ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Brain and Language xxx (2005) xxx–xxx

Brain and Language

www.elsevier.com/locate/b&l

An electrophysiological investigation of the effects of coreference on word repetition and synonymy ☆

Jane E. Anderson [a], Phillip J. Holcomb [b,*]

[a] *Department of Psychiatry, Harvard Medical School, USA*
[b] *Department of Psychology, Tufts University, 490 Boston Ave., Medford, MA 02155, USA*

Accepted 6 January 2005

Abstract

In two experiments the effects of word repetition, synonymy, and coreference on event-related brain potentials during text processing were studied. Participants read one (Experiment 1) or two sentence (Experiment 2) texts in which critical nouns were preceded by the definite (*the*) or indefinite (*a*) articles. Experiment 1 was run as a control to verify that differences in article processing in the second sentences of Experiment 2 would not contaminate the ERPs to critical noun items. They did not. In Experiment 2, an initial sentence was used to set up a context and contained either a first presentation or synonym of the critical word from the second sentence. N400 (but not Late Positive Component; LPC) priming effects were found for repetitions and synonyms (larger for repetitions) in second sentences. This extends observations of priming in word lists and single sentences to two-sentence texts. There was also a greater left anterior negativity or "LAN" for coreferential critical nouns (those following the article *"The"*) compared to non-coreferential critical nouns (those following the article *"A"*) suggesting that ERPs are sensitive to working memory processes engaged during referential assignment. In response to the articles themselves, there was a greater N400-700 elicited by the article "A" vs. "The." Finally, there was a greater N400-like negativity to the final words of non-coreferential sentences implying that the meanings of these sentences were difficult to integrate with the discourse level representation established by the prior sentence.

Keywords: N400; LAN; ERPs; Coreference; Anaphoric processing; Sentence processing

1. Introduction

Rather than being a string of disjointed sentences, human communication is structured in a way that helps convey the meaning of the speaker's or writer's message. One mechanism that speakers and writers use at the *discourse level* (the level at which conversations and stories are comprehended) is to relate new information to what has come before. Anaphors, such as pronouns, noun repetition and synonyms, are one mechanism that the brain uses to link new and old information during language comprehension. For example:

(1a) The truck rolled into a ditch as the driver was flagging down a passing car.
(2a) The truck had a bad parking brake.
(2b) The vehicle had a bad parking brake.
(2c) It had a bad parking brake.

To refer back to "The truck" in 1a, the writer/speaker can repeat its name as in 2a, use a noun description, such as a synonym as in 2b, or use a pronoun as in 2c. All three allow the listener/reader to know that it is the truck in 1a that is being referred to in 2a–c. The focus of this study was on how the neural systems underlying text

☆ This research was supported by Grants HD25889 and HD043251 to P.J.H.
* Corresponding author. Fax: +1 617 627 3178.
E-mail address: pholcomb@tufts.edu (P.J. Holcomb).

0093-934X/$ - see front matter © 2005 Published by Elsevier Inc.
doi:10.1016/j.bandl.2005.01.001

comprehension use noun repetitions and synonyms (2a and b) to refer to a previously mentioned instance.

Repetition effects are a very robust finding in many language tasks including lexical decision, word identification, and naming (Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983; Monsell, 1985; Scarborough, Cortese, & Scarborough, 1977). The basic finding is that words are processed faster and more accurately when they are preceded by an earlier presentation of the same word. Such word *repetition priming* effects have also been demonstrated with event-related brain potentials (ERPs), and take the form of an attenuation of the N400 component and the augmentation of a subsequent late positive component (LPC) for repeated items (e.g., Bentin & Peled, 1990; Karayanidis, Andrews, Ward, & McConaghy, 1991; Nagy & Rugg, 1987; Rugg, 1985, 1987; Rugg, Furda, & Lorist, 1988; Smith & Halgren, 1989). Semantic priming effects are also very prevalent in both the behavioral (Neely, 1991) and ERP literatures (Anderson & Holcomb, 1995; Bentin, McCarthy, & Wood, 1985; Holcomb & Neville, 1990; Van Petten & Kutas, 1990). Like repetition, when a target word (e.g., cat) is preceded by a semantically related priming word (e.g., dog) response times are shorter and the N400 is attenuated in comparison to when an unrelated prime word (e.g., pan) precedes the same target word. Unlike repetition priming, semantic priming does not result in an enhancement of the subsequent LPC.

The most frequently cited explanation for N400 priming effects (semantic and repetition) is that they reflect the ease or effort associated with integrating the semantic information activated by a primed word as compared to an unprimed word into an ongoing discourse representation—larger N400s being indicative of more effortful integration (e.g., Holcomb, 1993). Rugg (e.g., 1990) has suggested that the late positive repetition component (LPC) reflects a larger discrepancy between the baseline familiarity of low frequency words and their high experimental familiarity.

In addition to single word or "list" studies, some researches have examined word repetition and semantic priming in sentences and even longer texts. For example, Van Petten, Kutas, Kluender, Mitchiner, and McIsaac (1991) recorded ERPs while participants read texts from Readers' Digest. They demonstrated that ERP repetition effects could be elicited during text processing. However, contrary to the previous findings of greater LPC amplitudes to repeated words in lists, Van Petten et al. found the opposite pattern—words that were *not* repeated had larger LPCs. Another study in which longer texts were utilized is that of Osterhout, Allen, McLaughlin, and Inoue (2002) who demonstrated that the N400 is elicited by semantic anomalies embedded in a naturalistic prose passage.

Several researchers have used the N400 to investigate language processing at a more global level. For example, St. George, Mannes, and Hoffman, (1989) presented subjects with paragraphs and found that the N400 to content words was larger when the paragraph was not coherent (i.e., it did not contain a context-framing title) compared to when it was coherent (i.e., it did contain a context-framing title). Additionally, Van Berkum, Hagoort, and Brown (1999) found an N400 effect for "discourse anomalies." Subjects were presented with three-sentence paragraphs (in Dutch) in which the first two sentences set up the context for the third sentence. In the third sentence, there was a critical word which was either coherent or anomalous based on the preceding text, but was coherent within the local context of the sentence. (For example, "Jane told the brother that he was exceptionally *slow*" in a context where the preceding sentences told a story of the brother being quick.) Importantly, the N400 to the discourse anomaly had a similar time course, distribution and morphology compared to the N400 elicited by a "local anomaly" (e.g., Gloomily the men stood around the *pencil* of the president), suggesting the presence of similar underlying processes for integration of local and global semantic context. In another study, the same researchers (Van Berkum, Brown, & Hagoort, 1999) also found evidence for immediate processing of definite noun phrases in a study that examined referential ambiguity. When there were two potential referents introduced in a story, a subsequent definite noun elicited a more negative-going waveform compared to when there was only one potential referent. Importantly, Van Berkum, Brown, Hagoort, and Zwitserlood (2003) and Van Berkum, Zwitserlood, Hagoort, and Brown (2003) have replicated these studies in the auditory modality with similar results, demonstrating that the findings generalize to a more natural presentation (continuous spoken language vs. serial presentation of individual words).

An important question to ask regarding repetition and semantic priming effects in text is whether or not the effects are due to word repetition/semantic priming alone (presumably lexical or semantic memory effects) or whether they might also be sensitive to reactivation of a previous referent (a discourse factor). Just because a word is repeated or related in meaning to an item earlier in the text does not mean that it is necessarily *coreferential* with the first occurrence. One heuristic for determining coreference is the use of the definite article. The definite article "the" generally is used to indicate that a subsequent noun or noun phrase refers to a recently mentioned entity in the text (as in 2a and 2b), while the indefinite article "a" (and "an") is used to indicate that a subsequent noun refers to *new* entity (Grieve, 1973; Halliday, 1970).

In this study, initial nouns were either repeated or followed by a synonym, and the definite or indefinite article was used to indicate whether the noun referred to a previous instance or whether it signified a new entity. For instance, in example 1 of Table 1, the word "cab" occurs in the first sentence and is referred to using a definite article with a repeated noun in the sentence that follows. However, in the second sentence that begins with "A" the indefinite article indicates that a *different* cab is being referred to.

There have been several reading time studies that have compared response times to definite and indefinite noun phrases. Using a lexical decision task, Irwin, Bock, and Stanovich (1982) found that reaction times to repeated words were faster than to words that were not repeated, but more importantly, they found that those preceded by the definite article were responded to even faster. They concluded that the definite article may provide a cue that old information is coming up and that this information facilitates its processing. Similarly, Murphy (1984) found faster reading times for sentences (embedded in paragraphs) containing the definite article compared to the indefinite article. Both of the studies suggest that finding the antecedent for a definite reference is easier than establishing a new referent. However, this conclusion is somewhat muted by the fact that both of these studies used tasks that are of questionable validity with regards to normal "online" comprehension processes. Murphy (1984) used sentence reading times which support the notion that participants did make the referential assignment, but does not allow for precise localization of the point where this process occurs (e.g., it could occur on the noun itself and/or on one or more of the subsequent words in the sentence). And while lexical decision (e.g., Irwin et al., 1982) does provide a more direct "online" measure to the critical stimuli, the presence of such judgments might have encouraged participants to adopt unnatural sentence processing strategies. Moreover, lexical decision does not allow the experimenter to examine the effects of repetition and coreference on the processing of words in the sentence subsequent to the repeated item. By recording ERPs to each word in the test sentences it is possible to overcome these limitations.

Table 1
Sample sentences from Experiment 1 (in italics) and 2 (regular and italics)

1. Kathy sat nervously in the *cab/taxi* on her way to the airport.

The cab came very close to hitting a car.
or
A cab came very close to hitting a car.

2. Tony patched up the *rip/tear* in the sail.
The rip was found earlier while sailing.
or
A rip was found later in another sail.

3. Tommy threw a *stone/rock* towards the pond.
The stone was heading straight for his brother.
or
A stone was thrown by his brother at the same time.

