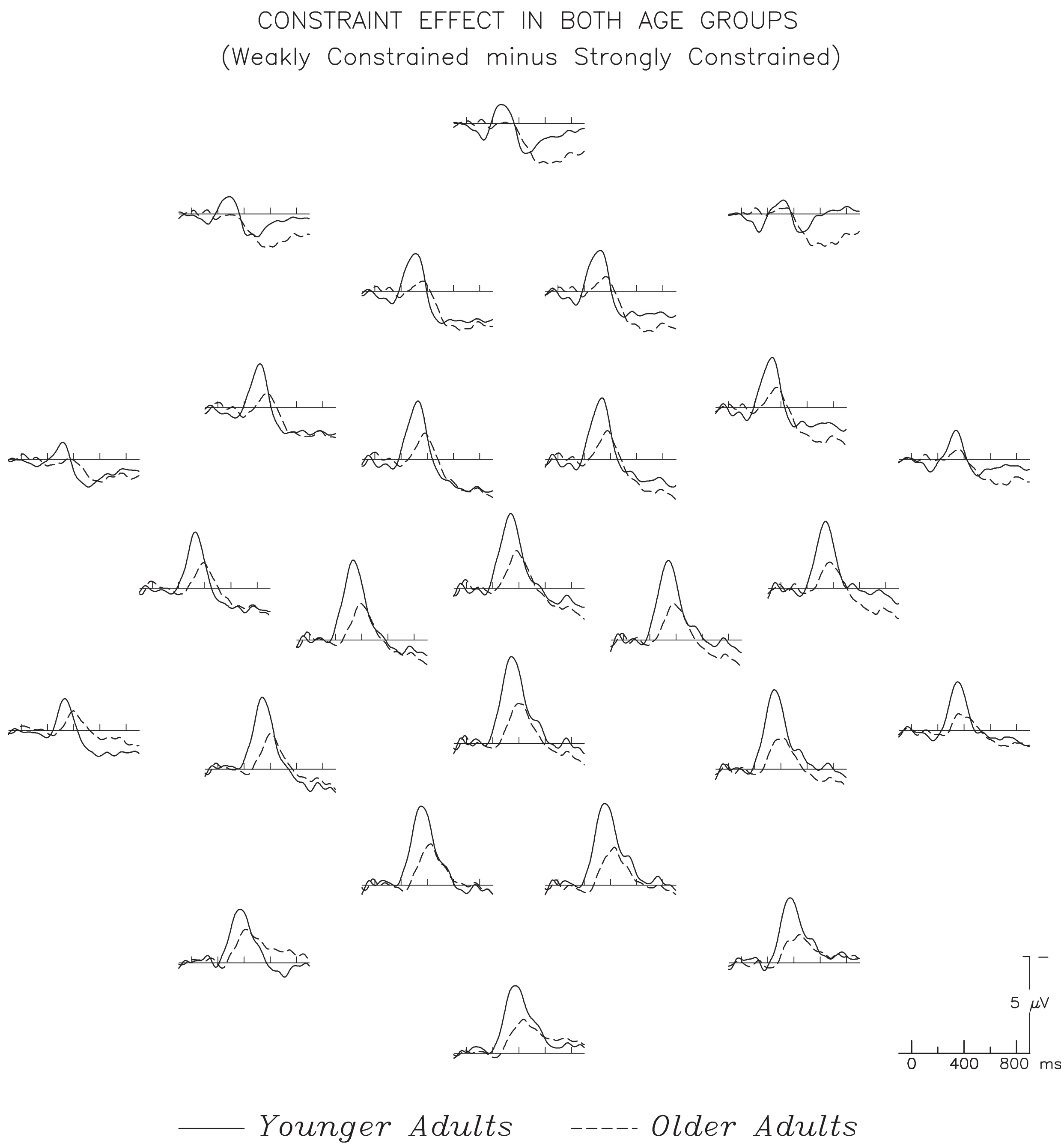

Figure 5. Difference waves (responses to targets in weakly constrained sentences minus responses to targets in strongly constrained sentences) overlapped for younger and older adults. The N400 constraint effect (300–500 ms) was both smaller and later in the older sample.

$t(15) = 3.23$, $p < .01$, were independently predictive. N400 effects peaked later with increasing age (beta = .44) and with decreasing reading span (beta = $-.76$). We followed up on this correlation by conducting the same analysis on the peak of the N400 *component* (again at MiPa) elicited by the weakly constrained targets (which were associated with clear N400 peaks). The N400 component peak was not correlated with the factors, either as a group, $F(4,15) = 0.23$, $p = .91$, or when considered independently. Therefore, it would seem that the shift in N400 effect latency is driven by the timing of the positivity elicited in strongly constrained sentences, as a function of both age and verbal working memory span.

Discussion

For young adults, replicating previous work (e.g., Kutas & Hillyard, 1984), we observed a clear effect of contextual constraint on the ERP responses to sentence-final words. N400 amplitudes were reduced when plausible target words were rendered predictable by a strongly constraining sentence context, as compared with when these same words completed weakly constraining contexts and were correspondingly less predictable. Neuropsychological measures (reading span, verbal and nonverbal fluency) were not predictive of either the size or timing of this N400 constraint effect for young adults.

