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Brain potentials elicited by prose-embedded linguistic anomalies

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Linguistic theories distinguish between syntax (sentence form) and semantics (sentence meaning). Correspondingly, recent studies have shown that syntactic and semantic anomalies elicit distinct changes in the event-related brain potential (ERP). However, these results have been obtained with highly artificial methodologies and have not yet been generalized to more natural reading conditions. Here, we recorded ERPs while subjects read a naturalistic prose passage. The subjects either read for comprehension with no other task being assigned or read for comprehension and made acceptability judgments after each sentence. Consistent with prior work and regardless of the subjects' assigned task, syntactic anomalies elicited a large positive wave (P600), whereas semantic anomalies elicited a large increase in N400 amplitude. These results demonstrate that the qualitatively distinct ERP responses elicited by syntactic and semantic anomalies are not artifacts of unnatural aspects of previously used stimuli, thereby providing additional evidence that separable syntactic and semantic processes exist.

One fundamental claim of current linguistic theories is that syntax (sentence form) and semantics (sentence meaning) are separable and independent (see Chomsky, 1986). Whether this claim is an accurate description of the processes underlying language comprehension has been a matter of debate. A common assumption within psycholinguistics is that separable, largely independent processes construct distinct syntactic and semantic representations of a sentence (Ferreira & Clifton, 1986; Frazier & Rayner, 1982). An alternative view is that sentence meaning can be derived directly, without an intervening syntactic level of representation (Johnson-Laird, 1983; Marslen-Wilson & Tyler, 1987; McClelland, St. John, & Taraban, 1989).

One means for contrasting these views involves recording event-related brain potentials (ERPs) elicited during language comprehension (see Hagoort, Brown, & Osterhout, 1999; Osterhout, McLaughlin, & Bersick, 1997). The advantage of this approach derives from the fact that ERPs provide an on-line, millisecond-by-millisecond record of the brain's electrical activity during comprehension. Furthermore, ERPs are multidimensional, varying in polarity, timing, morphology, and scalp distribution. If one assumes that cognitively distinct processes are mediated by neurally distinct brain systems, evidence that events occurring at the syntactic and the semantic levels elicit distinct brain responses (i.e., responses that differ in timing, distribution, or polarity) could be construed as supporting the claim that separable syntactic and semantic processes exist.

Particularly relevant to this issue is recent evidence that (at least under certain experimental conditions) syntactic and semantic anomalies elicit distinct changes in the ERP (for a review, see Hagoort et al., 1999, or Osterhout et al., 1997). Semantically inappropriate words (e.g., "The cat will *bake* the food") elicit a centroparietal negative wave that peaks at about 400 msec (the *N400 effect*; Kutas & Hillyard, 1980, 1984). Syntactically anomalous words (e.g., "The cat will *eating* the food") elicit a centroparietal positive wave that begins about 500 msec after word onset (the *P600 effect*) and persists for at least several hundred milliseconds (Hagoort, Brown, & Groothusen, 1993; Osterhout, 1997; Osterhout & Holcomb, 1992, 1993; Osterhout, Holcomb, & Swinney, 1994; Osterhout & Mobley, 1995; Osterhout & Nicol, 1999). In some reports, syntactic anomalies have also elicited an anterior negative wave peaking between 125 and 500 msec (Friederici, Hahne, & Mecklinger, 1996; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992). These findings have been shown to generalize well across types of linguistic anomalies (see Osterhout et al., 1997), types of languages (including English, Dutch, Italian, and French; Angrilli et al., 2002; Hagoort et al., 1993; Osterhout, McLaughlin, Allen, Inoue, & Loveless, 2002), modality (visual and auditory; Hagoort & Brown, 2000; Holcomb & Neville, 1991; Osterhout & Holcomb, 1993), and rates of word presentation (Allen, Badecker, & Osterhout, in press; Hagoort & Brown, 2000; Kutas, 1993; McKinnon & Osterhout, 1996).

Such evidence seems to indicate that at least some aspects of syntactic and semantic processing are neurobiologically distinct. However, this evidence has been obtained with highly artificial methods. For example, in the

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vast majority of these studies, subjects were instructed to read or listen to long lists of unrelated sentences. As far as we can ascertain, only two published studies have contrasted the ERP responses to syntactic and semantic anomalies embedded in naturalistic prose. Kutas and Hillyard (1983) had subjects read an English prose passage containing semantic anomalies and morphosyntactic anomalies involving errors in number agreement or verb tense (e.g., "As a turtle grows its shell *grow* too"). The semantic anomalies elicited an increase in N400 amplitude. Few reliable differences were found between the syntactically well-formed and the ill-formed conditions, although the syntactically anomalous words elicited a small increase in negativity between 300 and 400 msec at some anterior electrode sites. In a similar study (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998), subjects read a German prose passage containing semantically anomalous, morphosyntactically anomalous (involving case errors), and misspelled words. Only semantically anomalous words elicited a robust N400 effect. However, all anomaly types elicited positive waves onsetting at about 500 msec and persisting for at least 500 msec.

