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Electrophysiological Analysis of Context Effects in Alzheimer's Disease

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Event-related potentials elicited by semantically associated and unassociated word pairs embedded in congruous and semantically anomalous spoken sentences were recorded from patients with Alzheimer's disease (AD) and healthy older and young controls as a means of examining the nature, time course, and relation between word and sentence context effects. All groups demonstrated lexical priming in nonsensical sentences, but it was earlier in the young (200–600 ms) than in the older controls (600–800 ms), and even later in the probable AD patients (800–1,000 ms). Moreover, processing in both the elderly and AD groups benefited disproportionately from a meaningful sentence context. The results do not accord well with either a strictly structural or a strictly functional account of the semantic impairments in AD.

Semantic memory refers to that component of long-term memory containing knowledge of objects, facts, and concepts, as well as words and their meanings (i.e., the mental lexicon). Semantic memory is generally thought to be organized conceptually, without reference to the time and context in which this knowledge was acquired (Collins & Loftus, 1975; Tulving, 1983, 1984). In contrast to the relative preservation of semantic memory with normal aging, patients with Alzheimer's disease (AD) demonstrate abnormalities on a range of semantic tasks, the nature of which remains unclear.

Indeed, language deficits common in AD are now widely viewed as resulting from an impairment in semantic memory (for a review, see Gainotti, 1993). For example, patients with AD tend to have difficulty on object-naming tasks, making numerous superordinate and within-category errors (Bayles & Tomoeda, 1983; Hodges, Salmon, & Butters, 1991). Within-category errors also have been observed in this group on word-to-picture matching tasks (Huff, Corkin, & Growden, 1986), indicating that the deficit is at a semantic level and is not simply due to a problem in lexical retrieval. The conclusion that the lexical–semantic information is indeed lost is further supported by Henderson, Mack, Freed, Kempler, and Anderson's (1990) finding that patients with AD have problems with essentially the same items (~80% overlap) when confronted with the same naming test administered 6 months apart. On verbal fluency tests, individuals with probable AD exhibit a disproportionately greater reduction in category as opposed to letter fluency, which some researchers have taken to reflect a breakdown in semantic processing (Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Hodges, Salmon, & Butters, 1990). Patients with AD demonstrate a reduced ability to answer questions about the physical features or functions of pictured objects (Martin & Fedio, 1983) and tend to perform more slowly and less accurately than controls in sentence verification tasks requiring knowledge of specific semantic relations (Sailor, Bramwell, & Griesing, 1998). Many researchers thus have theorized that these impairments result from a systematic breakdown in the organization of semantic knowledge in AD, making it difficult for individuals with AD to appreciate and differentiate related concepts (Chertkow & Bub, 1990; Hodges, Salmon, & Butters, 1991, 1992; Hodges & Patterson, 1995; Martin & Fedio, 1983). Medial temporal lobe areas well-known to be important for long-term semantic memory are greatly affected by AD pathology (e.g., Terry & Katzman, 1983), and it is this degeneration that is thought to be the basis for the disintegration of semantic knowledge evidenced in impaired verbal fluency, picture naming, object naming, and word association effects (Salmon, Heindel, & Lange, 1999).

Other researchers, however, have pointed out that the types of tasks with which patients with AD have difficulties

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(as noted above) also place a high demand on the explicit retrieval of specific semantic knowledge (Nebes, Martin, & Horn, 1984). Viewed from this perspective, the problems that patients with AD have on these tasks may reflect nonlinguistic deficits in attention and/or controlled processing (*functional account*) rather than a breakdown in the structure of semantic memory per se (*structural account*). In fact, using more automatic tasks (as opposed to controlled tasks) such as pronunciation and lexical decision, some researchers have found normal semantic processing in patients with AD (Nebes et al., 1984; Ober, Shenaut, Jagust, & Stillman, 1991). Overall, semantic priming experiments have yielded mixed results, with some studies showing decreased priming (Ober & Shenaut, 1988) and others showing increased priming (Chertkow, Bub, & Seidenberg, 1989; Nebes, Brady, & Huff, 1989) in participants with AD relative to controls. A meta-analysis of 21 semantic priming experiments by Ober and Shenaut (1995) suggests that these inconsistencies may be due to various methodological differences between the studies in the extent to which they call for automatic versus controlled processing—differences such as experimental design (pairwise priming vs. continuous priming), stimulus makeup (proportion of related stimuli), and stimulus onset asynchrony (long vs. short). The performance of participants with AD did not differ from that of controls in studies that favored automatic processing but showed hyperpriming in studies in which the conditions encouraged controlled processing. Another observation supporting the position that the semantic deficit in AD is at least partly due to the controlled versus automatic nature of the task is that these patients perform better with target stimuli subject to high contextual constraint. For example, Nebes, Boller, & Holland (1986) presented young and healthy older individuals and patients with AD with short sentences in which the final word was missing, followed by a target word that was either congruous or neutral with respect to the sentence context. All three groups were quicker to name the target word in the congruous than in the neutral condition, and the magnitude of this effect was the same for all groups. Nebes & Brady (1991) varied the cloze probability (a measure of contextual constraint) of the target word and found that the greater the constraint, the faster the decision for both the patient and the normal older groups, although the patients with AD benefited more. Moreover, Nebes & Halligan (1999) found that patients with AD who had mild–moderate dementia were able to use sentence context to specify the particular category exemplar that best fit with the meaning of a sentence even if they were unable to name that exemplar, suggesting that access to semantic knowledge can be guided by the sentence context and is not contingent on the ability to name the concept.

It thus seems that patients with AD are able to make use of semantic information under some conditions. Taken as a whole, it seems that patients with AD do better on tasks that are highly constrained and that decrease demands on controlled cognitive processing. It is, however, difficult to directly compare results across experiments in which the stimuli, tasks, and participants vary. Ours is the first study to directly examine the role of context in supporting semantic processing in AD by systematically varying the stimuli while holding the task and participants constant. This was made possible by using a brain measure—event-related potentials (ERPs)—that is sensitive to semantic context effects yet minimizes the task demands on the participant. We used the pattern of ERP effects in patients with probable AD to examine the structural versus functional accounts of their semantic processing capabilities.

ERPs are a relatively nonintrusive measure of electrical brain activity that provides continuous information about the sequence and timing of brain activity; ERPs do not rely on an overt response. The electrical activity at the scalp is primarily the summation of graded postsynaptic potentials generated by the depolarization and hyperpolarization of, in large part, pyramidal cells in neocortex (see Nunez, 1981; Wood & Allison, 1981). ERPs time-locked to the onset of a stimulus (or to a response) are characterized by voltage peaks and troughs (components) that vary in size, timing, or scalp distribution with changes in stimulus, response, and cognitive processing parameters.

The N400 component, first described by Kutas and Hillyard (1980), is one such component that provides a sensitive brain measure of semantic processing. The N400 is large to sentence final words that are semantically anomalous and is much smaller, if at all present, to congruent sentence completions as a function of their predictability, that is, how expected they are within the given context (Kutas & Hillyard, 1984). The sensitivity of the N400 to semantic relationships has been demonstrated in word pair experiments using lexical decision tasks (Bentin, McCarthy, & Wood, 1985; Holcomb, 1988), as well as category membership verification tasks (Boddy, 1981; Neville, Kutas, Chesney, & Schmidt, 1986). ERP studies of language processing in healthy young participants have demonstrated that word-level, message-level, and discourse-level context effects can all affect the amplitude of the N400 component (van Berkum, Hagoort, & Brown, 1999; Van Petten, 1993; Van Petten, Weckerly, McIsaac, & Kutas, 1997).

The N400 has been successfully used in studies of semantic processing in AD. For example, in a semantic categorization task with written words following a spoken context, Iragui, Kutas, and Salmon (1996) observed that the N400 congruity effect was decreased in amplitude in healthy older individuals and further attenuated in amplitude and delayed in latency in participants with AD. Similarly, Schwartz, Kutas, Butters, Paulson, & Salmon (1996) found N400 reductions with aging and even further reductions in AD in a category priming experiment. Aside from these amplitude reductions, however, the pattern of ERP responses to the manipulation of category level (superordinate, basic, and subordinate) was the same for the young group, the older group, and the group with AD; all three groups showed larger N400 congruity effects on basic and subordinate category levels than on superordinate categories. Taken together, the ERP data have suggested quantitative but not qualitative differences between participants with AD and older controls. Other researchers have shown that the N400 effect is decreased in patients with AD in response to a nonverbal, picture–semantic matching task

(Castenada, Ostrosky-Solis, Perez, Bobes, & Rangel, 1997; Ostrosky-Solis, Castaneda, Perez, Castillo, & Bobes, 1998), as well as being decreased and delayed in spoken sentences (Ford et al., 1996; Revonsuo, Portin, Juottonen, & Rinne, 1998), thereby demonstrating the utility of this measure of semantic processing across modalities. Of particular interest to our present concerns is Ford et al.'s (2001) finding that pictures primed word targets (as reflected in reduced N400 amplitudes) in patients with AD even when their names were inaccessible, suggesting caution when inferring integrity or breakdown of semantic knowledge from overt naming alone.