4. Joshua was riding on his bus to school one morning.
A bus was stalled at the butter.

5. Joanne had just won her bet at the horse races.
She waited in line to get 75 dollars.

Based on the findings of the studies by Irwin et al. (1982) and Murphy (1984), one set of predictions with regard to ERPs is that *stronger* repetition effects should be found for words preceded by the definite as opposed to the indefinite article. Specifically, greater attenuation of the N400 component for words preceded by the definite article should be expected since they are presumably easier to integrate into a discourse model (e.g., Holcomb, 1993). According to this view, a similar pattern should be expected for the synonyms, although to a lesser degree, since semantic priming effects tend to be smaller than repetition effects and because synonyms are less explicit as anaphors (Garrod, Freudenthal, & Boyle, 1994; Gernsbacher, 1989). Such a pattern of findings would be noteworthy for at least two reasons. First, because it would buttress Irwin et al.'s (1982) findings with lexical decision, but it would do so in a more realistic, less intrusive reading task. Second, because it would indicate that in addition to lexical and sentential factors, the neural processes indexed by the N400 are also sensitive to coreference (a discourse factor). To date, the N400 has been largely attributed to lexical and sentential factors (e.g., see Osterhout & Holcomb, 1995, for a review of the N400), with the exception of several studies linking it to discourse level processing (see above; St. George et al., 1989; Van Berkum, Brown, et al., 2003; Van Berkum, Hagoort, et al., 1999). If it also proved sensitive to discourse-level processes, a whole new arena of issues would be open for study with this measure.

If repetition and synonym effects on the N400 are primarily or exclusively sensitive to lexical/sentential processes in the present study, then it is possible that differential N400s will not occur for words following definite and indefinite articles. In other words, repetitions/synonyms following definite and indefinite articles may produce equivalent N400 attenuation. In this case, it is possible that some other ERP component might prove sensitive to coreference. For example, if definite articles signal the need to keep old information from the prior sentence "online" (e.g., active in working memory) or alternatively, the need to re-activate this information, while indefinite articles signal that old information need no longer be maintained, then one prediction is that words following definite articles will result in a heavier load on working memory. Interestingly, King and Kutas (1995) have shown that increases in working memory load during sentence processing are associated not with a larger N400, but rather with a larger left anterior negativity (LAN) that spans several words in the sentence. (For further discussion of the LAN see Friederici, Hahne, & Mecklinger, 1996; Kluender & Kutas, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Rosler, Pechmann, Streb, Roder, & Hennighausen, 1998.)

Therefore, an alternative prediction for the current study is that repeated and synonym noun phrases following definite articles should produce a larger LAN than those following indefinite articles because the former signal that information from the prior sentence is relevant and needs to be kept active. It is also possible that when the reader encounters the *indefinite* noun phrase, he/she must hold both the new and the old entities in working memory, resulting in more difficulty with integrating the indefinite noun phrase into the text. However, lexical integration costs have generally been associated with the N400 component. It is possible, then, that processing differences may be indexed in the N400, the LAN or in both of these components.

A final prediction is that sentence final words would produce differences for the definite/indefinite comparison. This should happen because readers find the indefinite sentences to be relatively less semantically coherent because they are not associated with the first sentence (i.e., not referentially linked with the first sentence). Prior studies (e.g., Osterhout & Holcomb, 1992) have shown that sentence final words from semantically difficult to interpret sentences (e.g., with a syntactic anomaly earlier in the sentence) often have somewhat larger negativities, even if the final word itself is not particularly odd or unexpected. This effect has been interpreted as reflecting a sentence-level closure or wrap-up process whereby the degree of coherence of the entire sentence is evaluated (see Osterhout & Holcomb, 1995).

2. Experiment 1

Before conducting the experiment outlined above it was deemed important to first verify that the ERPs to nouns following articles do not differ simply because the words "The" and "A" are different stimuli with different representations in lexical memory. Whenever ERP comparisons are made, it is preferable to keep the physical/lexical differences between conditions to a minimum (ideally identical) to avoid the possibility that differences in the ERPs between conditions are the result of item-based differences, as opposed to the variable(s) of interest (coreference). Such confounding effects can occur even if the ERPs being compared are recorded to identical lexical items, if the items occurring *before* the items of interest are themselves different. This is because item-specific processing frequently persists or "carries-over" into the ERP epoch of adjacent words, particularly when words are presented at relatively rapid rates. In such cases it is difficult to know whether the differences in ERPs to the items of interest are due to the manipulation under study, to the persisting effects from the prior item or to some combination of the two. This problem can frequently be minimized through the use of appropriate counterbalancing schemes. However, in the current study, this was impossible because the inclusion of the two different articles was the key manipulation that determined the coreferential status of the following word. Therefore, in Experiment 1 we used the second best strategy available to combat against carry-over effects. In this "control" experiment we presented participants with only the second sentence of each discourse pair used in Experiment 2 (i.e., without the first "context" sentence). For example, participants read sentences such as, "The cab came very close to hitting a car." or "A cab came very close to hitting a car." without first seeing a lead-in context sentence (see Table 1).

To summarize, the purpose of this experiment was to examine the ERPs to the noun phrase (e.g., The cab) *without* any preceding context. Without the first sentence, there was no antecedent for the noun to refer to, hence a referential assignment could not be made. Because the articles "The" and "A" differ in their physical parameters as well as in their discourse functions, this control experiment allowed us to isolate ERP effects that were due to physical/lexical differences alone and to determine to what extent any differential effects of article processing carried over into the ERP epoch of the adjacent noun.

2.1. Method

2.1.1. Participants

Twenty-four Tufts University undergraduates (12 females and 12 males) with a mean age of 18.54 ($SD = .78$) participated for partial course credit. All were right-handed and native English speakers with normal or corrected-to-normal vision.

2.1.2. Stimuli

There were 120 experimental trials, each consisting of the second sentence of the two sentence pairs used in Experiment 2 (see Table 1). In 60 sentences (trials) the definite article "the" was used as the first word of the sentence and in the other 60 sentences the article "a" was used. A noun, hereafter referred to as the "critical word," followed the two articles. In Experiment 2 the critical words served as the repeated or synonymous stimuli and were the events hypothesized to differ between conditions due to discourse factors. The frequency of the critical nouns was moderate (mean frequency of 65/million [median = 32]; Francis & Kucera, 1982).

In addition to the above experimental items there were also 30 filler trials which in Experiment 2 did not contain a repeated noun in the "critical word" position and which had a different sentence structure than the experimental trials (see example 5 in Table 1). Finally, there were 30 trials that contained a semantic anomaly (see example 4 in Table 1). The reason for including these trials was to give the participants an additional reason to pay attention to the meaning of the sentences.

The basic structure of these trials was similar to the experimental trials. The only difference was that they contained a word that rendered the sentence semantically anomalous. The anomalous word was placed an equal number of times at the beginning, middle, or end of the sentence. In addition, the use of the definite and indefinite articles was equal across these trials.

2.1.3. Procedure

The sentences were presented to participants one word at a time in the center of a computer screen. Participants were told to read each sentence and to determine if it was a semantically good sentence or if it contained a semantic anomaly. In addition, they were told to expect comprehension questions at each rest break. Each trial proceeded as follows: A fixation cross appeared in the center of the screen for 500 ms. Five hundred milliseconds later the first word of the sentence appeared for 345 ms. After a blank interval of 70 ms the next word appeared also for 345 ms. This continued until the end of the sentence. Fifteen hundred milliseconds after the final word of the sentence, the message "RESPOND NOW" was presented on the screen, signaling the participant to respond by pressing buttons labeled "yes" or "no" depending on whether or not the sentence had a semantic anomaly. Participants were instructed to try not to blink during the presentation of the sentences. There were 12 practice trials before the beginning of the experimental run.

After every 30 trials, participants were given a break preceded by four true/false statements. These statements were presented to test the participant's comprehension of the preceding set of sentence pairs. Each statement was presented on the screen all at once instead of one word at a time (ERPs to these statements were not recorded). Each statement stayed on the screen for 2000 ms, and was followed by a message "RESPOND NOW" to which the participant responded by pressing the button labeled "YES" for true statements or "NO" for false statements. As with the sentence judgments, they were told to respond accurately but that speed was not important.

2.1.4. Recording procedure

The participant sat in a comfortable chair in a sound-attenuating chamber. An elastic cap (Electrode-Cap International) with tin electrodes was placed on the their head. Scalp locations included standard International 10-20 system locations over the left and right hemispheres at frontal (F7 and F8) and occipital sites (O1 and O2) and three locations on the midline: frontal (Fz), central (Cz), and parietal (Pz). In addition, six electrodes were placed at the following non-standard locations previously found to be sensitive to language manipulations (e.g., Holcomb, Coffey, & Neville, 1992; Holcomb & Neville, 1990, 1991): left and right temporal–parietal (TPL and TPR: 30% of the interaural distance lateral to a point 13% of the nasion–inion distance posterior to Cz); left and right temporal (TL and TR: 33% of the interaural distance lateral to Cz); and left and right anterior-temporal (ATL and ATR: 50% of the distance between T3/4 and F7/8). To monitor for eye blinks, one electrode was placed below the left eye; to monitor for horizontal eye movement, an electrode was placed lateral to the right eye. All electrodes were referenced to the left mastoid, and the right mastoid was recorded from actively in order to determine if there were different experimental contributions between the mastoid sites (none were found).

The electroencephalogram (EEG) was amplified by a Grass Model 12 amplifier system using a bandpass of .01–100 Hz (3 db cutoff). Electrode impedance was maintained below 5 kΩ at all sites, except for the eye electrodes where it was kept below 20 kΩ. The EEG was sampled continuously throughout the experiment (200 Hz), and separate ERPs were averaged off-line for each participant at each electrode site for the experimental conditions. Trials contaminated with eye artifact or amplifier blockage were not included.