The results of these two studies are inconsistent with each other and with the results of studies in which lists of unrelated sentences were used. Procedural differences between Kutas and Hillyard's (1983) and Münte et al.'s (1998) experiments (and between these two studies and sentence list studies) might partly explain the discrepancies. For example, Kutas and Hillyard (1983) presented English stimuli, whereas Münte et al. (1998) presented German stimuli. Kutas and Hillyard (1983) used word-onset intervals ranging from 640 to 760 msec, whereas Münte et al. (1998) used word onset intervals of 1 sec. Furthermore, Kutas and Hillyard (1983) plotted only the initial 600 msec of activity subsequent to critical word onset; this epoch might have been too short in duration to observe late positive waves, even if they were present in the data.[1] In any event, it remains unclear whether the finding that syntactic and semantic anomalies elicit the P600 and the N400 effects, respectively, can be generalized to conditions in which subjects read prose, rather than lists of unrelated sentences.

Another artificial methodological aspect of prior studies involves the task assigned to subjects. With a few exceptions, researchers have asked subjects to judge the acceptability or grammaticality of each sentence, in addition to reading for comprehension. It is unclear what effect this secondary task might have on the primary task of interest (language comprehension) and on the processing of and brain responses to linguistic anomalies. To date, only one study has included a task manipulation within a single experiment, using identical materials across task conditions. Osterhout, McKinnon, Bersick, and Corey (1996) presented a series of unrelated sentences (some of which contained a syntactic anomaly) and asked subjects either to read for comprehension or to read for comprehension and make a sentence acceptability judgment at the end of each sentence. Syntactic anomalies elicited a large positive wave under both task conditions, although the amplitude of this effect was larger in the acceptability judgment condition. Here, we replicated this task manipulation by presenting prose, rather than lists of sentences, and by including semantic, as well as syntactic, anomalies.

In summary, we asked subjects to read a natural, connected prose passage that contained syntactically and semantically anomalous words. The subjects either read the prose for comprehension or read for comprehension and made a sentence acceptability judgment after each sentence. Our goals were twofold: first, to verify that syntactic anomalies elicit the P600 effect (and perhaps anterior negativities) and semantic anomalies elicit the N400 effect under these more naturalistic reading conditions, and second, to determine which (if any) of these brain responses are strongly influenced by the task assigned to the subjects. Evidence that these brain responses are observed even when subjects simply read prose for comprehension would extend the generalizability of such findings to more natural reading conditions, thereby providing additional evidence that separable syntactic and semantic processes exist.

METHOD

Subjects

Twenty-four neurologically normal, right-handed native English speakers (18–45 years of age) participated for class credit after giving informed consent. Twelve subjects participated in each of the two task conditions.

Stimuli and Procedures

The subjects read a modified version of an essay taken from an English as a second language text describing Amelia Earhart's last flight (Kenan, 1998). The text contained 173 sentences, ranging from 4 to 15 words in length, and approximately 1,700 words. Ninety sentences were chosen to be the critical sentences. Three versions (well-formed control, semantically anomalous, and syntactically anomalous) of each sentence were constructed by replacing a sentence-embedded word (50% nouns and 50% verbs) with a semantically anomalous word or by modifying the selected word so that it became syntactically anomalous. The syntactic anomalies involved inappropriate inflectional morphology resulting in an agreement or verb tense error. These sentences were then used to construct three versions of the text, so that only one version of each sentence appeared in each version of the text, and each text version contained 30 exemplars each of well-formed, semantically anomalous, and syntactically anomalous critical sentences. Example paragraphs of the text are shown in Table 1.

The subjects sat in a comfortable chair situated in a dimly illuminated room. The text was presented as a series of sentences. Each

Table 1
Example Paragraphs From the Essay Presented to Subjects

In 1937, Amelia Earhart was thirty-eight years of age. She was probably the most acclaimed woman pilot in the world then. She decided to realize a *dream/dreams/toaster* of hers she had as a girl. Flying around the world at the equators was her goal.
There would also be three fast U.S. ships which were positioned to assist. The U.S.S. Ontario was *positioned/positions/flirting* halfway between Lae and Howland. The U.S.S. Swan was positioned between Howland and Honolulu. The Coast Guard ship Itasca was *waiting/waits/laughing* just off Howland.

Note—Italicized words represent the critical words in the control, syntactically anomalous, and semantically anomalous conditions, respectively.

trial consisted of the following events. A fixation cross appeared for 500 msec, after which a sentence was presented in a word-by-word manner, with each word appearing on the center of the screen for 300 msec. A blank-screen interval of 400 msec separated words. Sentence-ending words appeared with appropriate punctuation. A 1,450-msec blank-screen interval followed each sentence to allow eye blinks. This interval was followed by a prompt asking the subjects to respond by pressing a button on a joystick.

Task was manipulated in a between-subjects manner. In the passive reading condition, the subjects passively read the text for comprehension and, when presented with the response prompt, pushed one of the buttons when ready for the next sentence. The subjects were told that anomalous words would occasionally appear in the text and were instructed to ignore the anomalies. In the sentence acceptability judgment condition, the subjects read for comprehension and made sentence acceptability judgments at the end of each sentence. The subjects indicated their responses by pressing one button on the joystick for *acceptable* and the other button for *unacceptable*. Button-response pairings were counterbalanced across subjects.

EEG Recordings and Analysis

Continuous EEG was recorded from 13 scalp sites, using tin electrodes attached to an elastic cap. Electrode placement included International 10–20 system locations (Jasper, 1958) over homologous positions over the left and right occipital (O1, O2) and frontal (F7, F8) regions and from frontal (Fz), central (Cz), and parietal (Pz) midline locations. Several nonstandard sites were also used, including Wernicke's area and its right-hemisphere homologue (WL, WR: 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz), temporal (TL, TR: 33% of the interaural distance lateral to Cz), and anterior temporal (ATL, ATR: one half the distance between F7/F8 and T3/T4) sites. Vertical and horizontal eye movements were monitored via two electrodes placed near the eyes. The above channels were referenced to an electrode placed over the left mastoid bone and were amplified with a bandpass of 0.01–100 Hz (3-db cutoff).