Of primary interest for this study was whether healthy older adults would be able to use constraining sentence-level information as quickly and effectively as younger adults. A qualitatively similar N400 constraint effect was evident in the older group. Thus, consistent with behavioral observations (e.g., Stine-Morrow et al., 1999), ERP measures confirm that message-level context information shapes older adults' on-line processing of words. This constraint effect, however, was both statistically smaller (by about 0.75 μV) and later (by about 50 ms at the peak of the effect) than that observed for the younger participants. This reduction and delay in N400 effects replicates prior studies that compared congruent and incongruent sentence completions (e.g., Federmeier et al., 2003; Gunter et al., 1992) and shows that such patterns also obtain when all sentence-final target words are semantically plausible. Indeed, these age-related changes are striking, because participants were simply reading for comprehension, at a relatively slow pace (two words per second), congruent sentences that were not particularly complex in terms of syntactic structure or vocabulary and would not seem to have required substantial revision or inhibition. The results thus suggest that age-related changes in language processing can be fairly pervasive, not limited to demanding sentence types or particular task conditions.

A central question, then, is whether older adults' language processing is different because of difficulty processing words in the absence of strong context information or difficulty making use of information that is available (as in strongly constraining contexts) in a timely and efficacious fashion. We observed no effects of age on either the timing or the size of the N400 response to the weakly constrained targets, and no correlation of the N400 in this condition with any of our neuropsychological measures. There was thus no indication of a fundamental shift in the processing of words in the context of a congruent—though not particularly predictive—sentence. Federmeier et al. (2003) similarly found that word level processing (indexed by word association effects, in the auditory modality) was preserved in both size and timing for normally aging older adults. Such findings seem to argue against generalized slowing as the primary determinant of age-related changes in comprehension. The age-related difference observed on the N400 constraint effect was driven instead by responses in the strongly constrained contexts, with older adults showing smaller positivities and delays in the peak of the effect. Thus, it seems that older adults as a group were slower and less successful than younger adults at using the information available in the more predictive contexts to shape their word processing (see also Federmeier et al., 2002, 2003).

The amplitude of the N400 constraint effect was not correlated with either age or fluency and working memory measures. The interpretation of amplitude differences in older adults can be complicated by the possibility of increased levels of variability in the timing of responses across trials (latency jitter), resulting in effects that are more spread out over time. Because this did not appear to be the case for the weakly constraining contexts, it is fair to say that older adults either obtained less facilitation from the strongly constraining contexts or were selectively more variable in the timing of their responses in this condition.

The peak latency of the effect, in contrast, was independently correlated with both age and reading span. As has been observed previously, advancing age was associated with delays in the N400 effect (Kutas & Iragui, 1998). Here, we found that lower reading span (Daneman & Carpenter, 1980) also was associated with delays, suggesting that reductions in working memory capacity might be one source of older adults' difficulty in rapidly using sentence-level information. In older adults, working memory resources have previously been linked to syntactic processing with both ERPs (Gunter, Jackson, & Mulder, 1995) and behavioral measures (e.g., Kemper, 1986; Kemper & Sumner, 2001), as well as to recall for simple texts (Stine & Wingfield, 1990). Wingfield et al. (1994) have also suggested that older adults' decrement in using the context following a word to aid its identification can be linked to difficulties maintaining a memory trace long enough for retrospective analysis—something clearly also important for building meaning representations that span multiple words. Here we found that the delays associated with working memory resources were specifically linked to processing within the strongly constrained contexts. Of course, both types of sentences must make use of working memory resources in order to hold onto word meanings over time as the sentence unfolds. The richer information provided by strongly constrained sentences, however, may place a greater burden not only on information retrieval processes but also on integrative processes needed to construct and update the ongoing message-level representation—and a reduction in working memory capacity could certainly make this process less efficacious (see Van Petten, Weckerly, McIsaac, & Kutas, 1997, for a similar conclusion). This might be especially true for word-by-word reading because (as is also true for auditory language comprehension) participants cannot control the pace of information delivery and because the relatively slow rate—while providing more time for on-line integration—may also in some ways have taxed working memory resources more heavily.

Although we have focused here on age-related changes in the impact of context information on semantic aspects of word processing (indexed by the N400), it is clear that normal aging is associated with changes at multiple processing levels. Consistent with the large literature attesting to changes in explicit memory across the normal life span (e.g., Light, 1991), we found that older adults were less able than younger adults to discriminate experimental stimuli from new words when memory was assessed at the end of the ERP recording session. Age-related changes in perceptual aspects of processing were also apparent, the most striking of which was the reduction in older adults' frontal P2 to sentence-final words. Both the neural bases and the precise functional significance of the P2 component remain unclear. The P2 is part of the normal ERP response to visual stimuli, and amplitude modulations of this component have been linked to the detection and analysis of visual features in paradigms such as selective attention tasks (Hillyard & Muente, 1984; Luck & Hillyard, 1994). Here, we found that P2 responses assessed at the sentence-initial word were similar in size for the two age groups, but by the second word of the sentence, and continuing through to the final word, were strikingly reduced for older adults. This age-related difference is thus not structural or pervasive, but arises when inputs are processed in a relatively rapid series, as during sentence processing. More generally, such aging effects serve as a reminder that even when semantic aspects of word processing do not seem substantially affected by age, as was the case for weakly constrained targets in the present study, other aspects of processing are clearly different for older than for younger adults. Developing an understanding of the bases for these differences—and their consequences for downstream processes—has to be an important goal for future investigations of age-related cognitive change.

In sum, although there is clear evidence from a variety of sources that context can shape and facilitate language processing in both younger and older adults (and may be especially important in the face of age-related changes in sensory processing capabilities), on-line measures of brain activity have revealed important age-related changes in the nature and time course of these contextual effects. In particular, we found here that older adults were less successful at rapidly exploiting the predictive information available from a strongly constraining sentence context, and that the tendency to show processing delays in these contexts was correlated with both age and the availability of working memory resources.

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