2.1.5. Data analysis

ERPs time-locked to the articles that preceded the critical word were examined in an extended epoch that included the full ERP to the critical noun as well. The advantage to using a pre-article baseline is that it occurred at a point where the stimuli did not differ (e.g., number of letters and discourse function) between conditions. However, because baselining in the period just prior to the critical word is more typical we conducted a second set of analyses in which the 100 ms prior to the critical word was used as a baseline. Several time windows were chosen for quantification: 150–300 and 300–600 ms after article onset, as well as 715–1015 and 1015–1415 ms. The first two windows were chosen because they correspond to the time windows associated with the P2 and N280 (150–300) as well as the N400 and N400-700 (300–600). The N280 and N400-700 are prominent components observed to closed class words in previous studies (e.g., Neville, Mills, & Lawson, 1992). The third window (critical word N400/LAN) was chosen for use in Experiment 2 to examine the ERP coreference response to the critical noun using a pre-article baseline. Here it was used to look for differential article carry-over effects. Finally, the ERP response to the last word of the sentence was measured by using two windows: 400–700 and 700–1100 ms.

Repeated measures analyses of variance (ANOVAs) were performed on the above dependent measures. Separate analyses were done for the midline sites and the lateral sites. To examine the effects of article type at the midline sites, a two-way repeated measures ANOVA was done with the variables: article type ("The" vs. "A"), and electrode site (Fz, Cz, and Pz). Analyses of lateral sites included the additional variable of hemisphere. The Geisser and Greenhouse (1959) correction was applied to analyses with more than one degree of freedom in the numerator.

2.2. Results

2.2.1. Behavioral data

Participants correctly judged the sentences that began with "The" to be acceptable 96% of the time and those that began with "A" 95% of the time. (The accuracy did not differ for these two conditions, $p > .4$.) The accuracy rate was 93% for both the anomalous and fillers trials.

2.2.2. Event-related potentials

Fig. 1 shows the article and critical word ERPs time-locked to the articles "The" and "A." Eleven percent of the trials were rejected due to artifact. Between 150 and 300 ms after presentation of the article, the waveform for the article "A" was significantly more negative-going than that of the article "The" (midline: $F(1,23) = 15.90$, $p < .0006$; lateral: $F(1,23) = 29.94$, $p < .00005$). In the 300–600 ms window, the waveform to the article "a" was more negative-going than that of "the" over midline sites ($F(1,23) = 5.63$, $p < .03$), with the greater differences over Fz and Cz (interaction of article and electrode site: $F(2,46) = 8.36$, $p < .002$). At the lateral sites the interaction of article and electrode site was significant ($F(4,92) = 9.61$, $p < .0004$) reflecting the anterior distribution of the difference with the "A" ERPs being more negative. In the important window that encompassed the critical words (715–1015 ms), there were no differences involving the article variable (all $ps > .2$).

When the ERPs to the critical words were analyzed using the 100 prior to the onset of the critical word as the baseline, there was a somewhat different pattern of results. Between 300 and 600 ms, there was a significant main effect of article type at the midline sites ($F(1,23) = 9.33$, $p < .006$), with a borderline interaction of article type and electrode site ($F(2,46) = 3.40$, $p < .06$) reflecting the tendency for the difference to be greater over the more anterior sites. The words following the article *The* were more negative-going than those follow-

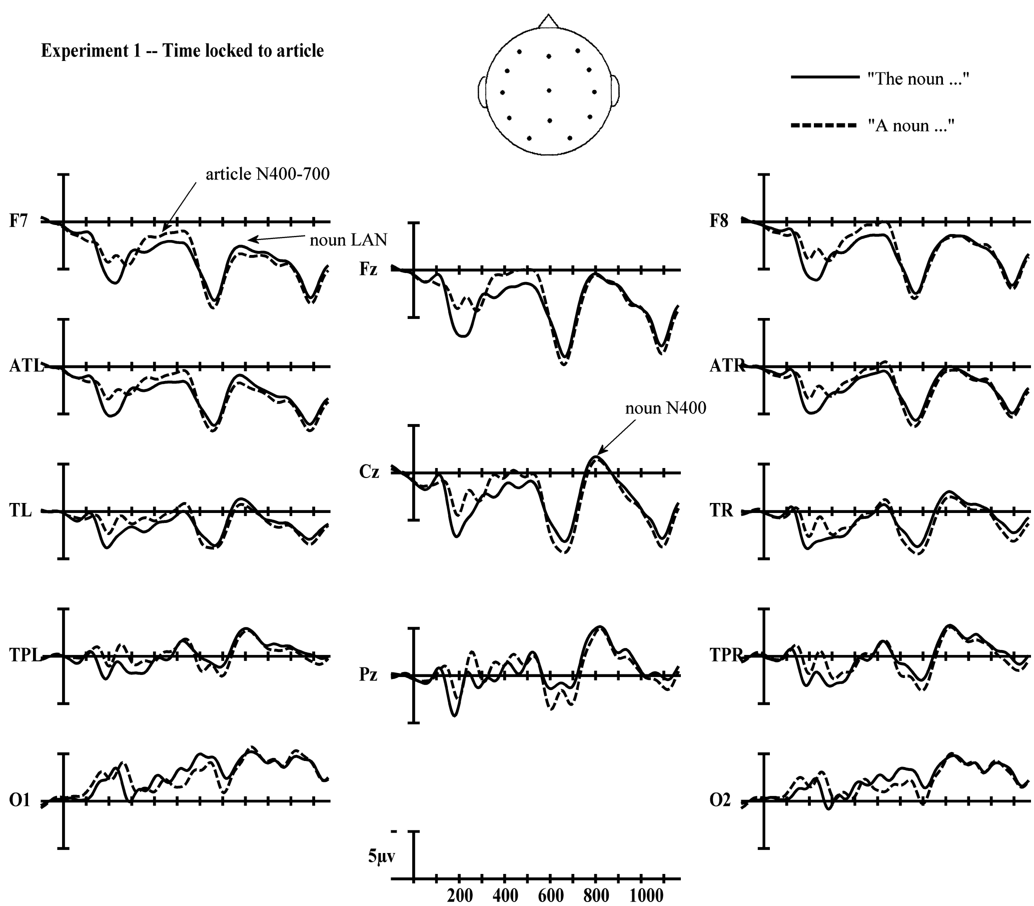

Fig. 1. Grand mean ERPs from 15 sites on the head time-locked to the onset of the sentence initial articles in Experiment 1. In this and all subsequent figures the ERP waveforms are plotted at the approximate locations shown in the head schematic located at the top of the figure (note that this is a view looking down at the top of the head with the nose pointed toward the top of the figure). The vertical calibration bar is placed at the time of the onset of the stimulus. Note that 100 ms of activity prior to stimulus onset is displayed (used as a baseline for equating the post-stimulus portion of each waveform).

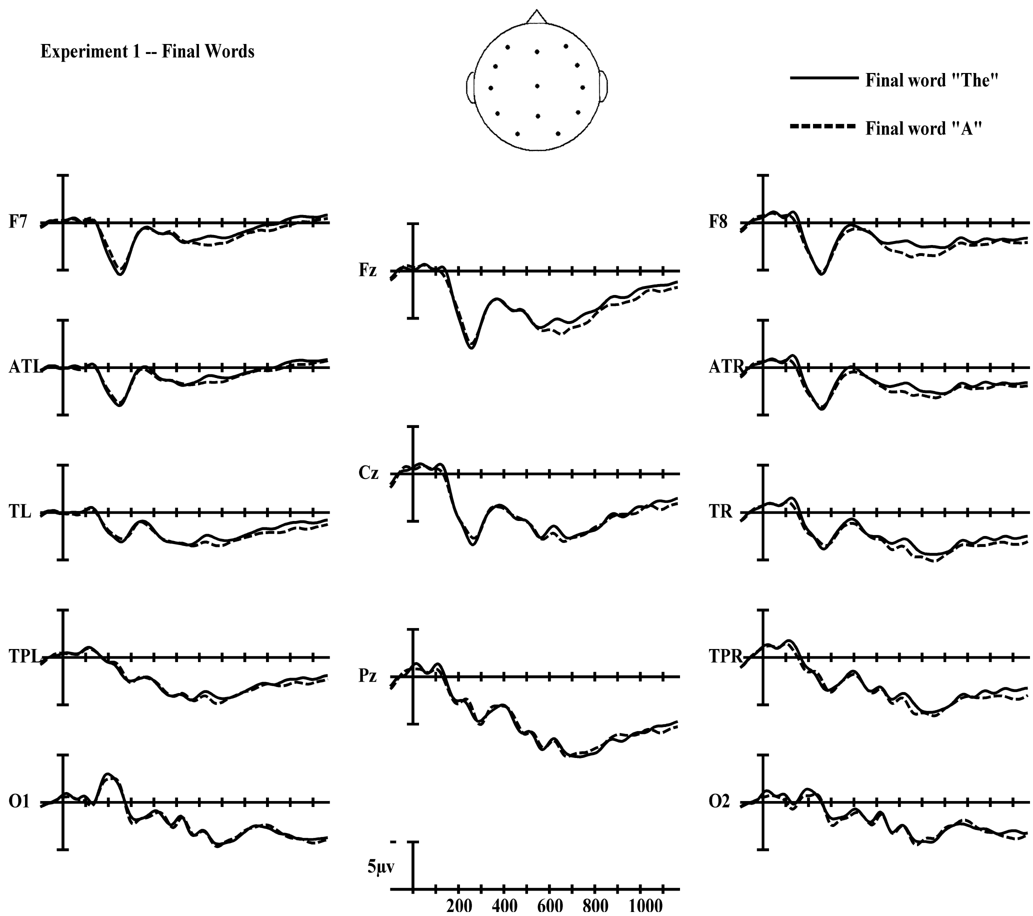

Fig. 2. Grand mean ERPs for final words from sentences beginning with the articles "The" and "A" (Experiment 1).

ing *A*, hence there was a reversal of the difference seen at the article itself. At the lateral sites, the words following *the* were also more negative-going (main effect of article: $F(1,23) = 4.18$, $p < .05$), especially over left anterior sites (interaction of article × hemisphere × electrode site: $F(4,92) = 6.30$, $p < .001$).

Final words. The grand averages of the ERPs to the final words are shown in Fig. 2. Sixteen percent of the trials time-locked to the final word were rejected due to artifact. There were no differences between the final words of sentences that began with "The" or "A" in either the 400–700 or 700–1000 ms windows.