EEG was sampled at 200 Hz throughout the experiment. Epochs comprised the 100 msec preceding and the 1,180 msec following word onsets. Trials characterized by excessive eye movement or amplifier blocking (8%) were removed prior to averaging. ERPs were quantified as the mean voltage within a latency range (time-locked to word onset), relative to a baseline of activity comprising the 100 msec preceding and the 50 msec immediately following critical word onset. Analyses of variance (ANOVAs) were performed on mean amplitudes within four time windows: 50–150, 150–300, 300–500, and 500–800 msec. These windows correspond to the latency ranges of the early negativities, N400, and P600 effects previously reported.

Data acquired at midline and lateral sites were treated separately to allow for quantitative analysis of hemispheric differences. ANOVAs with a between-subjects factor of task and within-subjects factors of sentence type and electrode site were performed on the data from the midline sites. The lateral site ANOVAS contained an additional within-subjects factor of hemisphere. To protect against Type I error owing to violations of the assumption of equal variances of differences between conditions of within-subjects factors, the Huynh–Feldt correction was applied when effects with more than one degree of freedom were evaluated. Corrected p values are reported. Reliable effects in the omnibus analysis were followed, when appropriate, by pairwise comparisons. These comparisons were evaluated using a modified Bonferroni procedure (Keppel, 1982). Under this procedure, $\alpha = .04$ for each comparison.

RESULTS

Acceptability Judgments

Well-formed, semantically anomalous, and syntactically anomalous sentences were judged to be acceptable on 87%, 4%, and 6% of the trials, respectively, in the sentence acceptability judgment condition.

Effects of Anomaly Type on Event-Related Potentials

Figure 1 plots the grand-average ERPs (collapsed over the task factor) to critical words in the three sentence types. Consistent with prior reports, a clear negative-positive complex was visible in the first 300 msec following word onset (the *N1–P2* complex). These potentials were followed by a negative-going component with a peak around 400 msec (N400).

Reliable differences between conditions did not emerge until approximately 300 msec after word onset. (For all analyses involving mean amplitudes between 50 and 300 msec, Fs < 2.) ANOVAs on mean amplitude within the 300- to 500-msec window revealed a main effect of sentence type [midline, $F(2,44) = 27.14$, $MS_e = 8.76$, $p < .0001$; lateral, $F(2,44) = 21.70$, $MS_e = 10.63$, $p < .0001$] and an interaction between sentence type and electrode position [midline, $F(4,88) = 11.80$, $MS_e = 1.05$, $p < .001$; lateral, $F(8,176) = 10.10$, $MS_e = 1.73$, $p < .01$]. Pairwise comparisons revealed that semantic anomalies elicited larger N400s than did the other conditions [semantic vs. well formed, midline, $F(1,22) = 47.86$, $MS_e = 8.20$, $p < .0001$, and lateral, $F(1,22) = 28.55$, $MS_e = 11.00$, $p < .0001$; semantic vs. syntactic, midline, $F(1,22) = 31.16$, $MS_e = 11.49$, $p < .0001$; and lateral, $F(1,22) = 3.51$, $MS_e = 12.04$, $p = .07$], particularly over posterior regions [sentence type × electrode site: semantic vs. well formed, midline, $F(2,44) = 18.90$, $MS_e = 1.17$, $p < .0001$, and lateral, $F(4,88) = 17.66$, $MS_e = 1.86$, $p < .0001$; semantic vs. syntactic, midline, $F(2,44) = 14.86$, $MS_e = 0.95$, $p < .0001$, and lateral, $F(4,88) = 3.66$, $MS_e = 1.90$, $p < .1$]. Although the syntactic anomalies elicited a slightly larger N400 than did the well-formed controls at midline sites, this N400 difference was not robust [midline, $F(1,22) = 0.62$, $MS_e = 6.58$, $p > .4$]. At lateral sites, ERPs to syntactic anomalies were slightly more positive-going than those to well-formed sentences at anterior locations and more negative-going than those at posterior locations [sentence type × electrode site: $F(4,88) = 8.80$, $MS_e = 1.73$, $p < .01$].

The main effect of sentence type was also robust between 500 and 800 msec [midline, $F(2,44) = 18.18$, $MS_e = 11.46$, $p < .0001$; lateral, $F(2,44) = 16.33$, $MS_e = 15.64$, $p < .001$], and differences between conditions were largest posteriorly, particularly over midline sites [$F(4,88) = 3.34$, $MS_e = 1.82$, $p < .1$]. These effects reflected the large positive wave (P600) elicited by syntactic anomalies, relative to the other two conditions (syntactic vs. well formed, midline, $F(1,22) = 21.11$, $MS_e = 12.90$, $p < .0001$, and lateral, $F(1,22) = 18.81$, $MS_e = 17.33$, $p < .001$; syntactic vs. semantic, midline, $F(1,14) = 27.39$, $MS_e = 12.71$, $p < .0001$, and lateral, $F(1,22) = 30.49$, $MS_e = 14.19$, $p < .001$]. The P600 effect was larger over posterior sites, particularly over midline sites [sentence type × electrode site: syntactic vs. well formed, $F(2,44) = 3.98$, $MS_e = 1.77$, $p < .05$, and syntactic vs. semantic, $F(2,44) = 5.38$, $MS_e =$