In the present experiment, associated and unassociated word pairs were embedded in both meaningful and anomalous (but syntactically correct) sentences and presented to patients with AD and healthy older and healthy young controls, in order to examine the effects of aging and dementia on lexical (word-level) and sentential (message-level) context effects. The following example shows the design (associated and unassociated word pairs are italicized for illustration purposes only):

> Congruent and associated: After taking his wallet they waved a *gun* and threatened to *shoot* him if he reported it.
>
> Anomalous and associated: After trying his Chinese they irritated a *gun* and expected to *shoot* him if he clipped it.
>
> Congruent and unassociated: The mill worker caught his hand in a piece of *machinery* and was *rushed* to the hospital.
>
> Anomalous and unassociated: The young shoes took their promotion in a discussion of *machinery* and were *rushed* to the aliens.

In this design, second words of critical pairs could be subject to both lexical and sentential context, either lexical or sentential context alone, or to neither (Van Petten, 1993). Processing of unassociated word pairs in anomalous sentences cannot benefit from either a prior lexical associate or the buildup of sentential context, whereas the processing of associated pairs in congruent sentences can benefit from contextual constraints at both the word and sentential levels. Furthermore, associated word pairs in anomalous sentences can only benefit from lexical context, whereas unassociated word pairs in congruent sentences can only benefit from the buildup of sentential context.

The sentences were presented auditorily. This method allows for an examination of the processing of spoken sentences with the rate, rhythm, and inflection of natural speech, rendering the findings more generalizable to real-world language demands. It has been demonstrated that the N400 effect elicited in a natural speech experiment is similar to but starts earlier than that which has been recorded in visual studies (e.g., Holcomb & Neville, 1991).

According to the structural account, AD results in the loss of semantic information from memory and a concomitant breakdown in the organizational structure of this memory (with different groups putting differential emphasis on the information loss and the organizational breakdown as the root of observed behavioral changes). That is, semantic knowledge itself disintegrates–disappears (Chan, Butters, Paulsen, Swenson, & Maloney, 1993; Chan, Butters, Salmon, & McGuire, 1993; Gonnerman et al., 1997; Hodges, Patterson, Graham, & Dawson, 1996; Hodges et al., 1992). In the strongest version of this view, patients with severe AD whose semantic memory has been devastated should demonstrate no lexical context effects (i.e., no N400 reduction), because the requisite information and/or the associative links between these concepts no longer exist. On this account, surrounding sentence context has no effect on lexical priming as there is no lexical effect to modulate. In a less extreme form, as may be more characteristic of individuals with mild-to-moderate AD, one would expect to see the degeneration of the semantic network reflected in less of an N400 reduction with association than in age-matched controls. Again, this effect should be unaffected by context. A shift in the scalp distribution of the N400 association effect would also be consistent with change in the structure of semantic memory.

By contrast, according to the functional account, the semantic network of adults with AD is intact but becomes inaccessible under some circumstances (Astell & Harley, 1996; Grossman et al., 1996; Margolin, Pate, & Friedrich, 1996; Nebes & Brady, 1990; Nebes & Halligan, 1996; Ober, Shenaut, & Reed, 1995). There are several different variants of a functional account, including a general slowing of cognitive processes (Myerson, Lawrence, Hale, Jenkins, & Chen, 1998) and a breakdown of inhibitory processes (Faust, Balota, Duchek, Gernsbacher, & Smith, 1997), as well as difficulty with controlled processing, which could manifest as an inability to access semantic knowledge quickly enough to support normal comprehension. These are not mutually exclusive, and thus all may contribute to the semantic processing problems of individuals with AD. What they have in common is the assumption that the contents and structure of semantic memories in patients with AD is relatively intact; it is access and/or use of this information that is somehow disrupted by the disease process. In the strongest version of a functional view, lexical-level N400 effects might be normal—that is, equivalent to those in normal older adults—even if the patients with AD could not explicitly state that the items were related or state the nature of the relation. In a less extreme version, a functional account would posit that a perhaps smaller or slower lexical priming effect in anomalous sentences would be augmented by greater contextual constraints provided by a congruent sentence. When these materials were read one word at a time by healthy undergraduates, the lexical effect and the sentence context effect were additive within the region of the N400 (Van Petten, 1993). Thus, any interaction between lexical and sentential information on the N400 (e.g., finding that lexical priming is greater within congruous than anomalous sentences) in the patients with AD would be more consistent with the functional account, and all the more so if the interaction is more pronounced in the group with AD than in the healthy older group.

Method

Participants

The patients were participants in the Alzheimer's Disease Research Center (ADRC) of the University of California, San Diego. The diagnosis of probable AD was made by two independent senior staff neurologists according to criteria of the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (McKann et al., 1984). Patients with a history of severe head injury, cardiovascular disease, or psychiatric illness were not included.

Twelve patients with a diagnosis of probable AD were tested (7 women and 5 men). The mean age of these patients was 76.5 (range = 71–83), and the average years of education was 15.75 (range = 12–20). The mean Dementia Rating Scale (DRS; Mattis, 1988) score was 119 (range = 104–135), which is considered to be in the mild-to-moderate range of dementia severity (lower DRS scores indicate higher levels of dementia).

The older control participants (8 women and 4 men) were also recruited from the ADRC, where they were screened to rule out past or present neurological or psychiatric illness. The older controls were matched to the participants with AD in education (m = 14.58 years; range = 12–20), $t(11) = 0.84$, *ns*; their mean age was slightly lower, at 71.5 years (range = 57–80), $t(11) = 2.38$, $p = .03$. DRS scores were significantly higher than those for the patients with AD, $t(11) = 55.64$, $p < .01$. For the older control group, the average DRS score was 141 (range = 136–144).

Twelve young control participants (6 women and 6 men) took part in the experiment as well. These participants were recruited from the University of California, San Diego, undergraduate and graduate student populations and were screened by interview to rule out neurological and psychiatric disorders. The mean age of the young controls was 23.8 years (range = 21–28), and their mean years of education was 16.3 years (range = 12–20).

Materials

Stimuli consisted of four types of sentences: first, semantically congruent sentences that include a pair of strongly associated words; second, semantically congruent sentences that lack any strongly associated word pairs, where unassociated word pairs were matched with associated word pairs on average frequency (Francis & Kucera, 1982), length, and word class; third, syntactically legal but semantically anomalous sentences that include the same associated pairs as the congruent sentences; and fourth, semantically anomalous sentences without such pairs. The mean length of each sentence type is 14.2 words (range = 8–22). See the Appendix for additional examples of each sentence type.

The stimulus set was constructed with 120 congruent sentences that incorporated a semantically associated pair of words, neither of which occurred as the sentence initial or sentence final word. For each sentence in this set, a second congruent sentence with the same number of words and no associated word pair was generated. This procedure yielded 240 congruent sentences, half containing associated word pairs and half containing unassociated control words in the same ordinal positions. An equal number of anomalous sentences were generated from these congruent sentences by replacing all of the open class words in a sentence except the critical word pairs with words from other sentences. Thus, overall, the same content words occur in congruent and anomalous sentences. Note that although the number of words intervening between the first and second member of a critical word pair varies across the stimulus set, this factor is equated among the four sentences.

Stimulus Recording

Sentences spoken by an adult male volunteer were recorded and digitized using the Wave for Windows program. Onset latencies for critical words within a sentence (first and last words and critical pairs) were subsequently determined by hand using combined visual and auditory cues.

Procedure

Each participant took part in two sessions, each lasting about 2 hr and spaced at least 1 week apart. In each session, the participant was presented with half of the sentences in each of the four sentence classes (a total of 60 of each) in random order. None of the critical pairs were repeated within a session. The two stimulus lists were counterbalanced across participants.

Participants sat in a chair 3 ft (.91 m) in front of a computer monitor, with speakers to either side of the monitor. Participants listened to each sentence spoken with normal conversational rate and inflection. The beginning of the next sentence followed 5.8 s later. In order to control excess eye movement, participants were asked to focus their eyes on a small circle that remained on the center of the computer monitor throughout the experiment.

A practice set of 20 sentences preceded the actual experimental runs. Rest periods were given to participants between each 20-sentence block of trials, and instructions were repeated to help ensure that patients with AD remembered the task.

Task

Participants' task was to listen to each sentence and judge whether or not the sentence made sense by pressing one of two buttons ("yes" or "no") at the sentence's end. Participants were asked to wait until the sentence was complete to give their response (although the judgment could usually be made much earlier), and no instructions to respond quickly were given. Responding thumbs were counterbalanced across participants, and reaction times were recorded. This task encouraged participants to listen carefully to each sentence.

Audiometry

In order to ensure that differences in hearing ability did not confound the experimental effects, each participant's hearing was tested during the first session. Tones of varied frequency (113, 200, and 2000 Hz) were randomly presented to each participant via speakers, and the decibel level increased until a threshold of 50% accuracy was determined. The sound level for the experiment was set at 50 dB above this threshold.

None of the young participants demonstrated any hearing loss, whereas 4 of the older controls and 4 of the patients with AD had some degree of high-frequency hearing loss: main effect of group for threshold, $F(2, 22) = 5.50$, $p < .02$. The older controls and the patients with AD did not differ in this respect, $t(11) = 0.79$, *ns*, but both groups had significantly greater hearing difficulty than did the young controls (both ps $< .05$).