2.3. Discussion

The purpose of Experiment 1 was to determine if there were ERP differences to articles, critical words and final words that were inherent in the processing of the two articles (*the* and *a*) without any manipulation of coreference. This was accomplished by comparing the ERPs to sentences beginning with "The" and "A" which were not preceded with a sentence containing a coreferential noun. There were three major findings involving the article, the critical word and the final word.

First, the ERPs elicited by the articles showed an interesting pattern. Both articles elicited the typical ERP pattern found with closed class words, the N280 and N400-700. [1] However, the waveform following the presentation of the article "A" was more negative-going than that following the article "The" especially over anterior sites. (Note that a similar difference in the preceding 0–150 ms window in the vicinity of the P2 may have carried over into the 300–600 window.) The fact that this difference between 300 and 600 ms occurs even without a preceding sentence suggests that it is not related to coreference per se, but that it could still be due to a lexical function of the articles. Van Petten and Kutas (1991) proposed that the N400-700 was not merely an indication of word-class per se, but rather reflected a functional property of closed class words. Specifically they linked it to the contingent negative variation (CNV), a slow negative component that in a typical CNV paradigm is a negativity that develops between a warning stimulus and a subsequent imperative stimu-

[1] In the present study, the later negativity extends to 600 ms rather than 700 ms. This is likely due to the rapid presentation rate of the present study.

lus (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). Since many closed-class words are found at the heads of phrases, subjects may be anticipating up-coming information (King & Kutas, 1995). Perhaps the greater negativity found for the article "A" reflects the anticipation of "new" information vs. "old" information. However, several researchers have found that there is a preference for the definite article at the beginning of sentences (to signal given information) and for the indefinite article in the object position (Yekovich, Walker, & Blackman, 1979; Wright & Glucksberg, 1976). Thus, it is possible that the presence of the indefinite article in the subject position created a less felicitous reading. The difference elicited by the articles is also likely due to a physical attribute of the articles themselves. In fact, the greater negativity to the one-letter article compared to the three-letter article is consistent with a recent study by Osterhout, Allen, and McLaughlin (2002). They examined ERPs elicited by open- and closed-class words and found that word length (vs. linguistic function) was found to be a main predictor of negativity. This explanation may not be at odds with the CNV explanation, in that it is possible that the word "A" was fixated and accessed in less time the word "The," leaving more time to "wait for" or anticipate the next word. This expectancy for the next word might be manifested as an enhanced CNV. If the enhanced negativity to the article "A" is due to a greater expectancy, it is difficult to say if this is due to the difference in the number of letters or to the different discourse functions of the articles. Further studies may help to shed more light on this finding.

A second major finding was that when time-locked to the preceding article, there were no reliable differences in the ERPs to critical nouns following the articles. This is important because it suggests that there should not be significant carry-over effects on nouns following the article when the coreference manipulation is added in Experiment 2. However, when the ERPs were time-locked to the critical words (i.e., the 100 ms preceding the critical word was used as a baseline), the words following *The* were more negative-going than those following *A*. This difference is not surprising given that the baseline was taken at a point where the waveforms diverged during processing of the articles. We submit that the pre-article baseline provides a more accurate indication of the critical word waveforms because it occurs at a point where the stimuli are the same across conditions (i.e., just prior to the article). In other words the pre-article baseline can be thought of as time-locking to the entire noun *phrase*.

Finally, the ERPs for the final words of sentences that began with "The" or "A" did not differ from each other (see Fig. 2). This is important because it suggests that article differences occurring at the beginning of the sentence also do not affect sentence wrap up effects associated with the ERPs to sentence final words.

3. Experiment 2

In Experiment 2, the single-sentence trials from Experiment 1 were all turned into two-sentence trials by the addition of an initial lead-in sentence. In the 120 experimental sentences this lead-in sentence set up the context for the second sentence and also contained a noun in object position that was either repeated or synonymous with the word in subject (critical word) position of the second sentence (see Table 1, examples 1–3). In addition, the critical noun was either coreferential or not, depending on its article (*The*: coreferential; *A*: non-coreferential). It was hypothesized that repeated/synonym critical words would produce smaller N400s and larger late positivities (repetitions only) than similar non-repeated items, even though the repetition occurred across a sentence boundary. Further, it was predicted that critical words following the definite article "The" would produce either a smaller N400 and/or a larger LAN than critical words following the indefinite article "A," because the definite, but not the indefinite, article signals that the following critical noun explicitly refers back to an instance of an item earlier in the discourse. Finally, it was predicted that words at the ends of sentences starting with an indefinite article would produce larger extended negativites than words at the ends of sentences beginning with a definite article, because readers will find these sentences to be relatively lacking in inter-sentence cohesiveness due to the absence of a coreferential tie.

The results of Experiment 1 served as a baseline for isolating effects due to coreference that are predicted in Experiment 2. In particular, the absence of ERP differences to critical nouns (using a pre-article baseline) and final words in Experiment 1 makes the finding of any such differences seen in Experiment 2 more clearly attributable to the coreferential manipulation.

3.1. Method

3.1.1. Participants

Twenty-four Tufts University students (14 females and 10 males) with a mean age of 18.63 ($SD = .65$) participated for partial course credit. All of the participants were right-handed, native speakers of English and had normal or corrected-to-normal vision. None had participated in Experiment 1.

3.1.2. Stimuli

There were 120 experimental trials, each consisting of two sentences (second sentences were the same as those used in Experiment 1). In 60 of the trials, the object of the first sentence was repeated in the second sentence. In half of these trials, the definite article "the" was used with the critical noun in the second sentence to indicate that the noun referred to the same entity as in the first sentence. In the other half, the indefinite article "a" was used to indicate that a new entity was being introduced (see 1–3 in Table 1 for examples of the coreferential and non-coreferential conditions). The first occurrence of the critical word was always in the object position of the first sentence, while the repetition or synonym always occurred in the subject position of the second sentence. In another 60 trials the critical word of the second sentence was a synonym of the previous noun. The object of the first sentence was altered to create the synonym trials, so that the critical word of the second sentence was always the same. The second sentence always began with the article followed by the critical word. The mean number of words intervening between the first occurrence/synonym of the first sentence and the critical word of the second sentence was seven (ranging from 4 to 10). Materials were counterbalanced such that each participant read only one form of the sentence pair, but each form was presented an equal number of times across participants. Hence, each participant was presented with 30 exemplars of each of the four-sentence types.

In addition, there were 30 filler trials that did not contain a repeated noun and had a different sentence structure than the experimental trials (see example 5 in Table 1). These materials were adapted from those used by Brownell, Potter, Bihrle, and Gardner (1986). The purpose of including these filler trials was twofold. One was to prevent the participant from always expecting a repeated or synonymous noun in the second sentence (although some of these filler sentences did contain a pronoun and referent as in Example 5). The second reason was to encourage them to process the pair of sentences as a unit. The fillers often required that an inference be made (or revised) to comprehend the meaning of the pair of sentences. Finally, there were 30 trials that contained a semantic anomaly (see example 4 in Table 1), always in the second sentence. The second sentence of each pair of filler and anomalous sentences were the fillers and anomalies used in Experiment 1.

3.1.3. Procedure

The sentence pairs were presented to participants one word at a time in the center of the computer screen. The participants were told to read each pair of sentences as a unit and to determine if the trial was semantically anomalous or not. In addition, they were told to expect comprehension questions at each rest break. Each trial proceeded as follows: A fixation cross appeared in the center of the screen for 500 ms. Five hundred milliseconds later the first word of the first sentence appeared for 345 ms. After a blank interval of 70 ms the next word appeared also for 345 ms. This continued until the end of the second sentence, with the exception that there was a blank interval of 370 ms after the final word of the first sentence. Hence, the stimulus onset asynchrony was 415 ms for individual words and 715 ms for the interval between the two sentences. Fifteen hundred milliseconds after the final word of the second sentence, the message "RESPOND NOW" was presented on the screen, signaling the participant to respond by pressing buttons labeled "yes" or "no" depending on whether or not the sentence pair had an anomaly. Participants were instructed to try not to blink during the presentation of the sentences. Breaks were given every 30 trials. There were 12 practice trials before the beginning of the experimental run. After every 30 trials, four true/false statements were presented to test the participant's comprehension of the preceding set of sentence pairs.

3.1.4. Data analysis

Analyses were conducted on mean amplitude values taken between a range of latencies using the 100 ms of activity that preceded word onset as a baseline. The ERP response was time-locked to the articles that preceded the critical word in the second sentence. (As in Experiment 1, analyses were also conducted using the 100 ms preceding the critical word as a baseline.) Waveforms to these items were examined in an extended epoch that included the full ERP to the critical noun as well. Several time windows were chosen for quantification: 150–300, 300–600, and 715–1015 ms after article onset (the latter window corresponds to 300–600 ms after critical word onset). The first two windows were chosen because they correspond to the time windows associated with the P2 and N280 (150–300) as well as the N400 and N400-700 (300–600). The N280 and N400-700 are prominent components observed to closed class words in previous studies (e.g., Neville et al., 1992). The third window (N400/LAN) was chosen to examine the ERP coreference response to the critical noun using a pre-article baseline. Finally, the ERP response to the last word of the second sentence was measured by using two windows: 400–700 and 700–1100 ms. These windows were chosen to examine the extended differences present in these waveforms.

Repeated measures analyses of variance (ANOVAs) similar to those used in Experiment 1 were performed. In addition, ANOVAs were also used to compare repetition/synonym and coreference/non-coreference, as well as a full factorial analysis with word and coreferential status both included as variables.

To more closely examine the effects of repetition and synonym at the midline sites, two additional sets of two-way repeated measures ANOVAs were performed using the mean amplitude in a 300–600 ms window and in a 600–1000 ms window. The first epoch was chosen because it corresponds to the time frame typically associated with the N400 and the second was chosen to capture activity associated with late positive-going waves. In the first set of analyses, the variables were word type (repetition, synonym, first occurrence in first sentence), and electrode site (Fz, Cz, and Pz), and in the second the variables were word type (repetition, synonym, and critical word of second filler sentences—see below), and electrode site (Fz, Cz, and Pz). For the comparable analyses at the lateral sites, an additional variable of hemisphere (left, right) was included, and the electrode site variable consisted of the five lateral sites (frontal vs. anterior temporal vs. temporal vs. temporal–parietal vs. occipital). The above analyses were followed up with pair-wise a priori contrasts of the repetition/synonym, repetition/first occurrence and synonym/first occurrence.