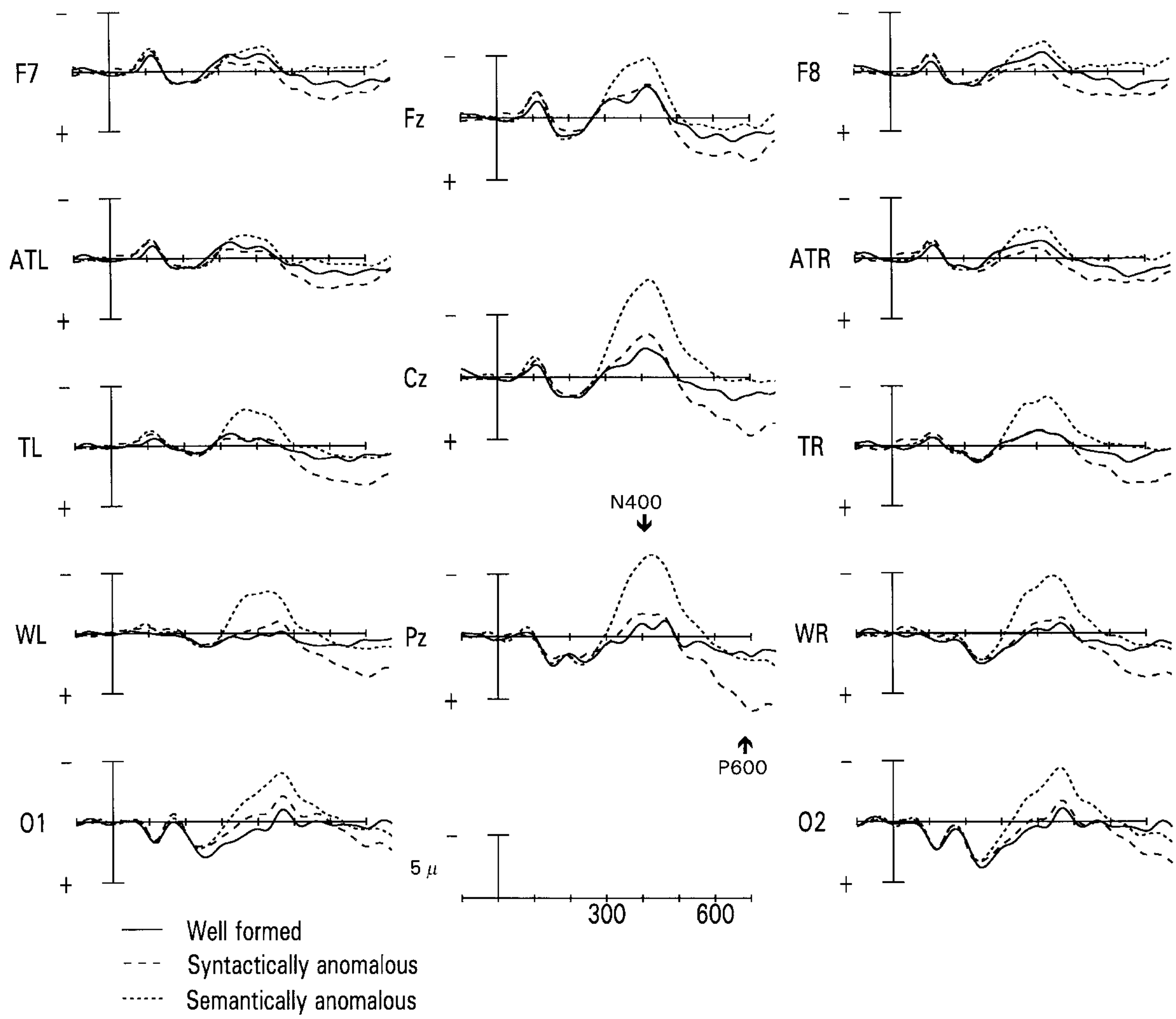

Figure 1. Grand average event-related potentials to well-formed, semantically anomalous, and syntactically anomalous words, recorded over 3 midline and 10 lateral electrode sites. Onset of the critical word is indicated by a vertical calibration bar. Each hashmark represents 100 msec. Negative voltage is plotted up.

1.21, $p < .05$]. ERPs to semantic anomalies were slightly more positive-going than those to well-formed sentences, beginning at about 600 msec, but only at the most posterior sites (Pz, 01, 02). However, there were no robust differences between the semantically anomalous and the well-formed controls within this window [main effect of sentence type, midline, $F(1,22) = 0.53$, $p > .4$, and lateral, $F(1,22) = 0.48$, $p > .4$; sentence type × electrode site, midline, $F(2,44) = 1.86$, $p > .15$, and lateral, $F(4,88) = 1.06$, $p > .3$].