Electrophysiological Recording

ERPs were recorded from tin electrodes embedded in an Electrocap (Electrocap International, Inc., Eaton, OH). The electrodes were located at 15 scalp sites (each referred to an electrode on the left mastoid process during recording and rereferenced to the average of the left and right mastoids after recording). Eye blinks and eye movements were monitored by one electrode placed below the infraorbital ridge of the right eye and bipolar recording from electrodes at the outer canthus of each eye. The scalp sites included Standard International 10–20 system locations Frontal left (F7) and right (F8), Temporal left (T5) and right (T6), Occipital left (O1) and right (O2), and midline sites over Frontal (Fz), Central (Cz), and Parietal (Pz) areas, as well as three pairs of electrodes approximately over Broca's area and its right hemisphere homologue (Bl and Br), Wernicke's area and its right hemisphere homologue (Wl and Wr), and primary auditory cortex (L41 and R41).

These 18 channels of electrophysiological data were amplified using Nicolet (Nicolet SM 2000, Nicolet Instrument Technologies, Madison, WI) amplifiers with a band-pass filter of 0.02–100 Hz. The electroencephalograph (EEG) recordings were continuously digitized at 6 ms/point and stored on a hard disk, along with stimulus codes for subsequent averaging. Trials with eye movement, muscle, or amplifier blocking artifacts were rejected prior to averaging. Epochs with correctable blinks (i.e., without amplifier blocking) were corrected using an adaptive filtering algorithm developed by Dale (1994) and included in the relevant ERP averages.

Results

Behavior

Both the young control and the older control participants attained an average of 99% correct for the sense–nonsense judgment, whereas the participants with probable AD were 92% correct on the average: main effect of group, $F(2, 33) = 23.62$, $p < .001$. For the patient group, the percentage correct ranged from 72% to 97%. All groups were more prone to responding to the anomalous sentences as sensible than vice versa: congruous versus anomalous sentences, $F(1, 71) = 5.11$, $p < .05$.

A 3 × 2 × 2 (group by sentence type by pair association) analysis of variance (ANOVA) of the reaction time data (responses at sentence end) also revealed a significant group difference, $F(2, 33) = 10.45$, $p < .02$. Follow-up tests revealed that, whereas there was no significant difference in the mean reaction times of the young and older controls, both of the control groups responded significantly faster than the participants with AD ($p < .0001$). All three groups responded more quickly to the congruent sentences that did not contain an associated word pair than to those that did, $F(1, 35) = 9.57$, $p < .01$. In contrast, for the anomalous sentences, reaction times were unaffected by the presence of associated word pairs.

ERPs

Computerized algorithms were used to measure mean amplitudes of the N400 component in four 200-ms time windows (200–400, 400–600, 600–800, and 800–1,000 ms). Statistical analyses within and across groups were performed with repeated measures ANOVAs, and repeated measures with greater than one degree of freedom were evaluated with probability values adjusted using the Huynh–Feldt epsilon correction factor.

Critical Word Pairs

For each group, the ERPs to the second words of critical word pairs were compared as a function of sentence type (congruent vs. anomalous) and association (associated vs. unassociated). Analyses were conducted at posterior electrode sites (Cz, Pz, T5, T6, Wl, Wr, O1, O2) where N400 effects are typically most prominent.

Young control participants. Figure 1 shows the overlapped grand average ERPs ($n = 12$) to the second word of critical pairs in each of the four conditions at the two lateral occipital sites and one midline posterior (Pz) site. Data were initially examined with an ANOVA on two levels of sentence type (congruent vs. anomalous), two levels of association (associated vs. unassociated), and eight levels of electrode for the four time windows of interest. In both the time windows of 200–400 ms and that of 400–600 ms there was a main effect of association with unassociated items eliciting greater negativity than associated items: 200–400 ms, $F(1, 11) = 10.09$, $p < .01$; 400–600 ms, $F(1, 11) = 15.40$, $p < .01$. Effects of sentence type were marginal from 200–400 ms, $F(1, 11) = 4.11$, $p = .07$, and significant by 400–600 ms, $F(1, 11) = 4.67$, $p < .05$; responses were more negative in anomalous than in congruent sentences. Sentence type and association did not interact during these two time windows (i.e., prior to 600 ms).

Sentence type and association did interact between 600 and 800 ms, $F(1, 11) = 5.99$, $p < .05$, and this interaction continued to be marginally significant from 800 to 1,000 ms, $F(1, 11) = 3.70$, $p = .08$. Follow-up comparisons revealed that during these time windows association influenced ERP responses in anomalous sentences, 600–800 ms, $F(1, 11) = 24.63$, $p < .01$; 800–1,000 ms, $F(1, 11) = 4.73$, $p = .05$, but not in congruent sentences, 600–800 ms, $F(1, 11) = 0.01$, *ns*; 800–1,000 ms, $F(1, 11) = 0.12$, *ns.* Effects of sentence type were significant for sentences without an associated pair, 600–800 ms, $F(1, 11) = 7.34$, $p < .05$; 800–1,000 ms, $F(1, 11) = 19.55$, $p < .01$, but not for those with an associated pair, 600–800 ms, $F(1, 11) = 1.06$, *ns*; 800–1,000 ms, $F(1, 11) = 1.01$, *ns.* In other words, between 600 and 1,000 ms, the presence of either a prior lexical associate or a congruent sentence context reduced N400 responses relative to the anomalous unassociated "baseline" condition, and these effects were not additive.

Older control participants. Older control participants' responses to the critical words at two lateral occipital sites and one midline posterior site are shown in Figure 2. An omnibus ANOVA was again conducted on two levels of sentence type (congruent vs. anomalous), two levels of association (associated vs. unassociated), and eight levels of electrode for the four time windows of interest. There were no main effects of either sentence type or association between 200 and 400 ms, but there was a three-way interaction

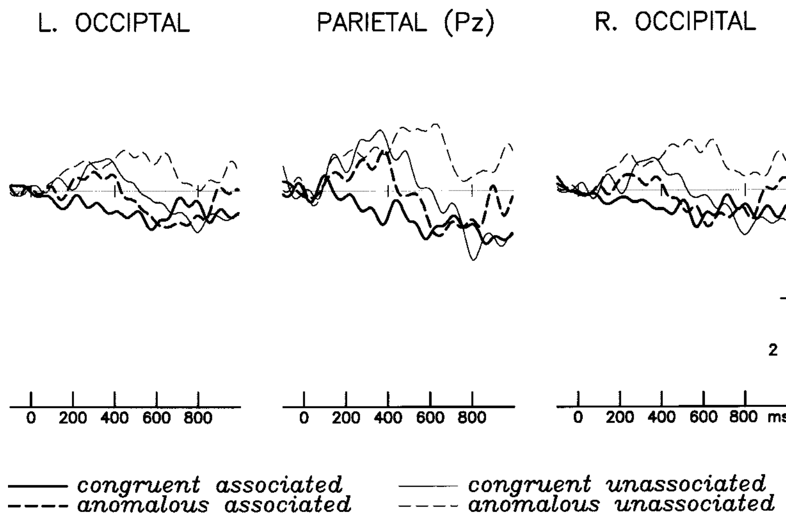

Figure 1. Event-related potentials to the second word of the critical word pair in the four experimental conditions for the young control participants. Data are shown at the left (L.) and right (R.) occipital sites and the midline parietal (Pz) site after filtering with a low-pass filter of 20 Hz. Negative voltage is plotted up.

between sentence type, association, and electrode, $F(7, 77) = 3.37$, $p < .05$. This effect continued in the time window of 400–600 ms, $F(7, 77) = 3.94$, $p < .01$, modulating main effects of both sentence type, $F(1, 11) = 5.96$, $p < .05$, and association, $F(1, 11) = 4.61$, $p = .05$. In both time windows, association affected ERP responses within congruent sentence contexts over posterior, right hemisphere electrode sites, 200–400 ms, $F(7, 77) = 4.22$, $p < .01$; 400–600 ms, $F(7, 77) = 3.49$, $p < .05$, but did not significantly affect ERP responses within anomalous sentence contexts, 200–400 ms, $F(1, 11) = 0.36$, *ns*; 400–600 ms, $F(1, 11) = 1.18$, *ns*. Message-level sentence context effects were evident only in sentences containing an associated pair. These effects were reversed in the 200-to-400-ms time window, with more negative responses to words within congruent than within anomalous sentences over right, posterior electrode sites, $F(7, 77) = 4.02$, $p < .01$. Effects between 400 and 600 ms then reversed, with increased negativity to words in anomalous sentence contexts, $F(1, 11) = 7.53$, $p < .05$. No effects of message-level context were observed for sentences without an associated pair, 200–400 ms, $F(1, 11) = 1.36$, *ns*; 400–600 ms, $F(1,$

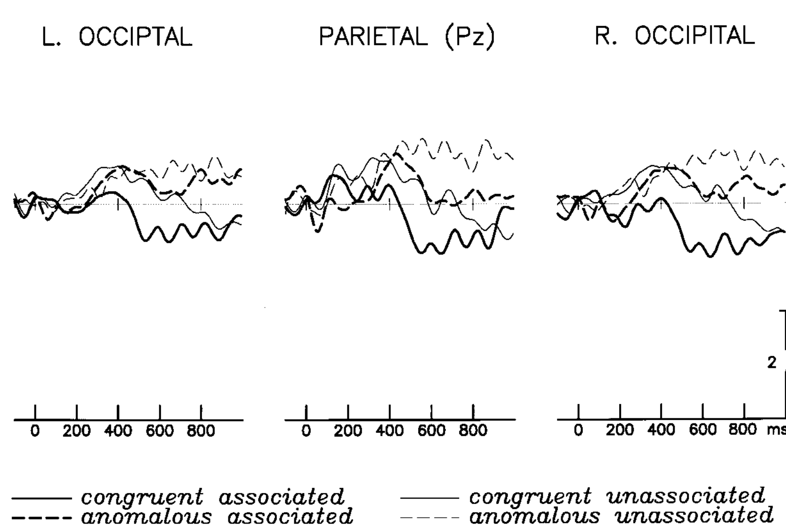

Figure 2. Event-related potentials to the second word of the critical word pair in the four experimental conditions for the healthy older control participants. Data are shown at the left (L.) and right (R.) occipital sites and the midline parietal (Pz) site after filtering with a low-pass filter of 20 Hz. Negative voltage is plotted up.