3.2. Results

3.2.1. Behavioral data

Participants accurately judged the sentence-pairs to be acceptable with greater than 93% accuracy (Coreferential/Repetition 96%, Non-Coreferential/Repetition 94%, Coreferential/Synonym 95%, and Non-Coreferential/Synonym 95%). There were no significant effects of word type or coreferential status.

3.2.2. Event-related potentials

Article and critical word—article effects. The waveforms for the two article conditions (collapsed across word type) are shown in Fig. 3 time-locked to the onset of the articles themselves. While the same set of early components (P1, N1, and P2) can be seen in this figure as were seen in Fig. 1, there are also a number of differences. As in Experiment 1, the articles were associated with an earlier anterior negativity peaking just before 300 ms (N280) and a later slow anterior negativity which continued to build until the onset of the subsequent critical word (N400-700). Following the N400-700 were the early components to the critical word itself. We used these waveforms for the coreference comparisons on the critical nouns to facilitate comparisons with the similar waveforms from Experiment 1 (i.e., to look for carry-over effects from the article).

There were no differences between the articles in the 150–300 ms window (P2 and N280), however, between 300 and 600 ms, there was a significant difference at the lateral sites ($F(1,23) = 5.39$, $p < .03$), with the waveforms for the article “a” being more negative-going. This difference was greatest over anterior sites (interaction of article and electrode site: $F(4,92) = 5.69$, $p < .01$).

The 715–1015 ms epoch (300–600 ms after presentation of the critical noun—Fig. 3) did not yield main effects of coreference status in either the midline or lateral analyses (midline: $p > .4$; lateral: $p > .7$). However,

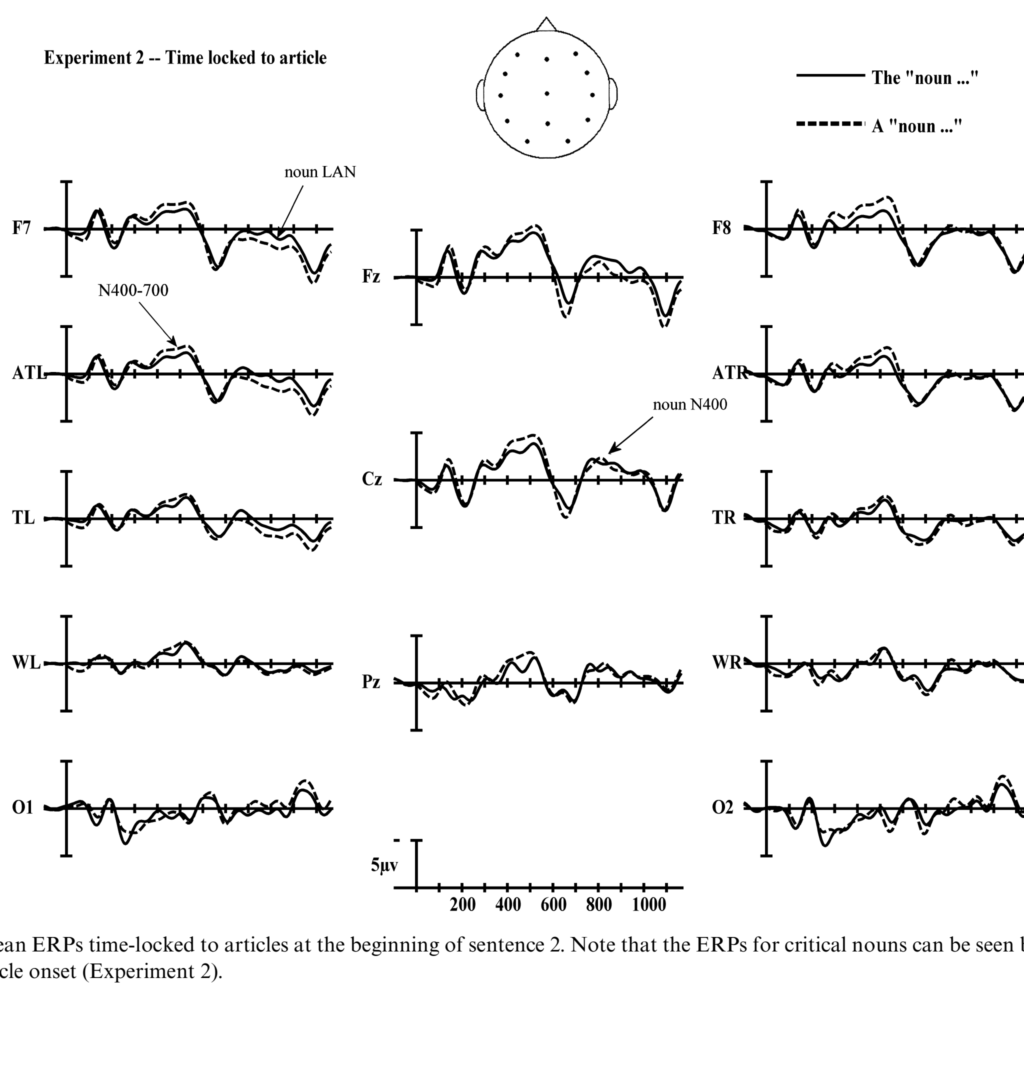

Fig. 3. Grand mean ERPs time-locked to articles at the beginning of sentence 2. Note that the ERPs for critical nouns can be seen beginning at about 400 ms after article onset (Experiment 2).

there were several significant and near significant interactions between coreference status and scalp distribution. At midline sites the electrode site by coreference status interaction was marginal ($F(2,46) = 2.83$, $p < .08$). At lateral sites there was an interaction between coreferential status and hemisphere ($F(1,23) = 4.67$, $p < .04$) as well as a three-way interaction between coreferential status, hemisphere and electrode site ($F(4,92) = 5.01$, $p < .006$). Follow-up analyses conducted to decompose these interactions revealed that there was a significant effect of coreference at Fz ($F(1,23) = 6.64$, $p < .017$), with coreferential critical words being more *negative-going* than non-coreferential words. There were no significant coreference effects at Cz or Pz ($ps > .8$). At the lateral sites coreferential critical words produced significantly more negative-going ERPs than non-coreferential words over left anterior sites as indicated by significant coreferential status by hemisphere interactions at frontal ($F(1,23) = 6.55$, $p < .018$), anterior-temporal ($F(1,23) = 4.82$, $p < .039$), and temporal sites ($F(1,23) = 6.07$, $p < .022$). At the temporal–parietal sites there was no detectable effect of coreference ($ps > .35$). Interestingly, at the left occipital site (O1) there was evidence of a reversal of the coreference effect, with the non-coreferential condition producing a marginally more negative deflection than the coreferential condition ($F(1,23) = 3.78$, $p < .064$).

As in Experiment 1, we analyzed the data using a baseline just prior to the critical word (300–600 ms window). Here, the re-baselined analyses showed very similar results except that the interaction of coreferential status and hemisphere did not reach significance ($p > .21$), but the interaction of coreference status, hemisphere, and electrode site *was* similar to the other baseline ($F(4,92) = 5.44$, $p < .006$).

Word type differences. Fig. 4 shows the waveforms elicited by the critical word (collapsed across coreference condition) timelocked to the preceding article. At the midline sites, the repeated words were less negative-going ($F(1,23) = 7.41$, $p < .01$). The word type difference did not reach significance at the lateral sites ($p > .11$; however, when baselined to the critical word, it did [$F(1,23) = 4.53$, $p < .04$]). This analysis assessed only the attenuation of the repetitions compared to the synonyms, so in order to examine the attenuation of N400 to *both* synonyms and repetitions, we compared these two word types to the corresponding word from the first sentence (i.e., the first occurrence or the synonym).

Plotted on the left side of Fig. 5 are the waveforms time-locked to the two critical word type conditions (collapsed across coreferential status) contrasted with waveforms time-locked to the corresponding word in the first sentence (i.e., the first occurrence or the synonym, labeled "antecedent"). As can be seen, onset of the critical word was associated with an early negativity (N1) at 140 ms followed by a positivity (P2) at 210 ms at most

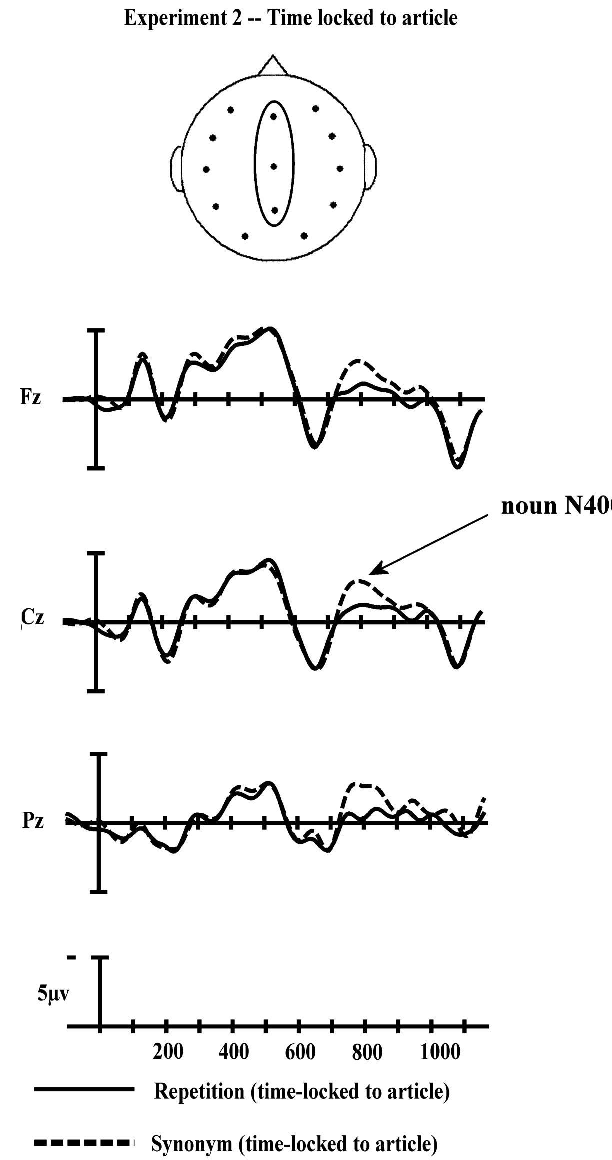

Fig. 4. Grand mean ERPs at the midline sites, time-locked to the article in the second sentence for the two word type conditions (collapsed across coreferential status) in Experiment 2.

sites anterior to O1/O2. At O1/O2 there was an initial P1 at 120 ms, N1 at 200 ms, and P2 at 260 ms. Because the onset of the next word occurred at 400 ms, a similar pattern of early components can be seen starting at about 500 ms.