Effects of Task on Event-Related Potentials

Difference waves, derived by subtracting the response to the well-formed control condition from the response to each type of anomaly, are shown in Figures 2A (semantic anomaly condition) and 2B (syntactic anomaly condition). For both anomaly types, midline ERPs were more positive-going for the judgment condition than for the passive reading condition, particularly over anterior locations, beginning at about 300 msec and continuing throughout the epoch [300–500 msec: task × sentence type × electrode site, $F(4,88) = 3.68$, $MS_e = 1.05$, $p < .05$]. This task effect was more robust for the syntactic anomalies [300–500 msec, task × sentence type × electrode, $F(2,44) = 6.07$, $MS_e = 1.03$, $p < .01$; 500–800 msec, $F(1,22) = 3.59$, $MS_e = 1.77$, $p = .07$] than for the semantic anomalies (Fs $\leq$ 1). Despite this effect of task, the P600 effect to the syntactic anomalies was reliable under both task conditions [judgment condition, midline, $F(1,11) = 39.16$, $MS_e = 6.93$, $p < .001$, and lateral, $F(1,11) = 19.77$, $MS_e = 9.06$, $p < .01$; passive reading condition, midline, sentence type × electrode site, $F(2,22) = 3.59$, $MS_e = 2.21$, $p = .05$, and lateral, main effect of sentence type, $F(1,11) = 5.78$, $MS_e = 25.59$, $p < .05$].

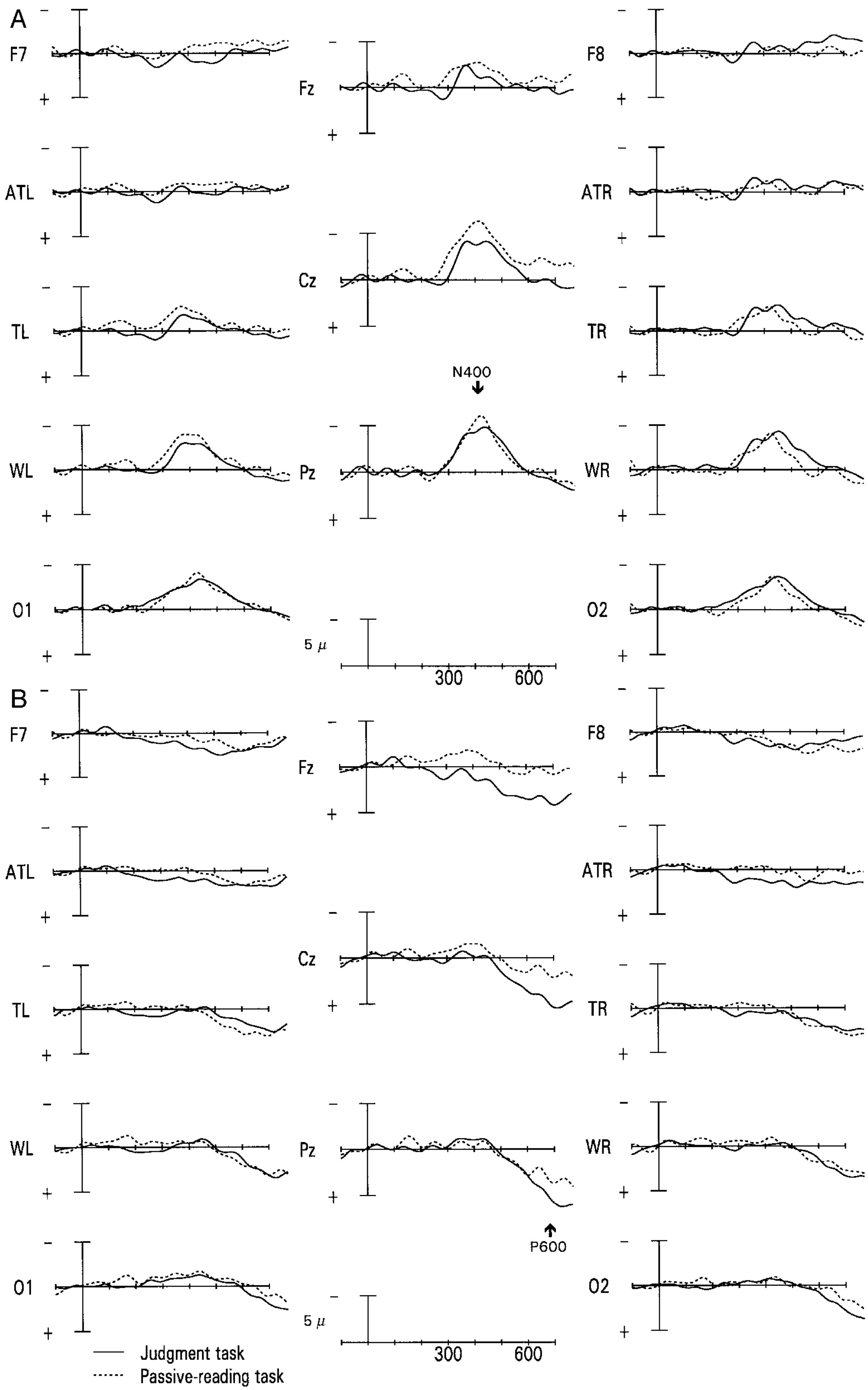

Figure 2. Difference waves formed by subtracting event-related potentials elicited by well-formed controls from those elicited by critical words in the sentence judgment (solid lines) or passive-reading (dashed lines) tasks. (A) Semantic anomaly condition. (B) Syntactic anomaly condition.