11) = 0.73, *ns,* though the tendencies followed the same general pattern. In the first 600 ms, therefore, older participants elicited significantly reduced negativities only when both lexical association and message-level context were available.

Between 600 and 800 ms, there were significant effects of both sentence type, $F(1, 11) = 8.83$, $p < .05$, and association, $F(1, 11) = 7.59$, $p < .05$, with no interaction between the two, $F(1, 11) = 0.22$, *ns.* Responses to associated words were more positive than those to unassociated words in both context types, and responses were more positive within congruent than anomalous sentences irrespective of lexical association. Effects of sentence type continued into the time window of 800–1,000 ms, $F(1, 11) = 10.13$, $p < .01$, modulated by a marginal sentence type by association interaction, $F(1, 11) = 3.48$, $p = .09$. Similar to the pattern seen in the young controls during this time window, effects of association were seen in anomalous sentence contexts, $F(1, 11) = 4.60$, $p = .05$, but not in congruent sentence contexts, $F(1, 11) = 0.11$, *ns.* Effects of sentence type were found in sentences without an associated pair, $F(1, 11) = 11.30$, $p < .01$, and also over right, posterior electrode sites for sentences with an associated pair, $F(7, 77) = 3.69$, $p < .05$.

Participants with AD. Figure 3 shows the ERPs to the target words overlapped at two lateral occipital sites and one midline posterior site for the group with AD. As for the young and older control participants, ANOVAs were conducted on two levels of sentence type (congruent vs. anomalous), two levels of association (associated vs. unassociated), and eight levels of electrode for the four time windows of interest. There were no effects of either sentence type or association in the time window of 200–400 ms. In both the time window of 400–600 ms and that of 600–800 ms, there were main effects of both sentence type, 400–600 ms, $F(1, 11) = 7.14$, $p < .05$; 600–800 ms, $F(1, 11) = 10.11$, $p < .01$, and association, 400–600 ms, $F(1, 11) = 12.22$, $p < .01$; 600–800 ms, $F(1, 11) = 16.64$, $p < .01$, and (marginal) interactions between the two, 400–600 ms, $F(1, 11) = 4.03$, $p = .07$; 600–800 ms, $F(1, 11) = 4.01$, $p = .07$. Pairwise comparisons revealed that ERP responses were more positive to associated than to unassociated pairs when these were embedded in congruent sentence contexts, 400–600 ms, $F(1, 11) = 11.15$, $p < .01$; 600–800 ms, $F(1, 11) = 16.70$, $p < .01$, but not when embedded in anomalous sentence contexts, 400–600 ms, $F(1, 11) = 0.03$, *ns*; 600–800 ms, $F(1, 11) = 0.10$, *ns.* Sentence context effects (more positive responses to words in congruent than in anomalous sentences) were evident for associated pairs, 400–600 ms, $F(1, 11) = 19.09$, $p < .01$; 600–800 ms, $F(1, 11) = 9.15$, $p < .05$, but not for unassociated pairs, 400–600 ms, $F(1, 11) = 0.15$, *ns*; 600–800 ms, $F(1, 11) = 0.00$, *ns.* In other words, during these two time windows, responses were more positive when both lexical association and sentence message-level context were present, but not for either type of context alone. In the time window of 800–1,000 ms, there were main effects of both sentence type, $F(1, 11) = 10.42$, $p < .01$, and association, $F(1, 11) = 18.26$, $p < .01$, and no interaction between the two, $F(1, 11) = 0.10$, *ns.* By this time window, then, the group with AD showed effects of lexical priming in both sentence types and effects of message-level context for both associated and unassociated pairs.

Comparison of groups. Figure 4 gives a bar graph of the pattern of effects across groups (and the time windows in which those patterns were reliable). All three groups showed a similar pattern—namely, additive effects of sentential and lexical context—in at least one time window (see Figure 4B; see also Figure 5). For young adults, this pattern began in the time window of 200–400 ms and was fully

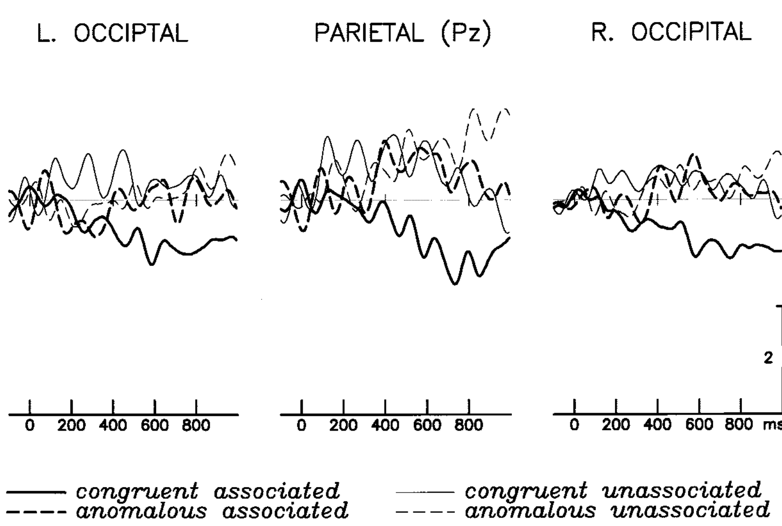

Figure 3. Event-related potentials to the second word of the critical word pair in the four experimental conditions for the patients with Alzheimer's disease. Data are shown at the left (L.) and right (R.) occipital sites and the midline parietal (Pz) site after filtering with a low-pass filter of 20 Hz. Negative voltage is plotted up.

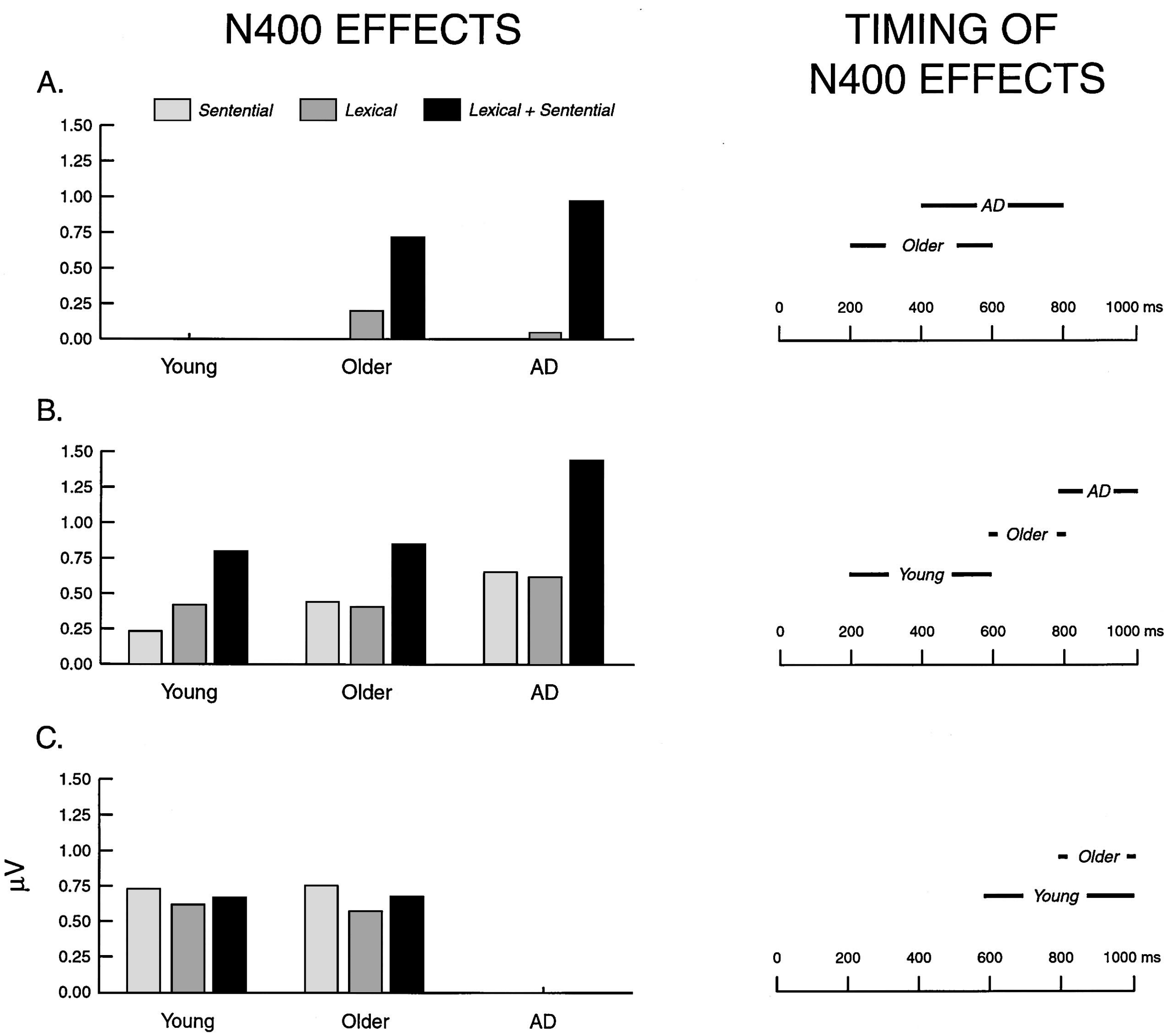

Figure 4. Group comparisons of effect patterns. Three basic patterns of facilitation were observed across groups: a "superadditive" pattern, in which facilitation when both lexical and sentential context were available was greater than the sum of the facilitation for either context type alone (A); an "additive" pattern, in which the response to the combination of lexical and sentential context was approximately the sum of either context type alone (B); and a "saturation" pattern, in which facilitation when both lexical and sentential context were available was no greater than that to either context type alone (C). The left side of the figure shows mean amplitude N400 responses for each group during the time window in which that pattern type was elicited (if at all). The right side of the figure then illustrates the time course of the effect pattern for the three groups. AD = Alzheimer's disease.