In the 300–600 ms measurement window there was a main effect of word type (first occurrence vs. repetition vs. synonym, midline: $F(2,46) = 18.51$ $p < .0001$; lateral: $F(2,23) = 16.17$, $p < .0001$). Follow-up analyses contrasting the three conditions revealed that first occurrences were significantly more negative-going than both repeated words (midline: $F(1,23) = 42.67$, $p < .00005$; lateral: $F(1,23) = 35.10$, $p < .0005$) and the synonyms (midline: $F(1,23) = 11.05$, $p < .003$; lateral: $F(1,23) = 10.60$, $p < .004$), and the synonyms were more negative-going

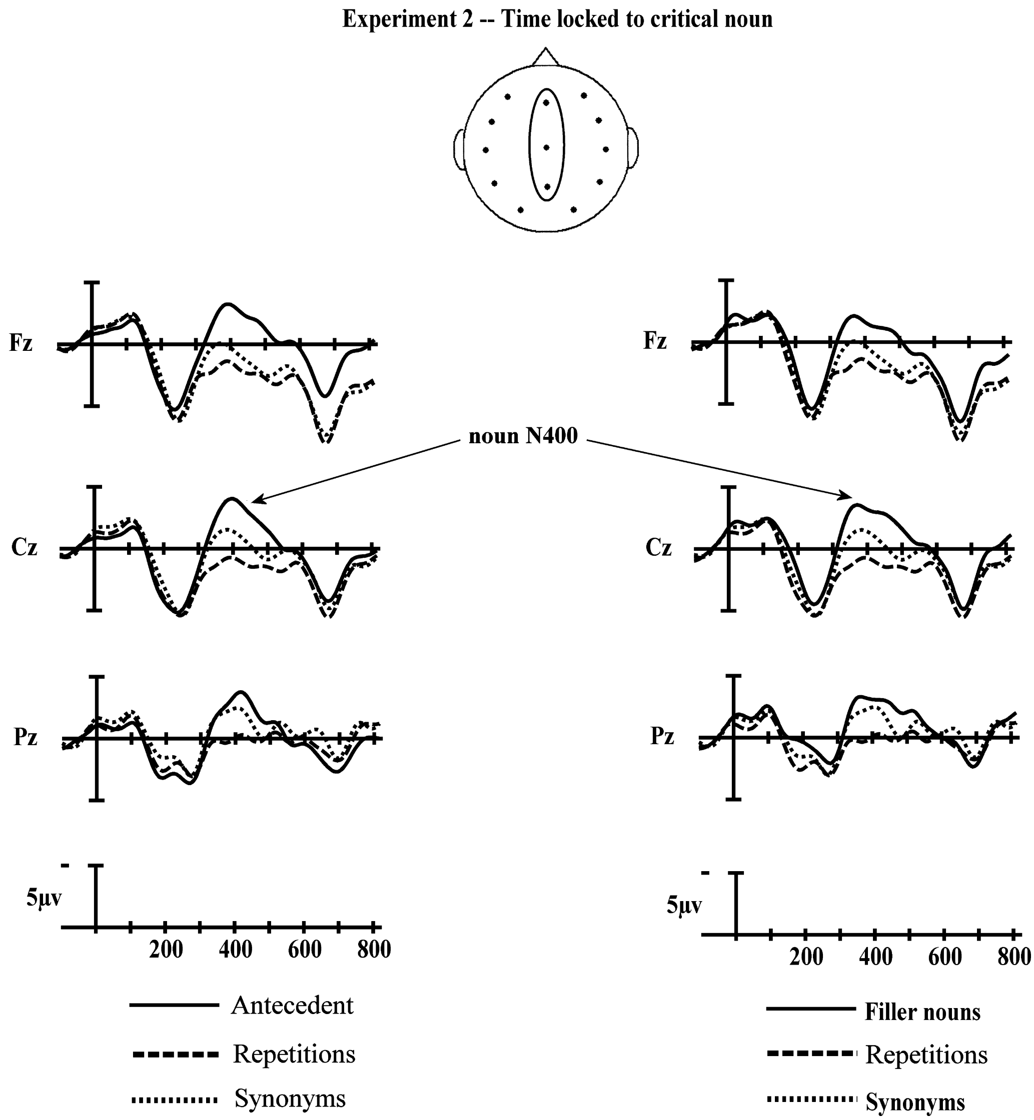

Fig. 5. Grand mean ERPs at midline sites for critical nouns in Experiment 2. Note that "antecedents" are words in sentence 1 that are either repeated or are synonyms of the critical words in the second sentence. Filler nouns are the first content words of the second sentence of the filler condition.

than the repeated words (midline: $F(1,23)=5.46$, $p<.03$; lateral: $F(1,23)=4.53$, $p<.04$). The differences between first occurrences and repetitions/synonyms were largest over Fz and Cz for midline comparisons (interactions of word and electrode site: repetition: $F(2,46)=15.78$, $p<.00005$; synonym: $F(2,46)=14.67$, $p<.0001$), and at most scalp sites except for the occipitals for lateral comparisons (interaction of word and electrode: repetition: $F(4,92)=26.66$, $p<.00005$; synonym: $F(4,92)=26.66$, $p<.00005$; synonym: $F(4,92)=22.18$, $p<.00005$). For the repetition/synonym comparison, there was an interaction of word type, hemisphere, and electrode site ($F(4,92)=2.92$, $p<.05$) reflecting a greater negativity for synonyms over the right temporal–parietal sites.

Van Petten and Kutas (1990) found that the N400 amplitude of content words in single sentences declines with increasing sentence position, most likely reflecting the build-up of contextual constraints. Van Petten (1995) reported that this decline over sentence position has not been found with longer texts. Since sentence position has not been examined with two-sentence texts, it was unclear what effect to predict for this experiment. For example, the smaller N400 for repeated and synonym items in sentence two might reflect the larger build up of context at this point vs. the point of the first occurrence in sentence one. Therefore, the critical repeated and synonym words in sentence two were also compared to the first content word of the second filler sentences (see the right-side of Fig. 5). Because these items follow a comparable build up of context, this allowed for a more appropriate comparison of sentence position. There was again a main effect of word type (first filler content vs. repetition vs. synonym, midline: $F(2,46)=14.46$, $p<.00005$; lateral: $F(2,46)=9.74$, $p<.0004$). Follow-up analyses revealed that the first content word of the filler trials was more negative-going than both the repetitions (midline:

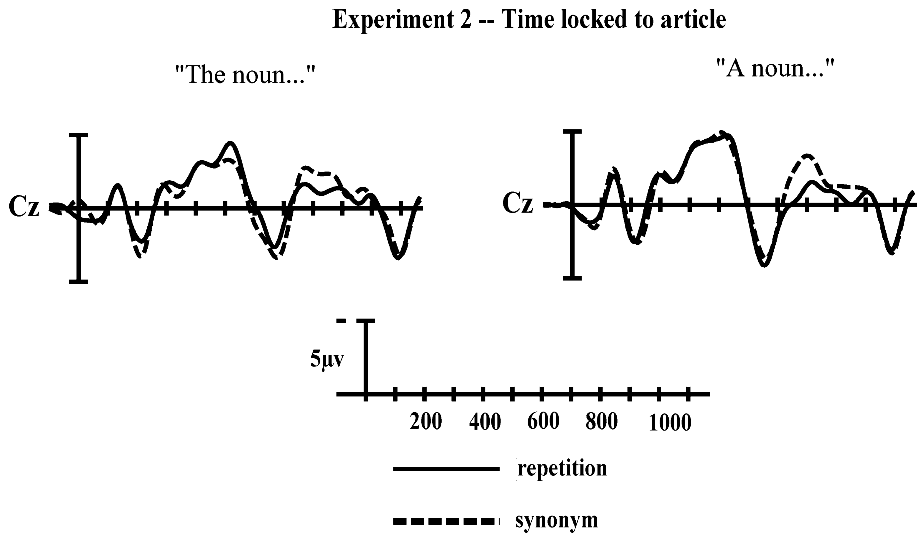

Fig. 6. Grand mean ERPs at Cz time-locked to the article in the second sentence comparing the two word type conditions in the coreference condition (on the left) and the non-coreference condition (on the right).

$F(1,23) = 22.07$, $p < .0001$; lateral: $F(1,23) = 15.37$, $p < .0007$) and synonyms (midline: $F(1,23) = 11.51$, $p < .003$; lateral: $F(1,23) = 6.16$, $p < .02$). For the repetition comparison, the difference was largest over temporal sites (interaction of word and electrode: $F(4,92) = 8.65$, $p < .002$). For the synonym comparison, the difference was larger over temporal (and frontal) sites (interaction of word and electrode: $F(4,92) = 6.66$, $p < .004$).

Word type by coreference. A full factorial ANOVA was done to see if the word type effect was modulated by coreferential status. This analysis was limited to a comparison of synonyms with repetitions (and not the first occurrences or first content words of the second filler sentences) vis-à-vis coreferential status. [2] The word type and coreferential variables did not yield a significant interaction (midline: $p > .5$; lateral: $p > .9$). For both of the coreference conditions, the attenuation of the repetitions compared to the synonyms had a similar magnitude (see Fig. 6).