Extended Epoch

We also examined an extended epoch of activity encompassing the 2,200 msec of activity that immediately followed critical word onset, collapsing across the task variable (Figure 3).[2] Mean amplitude differences between 300 and 500 msec and between 500 and 800 msec were highly similar to those reported using the shorter epochs. Between 300 and 500 msec, ERPs to semantically anomalous words were more negative-going over midline sites than were those to the well-formed [$F(1,17) = 26.58$, $MS_e = 10.71$, $p < .001$] and syntactically anomalous sentences [$F(1,17) = 19.74$, $MS_e = 13.62$, $p < .001$]. There was no reliable difference between the syntactically anomalous and the well-formed conditions [$F(1,17) < 1$, $p > .8$]. Between 500 and 800 msec, ERPs to the syntactically anomalous condition were more positive-going than were those in the well-formed condition [$F(1,17) = 15.44$, $MS_e = 14.52$, $p = .001$] and the semantically anomalous condition [$F(1,17) = 18.91$, $MS_e = 14.75$, $p < .001$]. ERPs to the semantically anomalous words did not differ reliably from ERPs to those in the well-formed condition [$F(1,17) < 1$, $p > .5$].

Inspection of Figure 3 also reveals that the large positive wave elicited by the syntactically anomalous words persisted for at least 1,600 msec—that is, for more than 2 sec and throughout the epochs elicited by at least two subsequent words. A much smaller amplitude positive shift was also observable in the ERPs to the semantically anomalous words; this effect became most notable 1,100 or 1,200 msec after critical word onset and persisted for more than half a second. ANOVAs were performed on mean amplitudes within two windows: between 800 and 1,700 msec (to capture the portion of the waveform containing the largest amplitude positive shift in the semantic condition) and between 800 and 2,200 msec (to examine the temporal extent of the effects in both anomalous conditions). ERPs to the syntactic anomalies were robustly more positive-going than were those to the well-formed condition in both time windows [800–1,700 msec, $F(1,17) = 13.26$, $MS_e = 17.21$, $p < .01$; 800–2,200 msec, $F(1,17) = 8.41$, $MS_e = 18.12$, $p = .01$], whereas ERPs to the semantic anomalies were not, under the modified Bonferroni procedure [800–1,700 msec, $F(1,17) = 4.82$, $MS_e = 8.59$, $p > .04$; 800–2200 msec, $F(1,17) = 2.41$, $p > .1$].

DISCUSSION

We report that syntactic and semantic anomalies elicit distinct brain responses (the P600 and the N400 effects, respectively), even when they are embedded in naturalistic, connected prose. The observation that syntactic and semantic anomalies elicit these two very different brain responses has now been generalized across languages (e.g., English, Dutch, French, and Italian), modalities (visual and auditory), types of anomaly, rates of word presentation, and various other methodological and stimulus factors. Such good generalization makes it unlikely that this result reflects an artifact of a particular combination of stimuli, methods, and language. Rather, the accumulating evidence supports the generalization that the human brain responds differently to linguistic anomalies involving syntax and se-

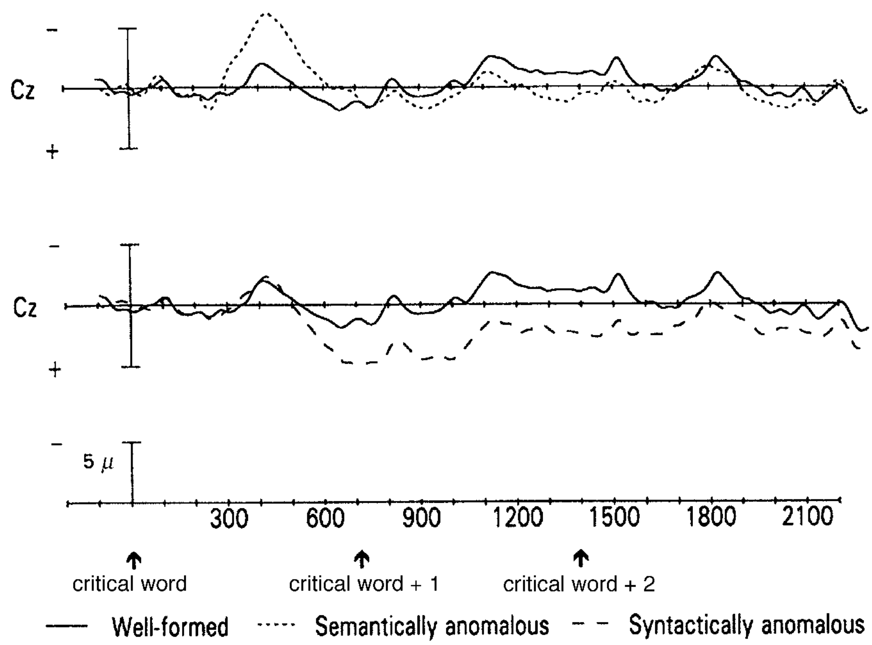

Figure 3. Extended epoch plotting event-related potentials to the critical word and to subsequent words in the sentence. Top panel: Semantic anomaly condition versus control condition. Bottom panel: Syntactic anomaly condition versus control condition.

mantics, as manifested in the P600 and the N400 effects. This conclusion, in turn, supports the claim that separable syntactic and semantic processes exist.