developed by 400–600 ms. For older controls, the pattern was seen between 600 and 800 ms, and for patients with AD, it was seen between 800 and 1,000 ms. To examine the size and distribution of these effects across the groups, we compared the mean amplitude measures taken in the time window when each showed this pattern most clearly (young, 400–600 ms; older, 600–800 ms; AD, 800–1,000 ms). These measures were subjected to an ANOVA on three levels of group (young, older, AD), two levels of sentence type (congruent vs. anomalous), two levels of lexical association (associated vs. unassociated), two levels of hemisphere (left scalp sites vs. right scalp sites), and three levels of electrode.

There was a main effect of sentence type, $F(1, 33) = 25.96$, $p < .01$, and a main effect of lexical association, $F(1, 33) = 37.15$, $p < .01$, but these variables did not interact with one another, $F(1, 33) = 0.01$, *ns*. Sentence type interacted with hemisphere, $F(1, 33) = 9.41$, $p < .01$, reflecting the expected right-lateralization of the N400 effect in anomalous sentences (whereas there was much less

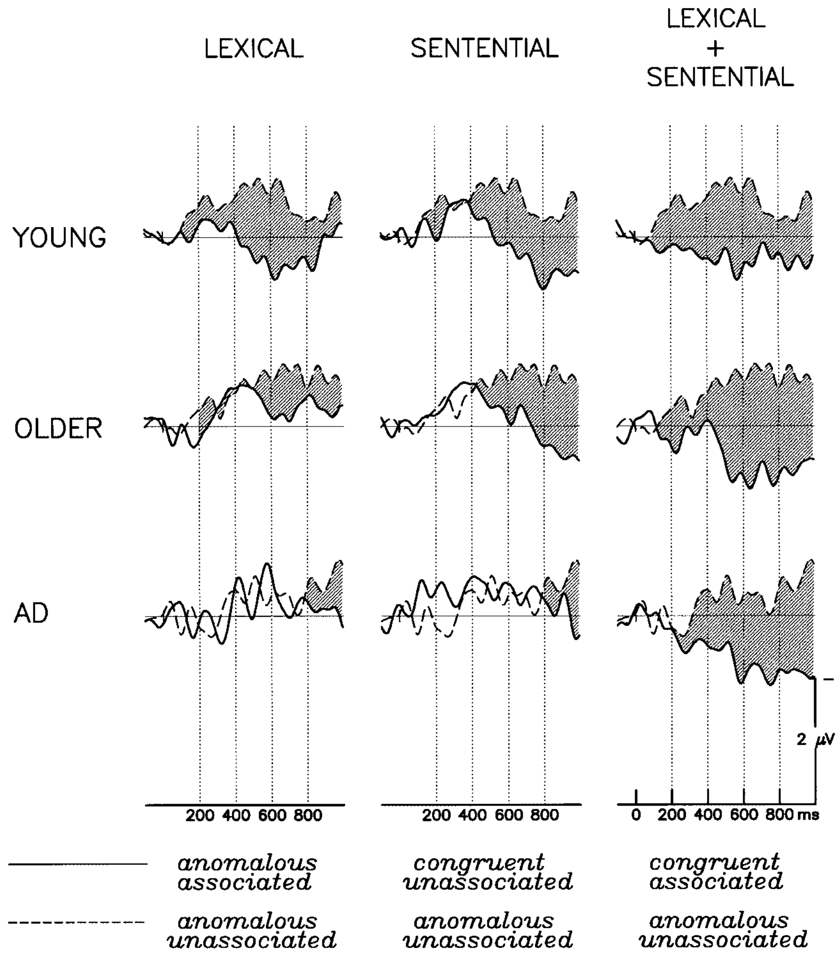

Figure 5. Effects of lexical, sentential, and both types of context combined for the young and older groups and group with Alzheimer's disease (AD), shown at the right hemisphere homologue of Wernicke's. Negative voltage is plotted up.

N400 activity in the congruent sentences). Group did not interact with either of the experimental variables, group by sentence type, $F(2, 33) = 0.57$, *ns*, and group by lexical association, $F(2, 33) = 0.38$, *ns*, or with any distributional variable. The size of both sentential and lexical effects thus seems to be similar in all three groups (for the different time windows in which they manifest the same pattern). Further, the similar scalp distribution of the effects across groups suggests that they reflect the same physiological processes in each case.

Prior to showing the additive pattern of N400 responses, both older controls and patients with AD showed a nonadditive pattern of facilitation (see Figure 4A and Figure 5). In these time windows, the presence of lexical or semantic context alone was not sufficient to significantly reduce N400 amplitudes relative to the baseline condition, but the combination of cues in the congruent associated condition did yield significant N400 reductions. To examine these effects, we compared mean amplitude responses to the congruent associated and anomalous unassociated conditions, using the time window immediately preceding that in which additive effects were observed (400–600 ms for the older participants and 600–800 ms for the patients with AD). These measures were subjected to an ANOVA on two levels of group, two levels of experimental condition (congruent–associated vs. anomalous–unassociated), two levels of hemisphere (left scalp sites vs. right scalp sites), and three levels of electrodes.

There was a main effect of group, $F(1, 22) = 8.71$, $p < .01$, and a group by hemisphere interaction, $F(1, 22) = 5.66$, $p < .05$. Older controls' brain waves were more negative overall than were those of patients with AD, and the responses were more negative over left than right scalp sites for the older controls, whereas patients with AD showed the opposite pattern. There was also a main effect of experimental condition, $F(1, 22) = 43.97$, $p < .01$. However, group did not interact with experimental condition, $F(1, 22) = 0.56$, *ns*, and there was no interaction of group and experimental condition with distributional variables. Again, then, this priming effect seems to be similar in its size and its physiological nature in the patients and in control participants of the same age.

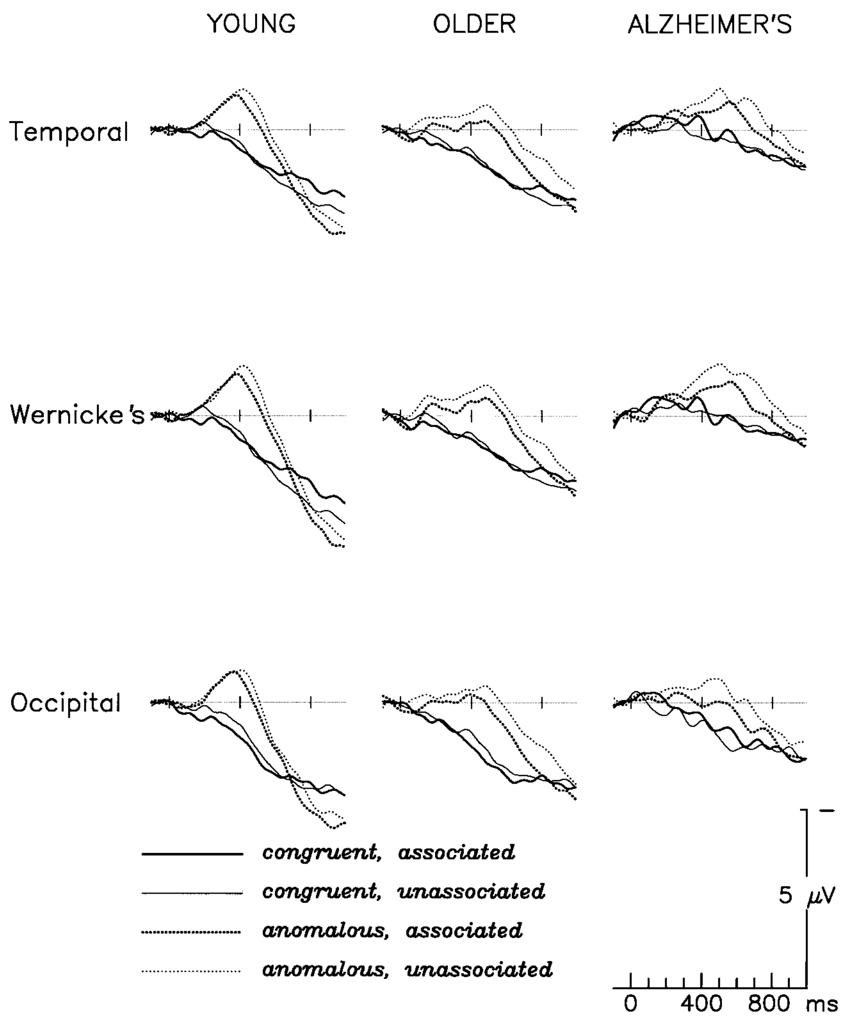

Figure 6. Event-related potentials to sentence final words from the four conditions in each of the three groups shown at temporal, Wernicke's, and occipital sites over the right hemisphere. Note that, regardless of association, the terminal words of anomalous sentences elicit large N400s and that these responses are larger for unassociated than associated anomalous sentences. Negative voltage is plotted up.