Final word. The grand averages for the final word (collapsing across word type) are shown in Fig. 7. Approximately 20% of the trials time-locked to the final word were rejected due to artifact. Following the N1 and P2 components, a negative-going component onset at about 300 ms. The divergence in the waveforms could be seen starting at about 400 ms and lasting until the end of the recording epoch. In the 400–700 ms window, there was a main effect of coreferential status, with the final words of the sentences that began with "A" being more negative-going (midline: $F(1,23) = 5.30$, $p < .03$; lateral: $F(1,23) = 6.36$, $p < .02$). Between 700 and 1100 ms, coreferential status interacted with electrode site (midline: $F(2,46) = 10.39$, $p < .001$; lateral: $F(4,92) = 5.98$, $p < .01$), indicating a larger effect at the central and posterior sites.

3.3. Discussion

In this experiment repeated words and synonyms were compared in contexts in which they either were or were not coreferential with a previous word. There were four major findings involving: (a) the article, (b) the word type (repetitions and synonyms), (c) the coreferential status of the critical word in the second sentence, and (d) the final words of the sentence pair. Each of these findings is discussed below.

As in Experiment 1, the article "A" elicited a greater N400-700 than the article "The." The presence of this difference both with and without a context sentence is interesting because it suggests that there were processing differences even when the article "the" was not explicitly referring to given information. As mentioned in the Discussion section of Experiment 1, the greater N400-700 elicited by the article *A*, may reflect anticipation of the upcoming noun. It is unclear if this is due to a discourse function (new vs. old information), word length or some other factor(s). As pointed out in the Discussion of Experiment 1, the difference in the ERPs elicited by the articles began in the vicinity of the P2 (150–300 ms window) in Experiment 1 so it may be a carry-over effect. It is unclear why the earlier difference was not present in the second experiment, but one possibility is that it is an exogenous component related to word size; hence it would tend to be refractory in Experiment 2 because subjects read a lead-in sentence. In fact, a comparison of Figs. 1 and 3 show that the P2 in general was smaller in Experiment 2 compared to that of Experiment 1, where

[2] As stated earlier, these two comparison conditions (first occurrences and first content words) are limited in that they are not in a comparable sentence position and are not matched on lexical features (e.g., word length, frequency).

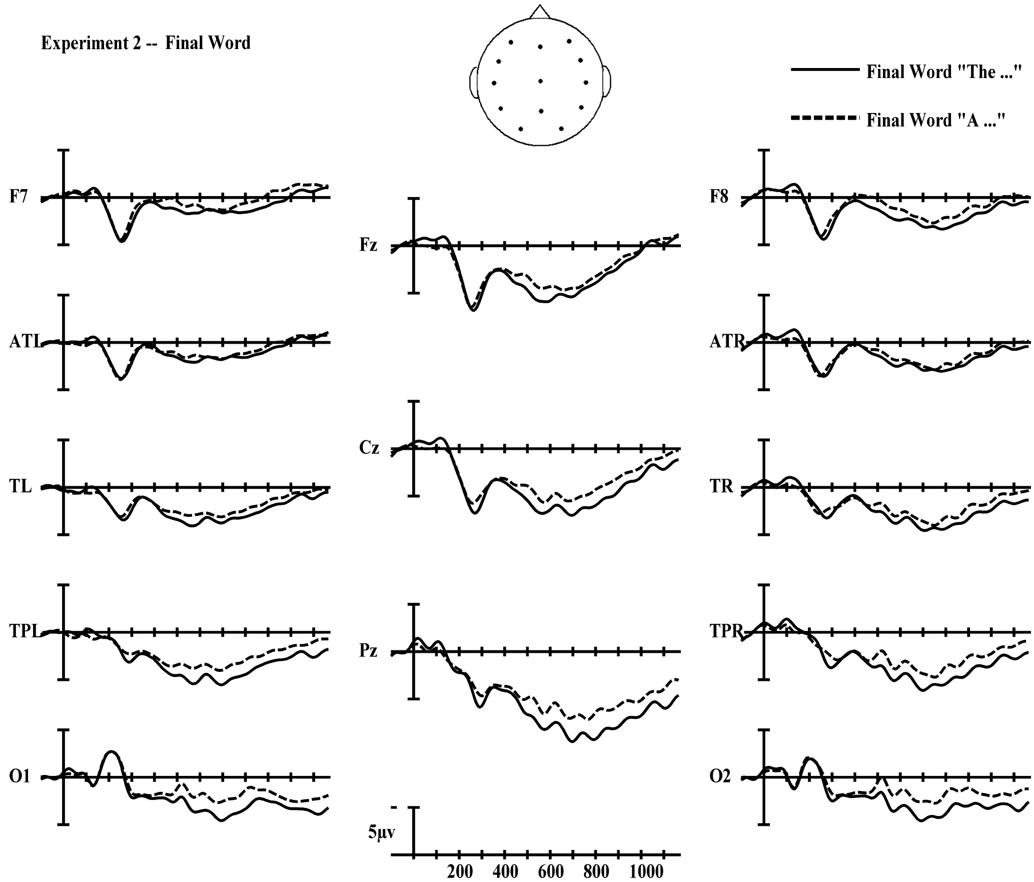

Fig. 7. Grand mean ERPs for final words from sentences beginning with the articles "The" and "A" (Experiment 2).

the articles were the first words presented in each trial. This difference found upon presentation of the articles, then, suggests that there are item-specific effects associated with the processing of these two articles, but that importantly they did not carry over into the epoch of the following critical noun contaminating the comparisons of interest.

Regarding the word type variable, based on findings from previous studies, we had predicted that there would be an attenuation of the N400 component to nouns in subject position of a second sentence, especially when this word was a repetition of a word from the prior sentence, but also to words that were synonymous with an earlier word. We found this precise pattern in comparisons to the first occurrence in the first sentence and to the first content word of filler sentences (which were not repetitions). Furthermore, the synonyms had greater amplitude N400s than the repeated items, but smaller amplitudes than first occurrences. These findings are consistent with repetition and semantic priming effects reported in previous list and sentence studies, and demonstrate that N400 repetition and semantic priming can occur across a sentence boundary.

We also predicted that the above word type effect might be modulated by the word's coreferential status. That is, if the subject of the second sentence was not only repeated or related but also constituted the same discourse entity, we expected to find even greater attenuation of the N400 compared to cases where the participant was forced to constitute a new discourse entity (i.e., when the subject was not coreferential).

One possible reason for why the coreferential variable did not appear to modulate the N400 is that the repetition and semantic priming effects may have been so strong that they obscured any attenuation due to a weaker coreference effect. During the reading of text, words that are identical or related in meaning may be automatically detected as such whether they are coreferential or not—especially when they occur in the immediately following sentence. Although context has been found to constrain priming effects (as in Garrod & Sanford, 1977), the only constraint in the present materials was the type of article that immediately preceded the noun and this may not have been strong enough to modify the priming effects. [3]

[3] Even though the definite article generally refers to a previous stated noun, it does not *always* do so. For example, the second sentence in Table 1 could have read: *The cab that she was in yesterday came very close to hitting a car.*

When we compared the ERPs elicited by the coreferential and non-coreferential critical words, we found a very different pattern (from the N400) in which there was a greater negativity over left anterior and temporal sites to *coreferential* words. This "coreferential effect" not only had a different distribution than the N400, but also had the opposite polarity of the predicted N400 effect (i.e., coreferential items had larger negativities). The larger left anterior negativity or "LAN" elicited by coreferential words is noteworthy. This is because there have been several previous studies that have reported similar left anterior negativities.

In some of these studies, a syntactic violation has elicited such an effect (Kutas & Hillyard, 1983; Munte, Heinze, & Mangun, 1993; Neville et al., 1991; Osterhout & Holcomb, 1992; Rosler, Friederici, Putz, & Hahne, 1993). However, because the coreferential condition was *not* syntactically anomalous, it is difficult to explain how the left anterior negativity found in Experiment 2 is similar to such an effect. Interestingly, others have reported a somewhat different LAN that they claim may reflect an increase in the demands on working memory (King & Kutas, 1995; Kluender & Kutas, 1993). For example, King and Kutas compared the ERPs elicited by sentences that differed in their working memory requirements (object and subject relative sentences). They found a LAN to verbs in object relative sentences, such as "The reporter who the senator harshly *attacked* admitted the error" compared to subject relative sentences, such as "The reporter who harshly *attacked* the senator admitted the error." Their explanation was that when the first verb (attacked) is encountered, thematic roles must be assigned, a process that is more difficult in the object relative sentences, taxing the cognitive resources of working memory. In addition, they point out that when the main verb (*admitted*) is reached, the head noun must be "reactivated" to be assigned—indicating that referential assignment increases working memory load (e.g., Carpenter, Miyake, & Just, 1994) and the amplitude of the LAN. Therefore, it is possible that the LAN found in the present study reflects a similar increase in the demands of working memory. In other words, when a definite article is encountered, it signals that an upcoming noun will need to be assigned to an antecedent. This process of referential assignment causes an increase in the working memory load. However, when an indefinite article is encountered, it signals that no such assignment will be needed, because instead of referring to a previous entity the noun introduces new information.

Comparison of the ERPs to critical items following articles from Experiments 1 and 2 provides evidence that the greater LAN for coreferential words in Experiment 2 is specifically related to the assignment of reference. This is because a similar effect was not seen to these same items when they were not preceded by a context sentence containing the antecedent to the coreferential critical word. However, there was a difference in both experiments when the baseline was determined just prior to the critical word. As stated earlier, we feel that the "pre-article" baseline was a more neutral one. In the future, it will be important to replicate the LAN effect using other manipulations of coreference and working memory requirements.