Limitations and apparent exceptions to this generalization do exist. For example, several studies have reported that the ERP response to syntactic anomalies is dominated by an anterior negativity (usually maximal between 200 and 500 msec), rather than a P600-like positivity (Münte, Heinze, & Mangun, 1993; Rösler, Friederici, Pütz, & Hahne, 1993). There are numerous ways in which these experiments differ from those reporting P600 effects, and these differences could affect the results. For example, most studies reporting an anterior negativity, rather than a P600-like positivity, have placed the anomalous word at the end of the sentence. This potentially confounds the effects of the anomaly with end-of-sentence wrap-up effects (see Osterhout, 1997, for evidence in support of this possibility). Some of these studies have included tasks that might have confounded the response to the anomaly. For example, Rösler et al. asked participants to make lexical decisions to critical words. It is not clear how the lexical decision task might interact with the response to a linguistic anomaly. Finally, there might be limitations to generalizations across languages. Most of the studies reporting anterior negativities in the absence of P600s have presented German stimuli, whereas the majority of studies reporting P600 effects have presented English stimuli. Much of the grammatical work in English is encoded in word order, whereas similar grammatical work in German is encoded in a system of case-marking (but see Angrilli et al., 2002, for evidence of a P600 response in Italian, which is also a case-marked language). At the least, caution is needed in comparing the responses to ostensibly similar linguistic constructions presented in different languages.

Other studies have reported a biphasic response to syntactic anomalies, in which an anterior negativity is followed by a P600-like positivity (Friederici et al., 1996; Neville et al., 1991; Osterhout & Holcomb, 1992, 1993). Friederici and colleagues have proposed that there are two separable and functionally distinct anterior negativities: an early one ranging from 100 to 250 msec and a later one ranging from 300 to 500 msec (Friederici, 1995; Friederici et al., 1996). These researchers have also proposed that the early effect specifically reflects phrase structure anomalies, whereas the later effect reflects syntactic incongruity in general. In the present study, we did not observe any anterior negativities in response to the syntactic anomalies. A large number of prior studies have also failed to find such negativities (see, e.g., Hagoort et al., 1993; McKinnon & Osterhout, 1996; Osterhout, 1997; Osterhout et al., 1994; Osterhout & Nicol, 1999). This might be due, in part, to the small amplitude and variable temporal qualities of these negativities. Increased variance across trials or subjects or insufficient signal-to-noise ratios could obscure these effects even if they are present. In any case, a careful reading of the extant literature suggests that the antecedent conditions that elicit anterior negativities might not be sufficiently understood to allow for clear theoretical interpretations of these effects.

Our results are seemingly inconsistent with those reported by Münte et al. (1998). These researchers presented a prose passage containing sentence-embedded syntactic anomalies, semantic anomalies, and misspelled words. In contrast to the results reported here, all three types of anomaly elicited positive waves (although the semantic anomalies, but not the other anomalies, also elicited an N400 effect). We cannot, at present, reconcile these different outcomes. These different results might be due to differences in methods, stimuli, and/or language. However, it is our belief that the preponderance of evidence is consistent with our generalization. In particular, Münte et al.'s (1998) observation that sentence-embedded semantic anomalies elicit a positive wave is inconsistent with the results of a majority of the relevant studies (see, e.g., Hagoort & Brown, 1994; Osterhout, 1997; Osterhout & Mobley, 1995; Osterhout & Nicol, 1999). One important consistency between our results and those of Münte et al. (1998) is that the ERP responses to syntactic and semantic anomalies become less distinct over time. In the present study, both types of anomaly elicited more positive-going activity than did well-formed controls, beginning at about 1,100 msec, although this effect was much more robust in the syntactic condition. Because few reports have included extended-epoch averages, it is difficult to know whether this is true only under prose conditions or is more generally true. It is also unclear whether this late-onset positivity is an extension of the neural events underlying the P600 effect or a reflection of separate neural events.

In the present study, the task manipulation had a quantitative, rather than a qualitative, effect on ERPs. Specifically, syntactic anomalies elicited a larger amplitude P600 in the acceptability judgment condition than in the passive-reading condition (for a similar result, see Osterhout et al., 1996). There are many possible explanations for this task effect. For example, passive readers, more than those who were explicitly monitoring for anomalies, might have varied considerably in their attention to the prose and the anomalous words. The greater between-subjects variance within the P600 window in the passive-reading condition ($MS_e = 25.59\ \mu V$) than in the acceptability judgment condition ($MS_e = 9.06\ \mu V$) is consistent with this notion. Another possibility is that the response to the anomalies is influenced by their degree of task relevance (see Osterhout & Hagoort, 1999), either by virtue of modulating the neural processes underlying the P600 effect or by engaging neural systems that are sensitive to task relevance (such as those indexed by the P300; Donchin, 1981). It should be noted, however, that all of the subjects reported noticing the linguistic anomalies, regardless of task, and that the anomalies were relevant to both tasks, although perhaps in different ways.

We should mention explicitly that none of these results brings us closer to understanding the cognitive and neural underpinnings of these language-sensitive ERP effects. Most important, it is not clear whether these effects reflect linguistic processes themselves or processes that are correlated with, but indeterminately removed from, the linguistic processes themselves. For this reason, inferences about the timing of linguistic processing on the basis of the temporal aspects of the ERP results are premature.

Finally, although the experimental conditions used here more closely approximate "normal" reading conditions than have the methods used previously, people do not normally read sentences presented one word at a time at the slow rate of 700 msec per word. Faster visual presentation rates and connected natural speech introduce the potentially serious problems of component overlap in the responses to successive words. In the present study, the relatively long interval between words allowed us to more clearly ascertain the responses to the critical words without contaminating the response of interest with the responses to subsequent words. However, several studies have shown that the P600 and N400 effects can be observed with visual rates as fast as 400 msec per word and with connected natural speech (Allen et al., in press; Hagoort & Brown, 2000; Holcomb & Neville, 1991; Osterhout & Holcomb, 1993), indicating that the results reported here generalize to fluent, naturalistic speech, as well as to connected prose.