Sentence Final Words

Another perspective on the effects of sentential context on processing in healthy control participants and in those with AD is provided by comparing the sentence final words for the four sentence conditions (see Figure 6). A comparison of the last word ERPs among the three groups between 200–400 and 400–600 ms revealed a group by time window interaction, $F(2, 33) = 7.75$, $p < .00001$. In all three groups, the later portion of the ERPs to congruent sentences was more positive than those to anomalous sentences. The young controls showed a significantly larger congruency effect (ERPs to congruent sentences more positive than anomalous sentences) within the earlier time window than the patients with AD, $F(1, 22) = 6.17$, $p < .05$, with the amplitude of the effect for the older controls intermediate between the two. Within the later time window, all three groups showed significant effects of sentence congruity, $F(1, 33) = 114.79$, $p < .00001$, congruent more positive than anomalous, that was largest over posterior right hemisphere sites.

A five-way ANOVA (group by time window by association by hemisphere by anterior–posterior) confirmed our visual impression that there might be an influence of the presence of an associated word pair in the anomalous sentences: N400s to final words in associated anomalous sentences were reduced relative to those in unassociated anomalous sentences, $F(1, 33) = 7.73$, $p < .009$. Further analyses revealed that across all groups this effect of association on the N400 was only marginally significant between 200 and 400 ms, $F(1, 33) = 3.22$, $p < .08$, but reliable between 400 and 600 ms, $F(1, 33) = 6.92$, $p < .0128$.

Discussion

The present experiment is the first to directly compare word-level and sentence-level context effects in the same group of individuals with AD and to compare these with patterns in neurologically intact young and age-matched older controls. Semantically associated and unassociated word pairs were embedded within two types of sentence contexts: one that was meaningful and another that was syntactically well-formed but meaningless. A single measure was used, the N400 component of the event-related brain potential, to examine both lexical and sentential priming. The task remained constant across the various conditions and was chosen to be readily generalizable to the everyday demands of these patients: comprehending spoken sentences. Under these carefully controlled, ecologically valid conditions, the importance of context in supporting semantic processing in both healthy controls and patients with AD was demonstrated.

Participants were asked to press one button at the end of each sentence if it made sense and another button if it did not. Both the young and older controls were able to discriminate sensible from nonsensical sentences with fairly high accuracy. Although the patients with AD were slower and somewhat less accurate than the control participants, they still attained a group average of 92% correct. In addition to the reaction time measure of sentence sensibility, ERPs were recorded to the final word of each sentence. For all three groups, the final words of anomalous sentences elicited a large N400, whereas the final words of congruous sentences did not. This sentence final N400 effect peaked later for the older than the young participants, and later still for the patients with AD. By contrast, the amplitude of the N400 effect on the final word was largest in the younger participants and reduced by normal aging but was not significantly reduced in the group with probable AD. Most important, these data demonstrate that the patients stayed sufficiently focused throughout the course of the sentences (congruent and anomalous) to yield patterns similar to those seen in the young and older participants. Although ours may be an easier task, because entire sentences were or were not semantically anomalous, these findings are in general agreement with those of Nebes and Brady (1991), demonstrating that patients with moderate AD are able to listen to sentences and decide whether or not they are completed sensibly by target words. The findings also cohere with those of Hamberger, Friedman, Ritter, & Rosen (1995), who also examined sentence processing in AD using ERPs and concluded that the disruption of semantic processing in patients with AD occurred somewhere in the time interval between the elicitation of the N400 (which showed relatively normal semantic relatedness effects) and the generation of the response. Thus, the current findings indicate that individuals with moderate AD symptoms seem to appreciate message-level semantic information in much the same way as neurologically intact older individuals, although their processing is slower. It is important to note that these findings are representative of a set of patients with AD who could sit still and provide artifact-free EEG recordings.

Beyond this, the current experiment also provides evidence that individuals relied, in part, on this message-level context to access lexical information in a timely fashion. The electrical brain response of participants to the second of a pair of semantically associated versus unassociated words was the measure of lexical priming or association. Although all three groups showed some lexical priming within anomalous sentences, the groups differed markedly in the timing of these effects: The earliest main effects of lexical association occurred between 200 and 400 (continuing between 400 and 600) ms in the young participants, between 600 and 800 ms in the healthy older participants, and between 800 and 1,000 ms in the patients with AD. In other words, although the patients with AD did exhibit purely lexical priming (in the anomalous associated condition), it was more than half a second later than in our young participants and a little less than a quarter of a second slower than in our older controls. This delay relative to the older controls is much greater than would be predicted by the fact that the patients with AD were on average about 5 years older than the older controls. Previous work has shown that N400s are delayed on the order of 2 ms per year (Kutas & Iragui, 1998), with an expected group difference in this study of only 10 ms. Instead, N400 effects in the group with AD differed from those in older controls by hundreds of milliseconds.

This is greater slowing than we have seen under other circumstances. In Schwartz et al. (1996), for example, participants were presented with category headings (spoken) and asked to determine whether or not specific visually presented exemplars belonged to these categories. There was approximately 1 s between the presentations of the context and the target. Under these conditions, asked to focus on the meaning of single words, patients with AD did show significant N400 reduction (i.e., a priming effect) that was only 50–100 ms slower than in healthy older controls. In the current study, participants were asked to focus their attention on the meaning of the entire sentence rather than on any particular word. However, in the anomalous associated condition the sentences were meaningless, albeit structured, and this could have interfered with the processing of word-level relationships. Moreover, in the present study, words were presented at a much faster (natural) rate, and this too may have made it more difficult for the patients with AD to linger on the processing of individual words. Therefore, we would not want to conclude from the present results that patients with AD are unable or prohibitively slow to appreciate lexical relationships in all cases. Rather, it may be that in order to appreciate associative lexical relationships outside of a supportive context, patients with AD need to direct more of their attention to each incoming word and to have sufficient time to deal with its processing. This line of reasoning is supported by our finding that the ERP to the sentence final word of anomalous sentences in patients with AD does seem to reflect the prior presence of an associated pair of words in the sentence: The N400 is smaller for sentences that contained an associated (as compared with unassociated) word pair. Patients with AD thus do seem to access the words of the sentence and to show lexical priming but do so very slowly—so slowly that the effects are not evident until the last few hundred milliseconds into the processing of the associated word and then again on the final word of a sentence (as in the associated anomalous condition).

Although the time course of the pattern of results across the groups is different, all three groups demonstrated robust effects when the associated pairs were embedded in a congruous sentential context—that is, when message-level information was available to boost the influence of the associated target word. Moreover, the scalp distribution of this effect was similar for all three groups. Differences in scalp distributions of ERP effects are usually taken to reflect at least some difference in the underlying process, or processes, engaged. A lack of topographical difference, as in this case, is alternately taken as evidence for a similarity in associated processing. Therefore, for this condition it is most parsimonious to assume that all three groups engaged similar mechanisms and similar processing strategies.

Moreover, the huge timing differences among the groups when only lexical- or sentential-level constraints are available are reduced to a more modest difference when the lexical- and sentence-level information are combined (congruent associated condition). For example, a 600-ms difference between young participants and patients with probable AD in the anomalous associated condition is reduced to approximately 200 ms when ERPs are compared in the congruent associated condition. In fact, in the patients with probable AD, combining the sources of contextual information speeds the latency of the onset of the priming effect by 50% relative to both lexical and sentential context alone.

Our young participants exhibited main effects of both lexical association and sentential context from 200–600 ms, and these were additive during this interval. Although our young participants continued to show context effects thereafter, there is no time interval in which they derived a processing benefit from the conjoined condition that cannot be accounted for by the individual contributions of lexical association and sentential constraints. This replicates the pattern of effects observed for visual presentation of these same materials to young adults of average or high working memory capacity (Van Petten, 1993; Van Petten et al., 1997). For young participants of low working memory capacity, visual N400s were not influenced by sentential constraint alone in any latency range but were significantly reduced by lexical association alone; this effect was augmented by placing related pairs in congruent sentences (Van Petten et al., 1997). By contrast, in both the healthy older participants and the patients with probable AD (both of whom may have reduced working memory capacity relative to young adults), there was a significant time interval during which the combined presence of lexical association and sentential constraint was requisite for any reliable priming effect to be observed. In both groups, these were the earliest effects of priming seen in the ERPs, between 200 and 600 ms in the healthy older participants and between 400 and 800 ms in the patients with AD. Also in both groups this interval was followed by another ~200 ms in length during which there were independent, additive effects of lexical association and sentential constraint (similar to those seen from the outset in the younger participants and to what would be expected based on the visual results; Van Petten, 1993). Finally, this pattern was followed in the healthy older group (as it had been, albeit earlier in latency, in the younger participants) by an interval in which the size of the combined lexical and sentential priming effect was no larger than that of either variable alone. This pattern as not observed in the ERPs of patients with AD.