The final words of the sentence pairs elicited differences in the ERPs as well (see Fig. 7). The waveform for sentence final words from the non-coreferential trials was more negative-going than the comparable waveform from the coreferential trials. So, while there was no evidence of an N400 effect due to coreference on the critical nouns following the articles, there was some evidence of a delayed negative-going effect by sentence end. Although this difference is more extended in time than that seen in most sentence studies of the N400, it did have a similar scalp distribution to the typical N400 effect (central–parietal). It was also similar to the extended negativity observed to the final words of sentences containing a gender-mismatching pronoun (e.g., Osterhout & Mobley, 1995), and in several studies by Osterhout and Holcomb (1992, 1993) examining syntactic violations. One possibility proposed in the Introduction was that such an effect might reflect difficulty in processing the message of the sentence (see Osterhout & Holcomb, 1995). For example, it is possible that in Experiment 2 participants had more difficulty integrating the meaning of sentences that began with "A" compared to those that began with "The" even though the sentences did not contain a semantic or syntactic anomaly. In the case of the coreferential trials, the second sentence could be easily integrated with the first sentence because the sentence subject referred to a previous entity. In other words, the coreferential trials were more coherent than the non-coreferential ones, because the words and sentences were connected to one another to a greater degree. The fact that participants were slightly more accurate at correctly classifying the repetition/coreferential trials as semantically acceptable is consistent with this argument.

We had originally expected to examine a late positive component that has been observed in previous studies of repetition priming (Rugg, 1990; Van Petten et al., 1991). However, a late positivity was not observed to repeated items in the second sentences of this experiment. The ERPs in the time window following the critical word tended to maintain the same predominantly left anterior negativity to coreferential words that was present in the preceding epoch. In the previous studies by Rugg (e.g., 1990) and Van Petten and colleagues (1991), there was an N400 effect present just prior to the LPC. In the present study, the only N400 effect found was in the comparisons involving repeated words, synonyms and two types of control words. These were not followed by an LPC. One possibility is that the words used in the present study were not of low enough frequency, a factor that has been important in the elicitation of prior repetition effects (see Rugg, 1990). An alternative possibility is that rapid presentation rate used in the current study (to more closely match normal reading rates) precluded the presence of such a late positivity. This could happen, for example, because the demands for rapid word processing might supersede the process reflected by the LPC component of repetition.

To summarize, the results of these experiments revealed some important findings regarding the processing of noun phrase anaphors in text. First, the greater anterior negativity (N400-700) found in response to the indefinite article (*A*) compared to the definite article (*The*) suggests differential processing even at this early time in the noun phrase. Second, the larger N400-priming effects found for repetitions vs. synonyms extended previous priming effects to two-sentence texts. Third, the greater left anterior negativity or LAN for coreferential items implicates working memory processes in the referential assignment of noun anaphors. Finally, the greater negativity to the final words of non-coreferential trials implies that the meanings of these sentences were more difficult to integrate with a discourse representation established by an earlier sentence than were the meanings of coreferential sentences.

References

Anderson, J. E., & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus onset asynchronies: An event-related brain potential study. *Psychophysiology, 32*, 177–190.

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

Bentin, S., & Peled, B. S. (1990). The contribution of task-related factors to ERP repetition effects at short and long lags. *Memory & Cognition, 18*, 359–366.

Brownell, H. H., Potter, H. H., Bihrle, A. M., & Gardner, H. (1986). Inference deficits in right brain damaged patients. *Brain and Language, 27*, 310–321.

Carpenter, P. A., Miyake, A., & Just, M. A. (1994). Working memory constraints in comprehension: Evidence from individual differences, aphasia, and aging. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics*. San Diego: Academic Press.

Feustel, T. C., Shiffrin, R. M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General, 112*, 309–346.

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

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1219–1248.

Garrod, S., Freudenthal, D., & Boyle, E. (1994). The role of different types of anaphor in the on-line resolution of sentences in a discourse. *Journal of Memory and Language, 32*, 1–30.

Garrod, S. C., & Sanford, A. J. (1977). Interpreting anaphoric relations: The integration of semantic information while reading. *Journal of Verbal Learning and Verbal Behavior, 16*, 77–90.

Geisser, S., & Greenhouse, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95–112.

Gernsbacher, M. A. (1989). Mechanisms that improve referential access. *Cognition, 32*, 99–156.

Grieve, R. (1973). Definiteness in discourse. *Language and Speech, 16*, 365–372.

Halliday, M. A. K. (1970). Language structure and function. In J. Lyons (Ed.), *New horizons in linguistics* (pp. 140–165). Baltimore: Penguin Books.

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology, 30*, 47–61.

Holcomb, P. J., Coffey, S., & Neville, H. (1992). The effects of context on visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology, 8*, 203–241.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes, 5*, 281–312.

Holcomb, P. J., & Neville, H. J. (1991). The electrophysiology of spoken sentence processing. *Psychobiology, 19*, 286–300.

Irwin, D. E., Bock, J. K., & Stanovich, K. E. (1982). Effects of information structure cues on visual word processing. *Journal of Verbal Learning and Verbal Behavior, 21*, 307–325.

Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 21–38.

Karayanidis, F., Andrews, S., Ward, P. B., & McConaghy, N. (1991). Effects of inter-item lag on word repetition: An event-related potential study. *Psychophysiology, 28*, 307–318.

King, J. W., & Kutas, M. (1995). Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience, 7*, 376–395.

Kluender, R., & Kutas, M. (1993). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience, 5*, 196–214.

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory & Cognition, 11*, 539–550.

Monsell, S. (1985). Repetition in the lexicon. In A. W. Ellis (Ed.), *Progress in the psychology of language* (Vol. 2, pp. 147–195). Hillsdale, NJ: Erlbaum.

Munte, T. F., Heinze, H., & Mangun, G. (1993). Dissociation of brain activity related to syntactic and semantic aspects of language. *Journal of Cognitive Neuroscience, 5*, 335–344.

Murphy, G. L. (1984). Establishing and accessing referents in discourse. *Memory & Cognition, 12*, 489–497.

Nagy, M. E., & Rugg, M. D. (1987). Modulation of ERPs by word repetition: The effects of inter-item lag. *Psychophysiology, 26*, 431–436.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Neville, H. J., Mills, D. L., & Lawson, D. S. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex, 2*, 244–258.

Neville, H. J., Nicol, J. L., Barss, A., Forster, K. I., & Garrett, M. F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 3*, 151–165.

Osterhout, L., Allen, M., & McLaughlin, J. (2002). Words in the brain: Lexical determinants of word-induced brain activity. *Journal of Neurolinguistics, 15*, 171–187.

Osterhout, L., Allen, M. D., McLaughlin, J., & Inoue, K. (2002). Brain potentials elicited by prose-embedded linguistic anomilies. *Memory & Cognition, 30*, 1304–1312.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*, 785–806.

Osterhout, L., & Holcomb, P. J. (1993). Event-related potentials and syntactic anomaly: Evidence of anomaly detection during the perception of continuous speech. *Language and Cognitive Processes, 8*, 413–437.

Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiological studies of human cognition*. Oxford: Oxford University Press.

Osterhout, L., & Mobley, L. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language, 34*, 739–773.

Rosler, F., Friederici, A., Putz, P., & Hahne, A. (1993). Event-related brain potentials while encountering semantic and syntactic constraint violations. *Journal of Cognitive Neuroscience, 5*, 345–362.

Rosler, F., Pechmann, T., Streb, J., Roder, B., & Hennighausen, E. (1998). Parsing of sentences in a language with varying word order: Word-by-word variations of processing demands are revealed by event-related brain potentials. *Journal of Memory and Language, 38*, 150–176.

Rugg, M. D. (1985). The effects of semantic priming and word repetition on event-related potentials. *Psychophysiology, 22*, 642–647.

Rugg, M. D. (1987). Dissociation of semantic priming, word and nonword repetition effects by event-related potentials. *Quarterly Journal of Experimental Psychology, 39A*, 123–148.

Rugg, M. D., Furda, J., & Lorist, M. (1988). The effects of task on the modulation of event-related potentials by word repetition. *Psychophysiology, 25*, 55–63.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. *Memory & Cognition, 18*, 367–379.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1–17.

Smith, M. E., & Halgren, E. (1989). Event-related potentials during lexical decision: Effects of repetition, word frequency, pronounceability, and concreteness. *Electroencephalography and Clinical Neurophysiology, Supplement, 40*, 417–421.

St. George, M., Mannes, S., & Hoffman, J. E. (1989). Global semantic expectancy and language comprehension. *Journal of Cognitive Neuroscience, 6*, 70–83.

Van Berkum, J. J. A., Brown, C., & Hagoort, P. (1999). Early referential context effects in sentence processing: Evidence from event-related brain potentials. *Journal of Memory and Language, 41*, 147–182.

Van Berkum, J. J. A., Brown, C., Hagoort, P., & Zwitserlood, P. (2003). Event-related brain potentials reflect discourse-referential ambiguity in spoken language comprehension. *Psychophysiology, 40*, 235–248.

Van Berkum, J. J. A., Hagoort, P., & Brown, C. (1999). Semantic integration in sentences and discourse: Evidence from the N400. *Journal of Cognitive Neuroscience, 11*, 657–671.

Van Berkum, J. J. A., Zwitserlood, P., Hagoort, P., & Brown, C. (2003). When and how do listeners relate a sentence to the wider discourse. Evidence from the N400 effect. *Cognitive Brain Research, 17*, 701–718.

Van Petten, C. (1995). Words and sentences: Event-related brain potential measures. *Psychophysiology, 32*, 511–525.

Van Petten, C., & Kutas, M. (1990). Interactions between sentence context and word frequency in event-related brain potentials. *Memory & Cognition, 18*, 380–393.

Van Petten, C., & Kutas, M. (1991). Influences of semantic and syntactic context on open- and closed-class words. *Memory & Cognition, 19*, 95–112.

Van Petten, C., Kutas, M., Kluender, R., Mitchiner, M., & McIsaac, H. (1991). Fractionating the word repetition effect with event-related potentials. *Journal of Cognitive Neuroscience, 3*, 131–150.

Yekovich, F. R., Walker, C. H., & Blackman, H. S. (1979). The role of presupposed and focal information in integrating sentences. *Journal of Verbal Learning and Verbal Behavior, 18*, 535–548.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature, 203*, 380–384.

Wright, P., & Glucksberg, S. (1976). Choice of definite versus indefinite articles as a function of sentence voice and reversibility. *Quarterly Journal of Experimental Psychology, 28*, 561–570.