In summary, our results demonstrate that syntactic and semantic anomalies elicit qualitatively distinct brain responses (the P600 and the N400 effects, respectively) even when they are embedded in prose and when subjects are assigned no task other than to comprehend what they are reading. These findings provide additional evidence from the normal, intact human brain that at least some aspects of syntactic and semantic processing are neurobiologically distinct. At present, little is known about the cognitive and neurobiological processes underlying the N400 and P600 effects. It is not unreasonable to believe that as we learn more about these processes, we will simultaneously be learning more about the differences in how the brain deals with the syntax and the semantics of language.

REFERENCES

Allen, M., Badecker, W., & Osterhout, L. (in press). Syntactic features are analyzed independently of their hosts. *Language & Cognitive Processes*.

Angrilli, A., Penolazzi, B., Vespignani, F., De Vincenzi, M., Job, R., Ciccarelli, L., Palomba, D., & Stegagno, L. (2002). Cortical brain responses to semantic incongruity and syntactic violation in Italian language: An event-related potential study. *Neuroscience Letters*, **322**, 5-8.

Chomsky, N. (1986). *Knowledge of language*. New York: Praeger.

Donchin, E. (1981). Surprise! . . . Surprise? *Psychophysiology*, **30**, 90-97.

Ferreira, F., & Clifton, C., Jr. (1986). The independence of syntactic processing. *Journal of Memory & Language*, **25**, 348-368.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, **14**, 178-210.

Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain & Language*, **62**, 311-341.

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

Hagoort, P., & Brown, C. M. (1994). Brain responses to lexical ambiguity resolution and parsing. In C. Clifton, Jr., L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 45-80). Hillsdale, NJ: Erlbaum.

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading: The P600/SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia*, **38**, 1531-1549.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift as an ERP measure of sentence processing. *Language & Cognitive Processes*, **8**, 439-483.

Hagoort, P., Brown, C., & Osterhout, L. (1999). The neural architecture of syntactic processing. In C. Brown & P. Hagoort (Eds.), *Neurocognition of language* (pp. 273-316). Oxford: Oxford University Press.

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

Jasper, H. H. (1958). Report to the committee on the methods of clinical examination in electroencephalography. *Electroencephalography & Clinical Neurophysiology*, **10**, 371-375.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Kenan, L. R. (1998). *New American profiles*. New York: Harcourt Brace Jovanovitch.

Keppel, G. (1982). *Design and analysis: A researcher's handbook*. Englewood Cliffs, NJ: Prentice-Hall.

Kutas, M. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence context effects. *Language & Cognitive Processes*, **8**, 533-572.

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

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

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

Marslen-Wilson, W. D., & Tyler, L. K. (1987). Against modularity. In J. L. Garfield (Ed.), *Modularity in knowledge representation and natural-language understanding* (pp. 37-62). Cambridge, MA: MIT Press.

McClelland, J. L., St. John, M., & Taraban, R. (1989). Sentence comprehension: A parallel distributed processing approach. *Language & Cognitive Processes*, **4**, 287-336.

McKinnon, R., & Osterhout, L. (1996). Constraints on movement phenomena in sentence processing: Evidence from event-related brain potentials. *Language & Cognitive Processes*, **11**, 495-523.

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

Münte, T. F., Heinze, H.-J., Matzke, M., Wieringa, B. M., & Johannes, S. (1998). Brain potentials and syntactic violations revisited: No evidence for specificity of the syntactic positive shift. *Neuropsychologia*, **36**, 217-226.

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

Osterhout, L. (1997). On the brain response to syntactic anomalies:

Manipulations of word position and word class reveal individual differences. *Brain & Language*, **59**, 494-522.

Osterhout, L., & Hagoort, P. (1999). A superficial resemblance does not necessarily mean you are part of the family: Counterarguments to Coulson, King, and Kutas (1998) in the P600/SPS-P300 debate. *Language & Cognitive Processes*, **14**, 1-14.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory & 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 & Cognitive Processes*, **8**, 413-438.

Osterhout, L., Holcomb, P. J., & Swinney, D. A. (1994). Brain potentials elicited by garden-path sentences: Evidence of the application of verb information during parsing. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **20**, 786-803.

Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language-specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family? *Journal of Cognitive Neuroscience*, **8**, 507-526.

Osterhout, L., McLaughlin, J., Allen, M., Inoue, K., & Loveless, J. (2002). *Changes in brain activity associated with the first year of adult foreign-language instruction.* Manuscript in preparation.

Osterhout, L., McLaughlin, J., & Bersick, M. (1997). Event-related potentials and human language. *Trends in Cognitive Sciences*, **1**, 203-209.

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

Osterhout, L., & Nicol, J. (1999). On the distinctiveness, independence, and time course of the brain responses to syntactic and semantic anomalies. *Language & Cognitive Processes*, **14**, 283-317.

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

NOTES

1. When the data reported by Kutas and Hillyard (1983) were inspected using a longer duration epoch, a P600-like positive wave became clear in the response to the syntactic anomalies (M. Kutas, personal communication, November 18, 2002).

2. Extended epochs could not be obtained for 6 of the subjects, owing either to excessive artifact rejection for the extended epoch or to problems in retrieving critical files from the data archive. Therefore, the data from 18 subjects were included in the extended-epoch grand average.

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