Careful scrutiny of the priming effects across the three groups of participants thus reveals a certain similarity of the experimental conditions and topographical distributions, albeit with different time courses. For example, the young showed additive effects of lexical association between 200 and 400 ms, the older controls between 400 and 800 ms, and the patients with probable AD between 800 and 1,000 ms (see Figure 4B). Likewise, the young and older controls both showed an interval during which the conjoined priming effect is equivalent in size to either of the priming effects alone, although the young showed it 200 ms earlier than the older controls (see Figure 4C). And, finally, both the older controls and the individuals with probable AD showed an interval in which only the combination of the lexical and sentential information suffices to yield an N400 priming effect, with that in the older controls appearing 200 ms prior to that in the group with AD (see Figure 4A).

So what does this pattern of results say about whether semantic processing difficulties in AD arise because of semantic knowledge loss and organizational changes (i.e., the structural account) or because of impaired access to intact knowledge as a function of attentional demands and/or contextual support? As so often happens in science, the answer depends on the level of specificity with which the question is asked and how terms are defined. At the highest level and with *structural breakdown* referring to complete absence of relevant knowledge, the results would seem to support a functional account. We do find evidence for lexical priming outside of any supportive context in the patients with probable AD. It is very late, but it is not gone. Moreover, the extent to which it is expressed is modulated by higher order factors such as sentential constraint (and attention). Even when lexical association and sentential constraint alone are too weak to yield any priming effect, the two can join forces, mutually supporting each other, to yield what appear to be relatively normal-sized priming, which is much closer in timing to similar effects in young and healthy older participants. Not surprisingly, then, contextual and strategic factors can help in word and sentence processing. It remains an open question just how much context is needed to overcome a 400-ms slowing of lexical association effects. Note, however, that this is not unique to the patients with probable AD; older control participants' processing is likewise subject to the mutual benefits of lexical association and contextual constraint, although at an earlier latency.

However, it would be injudicious of us not to recognize the extent of the time course differences among the groups, and to consider the possibility that there might indeed be some sort of "structural breakdown" resulting in qualitatively different processing even when the same pattern of effects appears at quantitatively different times. Without contextual support, the patients with AD, at least with these materials to which they merely listened with the aim of understanding, showed some lexical priming effects that were so late (800 ms after word onset) as to likely be effectively irrelevant to ongoing word processing. That is, although the brains of patients with AD clearly remain sensitive to lexical associative relationships at some level, this appreciation comes so late into a word's processing that it is unlikely to impact lexical access and integration in a normal fashion—and, indeed, may not show up in behavioral measures, particularly speeded ones, at all. From a computational perspective, then, such a great delay in the availability of the information accessed by virtue of the lexical association is for all intents and purposes tantamount to its not being present—certainly it cannot contribute to normal language comprehension processes. Providing higher order, sentential constraints brings the processing of patients with AD more in line with those of healthy older individuals (suggesting that the observed delays are not simply the result of a generalized slowing of processing in AD). However, even under the most optimal conditions (in this experiment)—making sense of congruent spoken sentences including lexical associates—the earliest effects of priming (relative to anomalous sentences without lexical associates) still occur 200 ms later in the patients with AD than the age-matched controls. In other words, priming effects in the patients with probable AD (when they exhibit only a mild form of the disease) are not normal, but delayed in time. Surely, by some definitions of *structural breakdown,* there is thus some evidence for a structural disintegration. The connections may not have disappeared, but they are certainly not functioning normally. Our results then suggest a position intermediate between the extreme structural and functional accounts and, furthermore, point to the explanatory force of timing differences in language processing. As slowed access or processing, for example, can lead to what appears to be qualitative differences in processing, this class of explanations must be ruled out before concluding that an effect is due to the engagement of a qualitatively different mechanism.

As Tippett and Farah (1994) stated, the sensitivity of semantic memory performance to the degree of task constraint in patients with AD is "consistent with some degree of semantic memory deficit in which answers are retrieved by a process of constraint satisfaction" (p. 12). Semantic network connections may be weaker, preventing patients with AD from gaining access to these memories unless the environment provides the necessary constraints. Context clearly helps even healthy individuals as they engage in semantic processing, but it becomes more crucial when memory links grow weaker. In the present experiment, no intentional, active search for specific information within semantic memory was required, and the nature of the task was more likely to foster relatively automatic, as opposed to controlled, processing. The natural, meaningful speech context provided the necessary constraints for the patients with AD by decreasing the need for a controlled use of resources to access the meaning of the words in the sentence. Exactly how language context information and various types of environmental supports facilitate semantic processing in dementia will have to be further explored in future research. However, as Ober and Shenaut (1999) discussed, the view of semantic networks as rigid mental structures appears less useful than that in which concept formation is a dynamic, flexible process that relies on not only current context but also an individual's goals and prior experiences (also see Barsalou, 1993).

In sum, sentence-level context influences the processing of sentence intermediate and sentence final words during normal speech processing, even in patients with AD. Such context effects emerge through their interaction with semantic memory, which appears to be intact, albeit difficult to access and thus use, at least in patients with probable AD exhibiting moderate symptoms. Context effects accrue and combine in a manner that requires experimental designs that manipulate not only the nature of the association and the context but also various aspects of timing, and various participant populations to tease them apart.

References

Astell, A. J., & Harley, T. A. (1996). Tip-of-the-tongue states and lexical access in dementia. *Brain and Language, 54,* 196–215.

Barsalou, L. W. (1993). Flexibility, structure, and linguistic vagary in concepts: Manifestations of a compositional system of perceptual symbols. In A. F. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 29–102). Hove, England: Erlbaum.

Bayles, K. A., & Tomoeda, C. K. (1983). Confrontational naming impairment in dementia. *Brain and Language, 19,* 98–114.

Bentin, S., McCarthy, G., & Wood, C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalography and Clinical Neurophysiology, 60,* 343–355.

Boddy, J. (1981). Evoked potentials and the dynamics of language processing. *Biological Psychology, 13,* 343–355.

Butters, N., Granholm, E., Salmon, D. P., Grant, I., & Wolfe, J. (1987). Episodic and semantic memory: A comparison of amnestic and demented patients. *Journal of Clinical and Experimental Neuropsychology, 9,* 479–497.

Castaneda, M., Ostrosky-Solis, F., Perez, M., Bobes, M., & Rangel, L. E. (1997). ERP assessment of semantic memory in Alzheimer's disease. *International Journal of Psychophysiology, 27,* 201–214.

Chan, A. S., Butters, N., Paulsen, J. S., Salmon, D. P., Swenson, M., & Maloney, L. (1993). An assessment of the semantic network in patients with Alzheimer's disease. *Journal of Cognitive Neuroscience, 5,* 254–261.

Chan, A. S., Butters, N., Salmon, D. P., & McGuire, K. A. (1993). Dimensionality and clustering in the semantic network of patients with Alzheimer's disease. *Psychology and Aging, 8,* 411–419.

Chertkow, H., & Bub, D. (1990). Semantic memory loss in dementia of the Alzheimer's type. *Brain, 113,* 397–417.

Chertkow, H., Bub, D., & Seidenberg, M. (1989). Priming and semantic memory in Alzheimer's disease. *Brain and Language, 36,* 420–446.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82,* 407–428.

Dale, A. M. (1994). *Source localization and spatial discriminant analysis of event-related potentials: Linear approaches.* Unpublished doctoral dissertation, University of California, San Diego.

Faust, M. E., Balota, D. A., Duchek, J. M., Gernsbacher, M. A., & Smith, S. (1997). Inhibitory control during sentence comprehension in individuals with dementia of the Alzheimer type. *Brain and Language, 57,* 225–253.

Ford, J. M., Askari, N., Mathalon, D. H., Menon, V., Gabrieli, J. D., Tinklenberg, J. R., & Yesavage, J. (2001). Event-related brain potential evidence of spared knowledge in Alzheimer's disease. *Psychology and Aging, 16,* 161–176.

Ford, J. M., Woodward, S. H., Sullivan, E. V., Isaacks, B. G., Tinklenberg, J. R., Yesavage, J. A., & Roth, W. T. (1996). N400 evidence of abnormal responses to speech in Alzheimer's disease. *Electroencephalography and Clinical Neurophysiology, 99,* 235–246.

Francis, W. N., & Kucera, H. (1982). Frequency analysis of English usage, lexicon, and grammar. Boston: Houghton Mifflin.

Gainotti, G. (1993). Mechanisms underlying semantic–lexical disorders in Alzheimer's disease. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 8, pp. 283–294). Amsterdam, the Netherlands: Elsevier Science.

Gonnerman, L. M., Andersen, E. S., Devlin, J. T., Kempler, D., & Seidenberg, M. S. (1997). Double dissociation of semantic categories in Alzheimer's disease. *Brain and Language, 57,* 254–279.

Grossman, M., D'Esposito, M., Hughes, E., Onishi, K., Biassou, N., White-Devine, T., & Robinson, K. M. (1996). Language comprehension profiles in Alzheimer's disease, multi-infarct dementia, and frontotemporal degeneration. *Neurology, 47,* 183–189.

Hamberger, M. J., Friedman, D., Ritter, W., & Rosen, J. (1995). Event-related potential and behavioral correlates of semantic processing in Alzheimer's patients and normal controls. *Brain and Language, 48,* 33–68.

Henderson, V. W., Mack, W., Freed, D. M., Kempler, D., & Anderson, E. S. (1990). Naming consistency in Alzheimer's disease. *Brain and Language, 39,* 30–38.

Hodges, J. R., & Patterson, K. A. (1995). Is semantic memory consistently impaired in the course of Alzheimer's disease? Neuroanatomical and diagnostic implications. *Neuropsychologia, 33,* 441–459.

Hodges, J. R., Patterson, K., Graham, N., & Dawson, K. (1996). Naming and knowing in dementia of Alzheimer's type. *Brain and Language, 54,* 302–325.

Hodges, J. R., Salmon, D. P., & Butters, N. (1990). Differential impairment of semantic and episodic memory in Alzheimer's and Huntington's disease: A controlled prospective study. *Journal of Neurology, Neurosurgery, and Psychology, 53,* 1089–1095.

Hodges, J. R., Salmon, D. P., & Butters, N. (1991). The nature of the naming deficit in Alzheimer's and Huntington's disease. *Brain, 144,* 1547–1558.

Hodges, J. R., Salmon, D. P., & Butters, N. (1992). Semantic memory impairment in Alzheimer's disease: Failure of access or degraded knowledge? *Neuropsychologia, 30,* 301–314.

Holcomb, P. J. (1988). Automatic and attentional processing: An event-related brain potential analysis of semantic processing. *Brain and Language, 35,* 66–85.

Holcomb, P. J., & Neville, H. J. (1991). Natural speech processing: An analysis using event-related brain potentials. *Psychobiology, 19,* 286–300.

Huff, F. J., Corkin, S., & Growden, J. H. (1986). Semantic impairment and anomia in Alzheimer's disease. *Brain and Language, 28,* 235–249.

Iragui, V., Kutas, M., & Salmon, D. (1996). Event-related brain potentials during semantic categorization in normal aging and senile dementia of the Alzheimer's type. *Electroencephalography and Clinical Neurophysiology, 4,* 1–15.

Kutas, M., & Hillyard, S. A. (1980, January 11). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207,* 203–205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307,* 161–163.

Kutas, M., & Iragui, V. (1998). The N400 in a semantic categorization task across 6 decades. *Electroencephalography and Clinical Neurophysiology, 108,* 456–471.

Margolin, D. I., Pate, D. S., & Friedrich, F. J. (1996). Lexical priming by pictures and words in normal aging and in dementia of the Alzheimer's type. *Brain and Language, 54,* 275–301.

Martin, A., & Fedio, P. (1983). Word production and comprehension in Alzheimer's disease: The breakdown of semantic knowledge. *Brain and Language, 19,* 124–141.

Mattis, S. (1988). *Dementia Rating Scale* (DRS). Odessa, FL: Psychological Assessment Resources.

McKann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services Task Force on Alzheimer's Disease. *Neurology, 34,* 939–944.

Myerson, J., Lawrence, B., Hale, S., Jenkins, L., & Chen, J. (1998). General slowing of lexical and nonlexical information processing in dementia of the Alzheimer type. *Aging, Neuropsychology, & Cognition, 5,* 182–193.

Nebes, R. D., Boller, F., & Holland, A. (1986). Use of semantic context by patients with Alzheimer's disease. *Psychology and Aging, 1,* 261–269.

Nebes, R. D., & Brady, C. B. (1990). Preserved organization of semantic attributes in Alzheimer's disease. *Psychology and Aging, 5,* 574–579.

Nebes, R. D., & Brady, C. B. (1991). The effect of contextual constraint on semantic judgments made by Alzheimer's patients. *Cortex, 27,* 237–246.

Nebes, R. D., Brady, C. B., & Huff, F. J. (1989). Automatic and attentional mechanisms of semantic priming in Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology, 11,* 219–230.

Nebes, R. D., & Halligan, E. M. (1996). Sentence context influences the interpretation of word meaning by Alzheimer patients. *Brain and Language, 54,* 233–245.

Nebes, R. D., & Halligan, E. M. (1999). Instantiation of semantic categories in sentence comprehension by Alzheimer patients. *Journal of the International Neuropsychological Society, 5,* 685–691.

Nebes, R. D., Martin, D. C., & Horn, L. C. (1984). Sparing of semantic memory in Alzheimer's disease. *Journal of Abnormal Psychology, 93,* 321–330.

Neville, H. J., Kutas, M., Chesney, G., & Schmidt, A. (1986). Event-related brain potentials during initial encoding and subsequent recognition memory of congruous and incongruous words. *Journal of Memory and Language, 25,* 75–92.

Nunez, P. L. (1981). *Electric fields and the brain: The neurophysics of EEG.* New York: Oxford University Press.

Ober, B. A., & Shenaut, G. K. (1988). Lexical decision and priming in Alzheimer's disease. *Neuropsychologia, 26,* 273–286.
Ober, B. A., & Shenaut, G. K. (1995). Semantic priming in Alzheimer's disease: Meta-analysis and theoretical evaluation. In P. Allen & T. R. Bashore (Eds.), *Age differences in word and language processing* (pp. 247–271). Amsterdam: Elsevier Science.
Ober, B. A., & Shenaut, G. K. (1999). Well-organized conceptual domains in Alzheimer's disease. *Journal of the International Neuropsychological Society, 5,* 676–684.
Ober, B. A., Shenaut, G. K., Jagust, W. J., & Stillman, R. C. (1991). Automatic semantic priming with various category relations in Alzheimer's disease and normal aging. *Psychology and Aging, 6,* 647–660.
Ober, B. A., Shenaut, G. K., & Reed, B. R. (1995). Assessment of associative relations in Alzheimer's disease: Evidence for preservation of semantic memory. *Aging and Cognition, 2,* 254–267.
Ostrosky-Solis, F., Castaneda, M., Perez, M., Castillo, G., & Bobes, M. (1998). Cognitive brain activity in Alzheimer's disease: Electrophysiological response during picture semantic categorization. *Journal of the International Neuropsychological Society, 4,* 415–425.
Revonsuo, A., Portin, R., Juottonen, K., & Rinne, J. O. (1998). Semantic processing of spoken words in Alzheimer's disease: An electrophysiological study. *Journal of Cognitive Neuroscience, 10,* 408–420.
Sailor, K. M., Bramwell, A., & Griesing, T. (1998). Evidence for an impaired ability to determine semantic relations in Alzheimer's disease patients. *Neuropsychology, 12,* 555–564.
Salmon, D. P., Heindel, W. C., & Lange, K. L. (1999). Differential decline in word generation from phonemic and semantic categories during the course of Alzheimer's disease: Implications for the integrity of semantic memory. *Journal of the International Neuropsychological Society, 5,* 692–703.
Schwartz, T. J., Kutas, M., Butters, N., Paulsen, J. S., & Salmon, D. (1996). Electrophysiological insights into the nature of the semantic deficit in Alzheimer's dementia. *Neuropsychologia, 34,* 827–841.
Terry, R. D., & Katzman, R. (1983). Senile dementia of the Alzheimer type. *Annals of Neurology, 14,* 497–506.
Tippett, L., & Farah, M. J. (1994). A computational model of naming in Alzheimer's disease: Unitary or multiple impairments? *Neuropsychology, 8,* 3–13.
Tulving, E. (1983). *Elements of episodic memory*. Oxford, England: Oxford University Press.
Tulving, E. (1984). Precis of "Elements of episodic memory." *The Behavior and Brain Sciences, 7,* 223–268.
van Berkum, J. J., Hagoort, P., & Brown, C. M. (1999). Semantic integration in sentences and discourse: Evidence from the N400. *Journal of Cognitive Neuroscience, 11,* 657–671.
Van Petten, C. (1993). A comparison of lexical and sentence-level context effects in event-related potentials. *Language and Cognitive Processes, 8,* 485–531.
Van Petten, C., Weckerly, J., McIsaac, H. K., & Kutas, M. (1997). Working memory capacity dissociates lexical and sentential context effects. *Psychological Science, 8,* 238–242.
Wood, C. C., & Allison, T. (1981). Interpretation of evoked potentials: A neurophysiological perspective. *Canadian Journal of Psychology, 35,* 113–135.

Appendix

Examples of Each of the Four Sentence Types Used in the Experiment

Note that in the following examples the critical pairs have been italicized only for the purposes of illustration.

Congruent Associated

When the *moon* is full it is hard to see many *stars* or the Milky Way.
She fixed the sticky drawer so that it *opened* and *closed* easily.
Much of the *public* land in the United States is leased to *private* interests.

Anomalous Associated

When the *moon* is rusted it is available to buy many *stars* or the Santa Ana.
She occupied the tall pellet so that it *opened* and *closed* usually.
Much of the *public* furniture in the Pacific Ocean is billed to *private* pies.

Congruent Unassociated

When the *insurance* investigators found out that he'd been drinking they *refused* to pay the claim.
As soon as they reached the *sand* he *stopped* to take off his shoes.
His *lungs* were coated with black dust from his *years* as a coal miner.

Anomalous Unassociated

When the *insurance* supplies explained that he'd been complaining they *refused* to speak the keys.
As soon as they decided the *sand* he *stopped* to break off his name.
His *lungs* were delivered with wallet from his *years* as a roof class.

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