Semantic Integration in Sentences and Discourse: Evidence from the N400

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Abstract

■ In two ERP experiments we investigated how and when the language comprehension system relates an incoming word to semantic representations of an unfolding local sentence and a wider discourse. In Experiment 1, subjects were presented with short stories. The last sentence of these stories occasionally contained a critical word that, although acceptable in the local sentence context, was semantically anomalous with respect to the wider discourse (e.g., *Jane told the brother that he was exceptionally slow* in a discourse context where he had in fact been very quick). Relative to coherent control words (e.g., *quick*), these discourse-dependent semantic anomalies elicited a large N400 effect that began at about 200 to 250 msec after word onset. In Experiment 2, the same sentences were presented without their original story context. Although the words that had previously been anomalous in discourse still elicited a slightly larger average N400 than the coherent words, the resulting N400 effect was much reduced, showing that the large effect observed in stories depended on the wider discourse. In the same experiment, single sentences that contained a clear local semantic anomaly elicited a standard sentence-dependent N400 effect (e.g., Kutas & Hillyard, 1980). The N400 effects elicited in discourse and in single sentences had the same time course, overall morphology, and scalp distribution. We argue that these findings are most compatible with models of language processing in which there is no fundamental distinction between the integration of a word in its local (sentence-level) and its global (discourse-level) semantic context. ■

INTRODUCTION

The combinatorial nature of language allows us to express an infinite variety of things by combining a limited set of words in different ways. We can use the same three words to express both that people like dogs and that dogs like people, and we can combine either phrase with yet other words. Because this feature of language pairs enormous communicative flexibility with only modest demands on memory, it obviously makes for a very efficient communication system (Miller, 1991). However, it also means that to arrive at the overall meaning of an utterance, a listener or reader must somehow integrate the semantics of the individual words.

Research on sentence comprehension has shown that language users very rapidly construct a higher-order semantic interpretation of the sentence, and do so incrementally, as the sentence input unfolds. Clear evidence for this came from the early studies of Marslen-Wilson and colleagues (e.g., Marslen-Wilson, 1975; Marslen-Wilson & Tyler, 1980) that revealed, among other things, that so-called close shadowers can correct semantic errors while repeating the words of a sentence with only 250-msec delay. Another important piece of evidence for incremental semantic processing—and the focus of this study—was obtained by Kutas and Hillyard (1980), who recorded event-related brain potentials (ERPs) from subjects as they were reading through a sentence. Kutas and Hillyard observed that relative to a coherent control word, a sentence-final word that was semantically anomalous in the sentence context, as in *He spread the warm bread with* ***socks***, elicited an N400 effect, a distinct negative shift in the ERP waveform that began at about 200 msec after onset of the critical word, peaked at about 400 msec poststimulus, was largest over posterior scalp locations, and was somewhat larger over the right than left hemisphere. In a follow-up study, Kutas and Hillyard (1983) showed that anomalous words at other positions in a sentence also elicited this N400 effect.

Since then, sentence-semantic N400 effects have been obtained many times, in a variety of languages, with written, spoken, and signed sentence materials and with semantic anomalies as well as more subtle manipulations of semantic fit (e.g., Ainsworth-Darnell, Shulman, & Boland, 1998; Besson, Kutas, & Van Petten, 1992; Friederici, Pfeiffer, & Hahne, 1993; Hagoort & Brown, 1994, 1997, 1998; Kutas, 1993; Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984; Kutas, Van Petten, & Besson, 1988; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Neville, Nicol, Barss, Forster, & Garrett, 1991; Nigam, Hoffman, & Simons, 1992; Osterhout & Mobley, 1995; Rösler, Putz, Friederici, & Hahne, 1993; Swaab, Brown, & Hagoort, 1997; Van Petten, 1993, 1995; Van

Petten & Kutas, 1990). On the basis of this extensive N400 research, we now know that in sentence processing, *every* open-class word as a rule elicits an N400 and that the amplitude of this component is inversely related to the degree of fit between the word and its sentence-semantic context (see Brown & Hagoort, 1999; Kutas & Van Petten, 1994, and Osterhout & Holcomb, 1995; for reviews). The latter regularity suggests that within the language domain, the N400 reflects some aspect(s) of the processes that integrate the meaning of a particular word into a higher-order semantic interpretation (Brown & Hagoort, 1999; Osterhout & Holcomb, 1992; Rugg, 1990; but see Kutas & Van Petten, 1994, for a somewhat different suggestion).

The standard N400 effect observed in sentence processing clearly shows that readers and listeners immediately relate the incoming words to a semantic representation of the preceding language input. However, with the exception of a few studies described below, the N400 effect has been elicited in single isolated sentences only. This means that we do not know to what extent it uniquely reflects the construction of local sentence meaning, as opposed to, for example, the semantics of the wider discourse. Do words that are fully compatible with local sentence meaning but anomalous with respect to the wider discourse also elicit this effect? For example, would *David covered the warm bread with* ***salami*** elicit an N400 effect if prior discourse had introduced David as a vegetarian who never touches any kind of meat? And how would it compare to the standard N400 effect elicited by a sentence like *David covered the warm bread with* ***socks*** presented in isolation?

Intuitively, one would perhaps expect the two effects to be identical. After all, the understanding of language input always goes beyond the local sentence. This is obviously true for the interpretation of a sentence in the context of a wider discourse. But it also holds for the interpretation of a single isolated sentence, in the sense that this interpretation will always draw upon general background knowledge (e.g., how likely one is to eat socks). In this respect, the notion of local sentence semantics is obviously not entirely unproblematic (cf. Clark, 1996; Gibbs, 1984).

On the other hand, there is a tendency in the literature to describe the analysis of linguistic input as proceeding through a number of levels of increasing complexity, with the local semantics of a sentence or sentence fragment being computed before relating the current sentence input to earlier discourse (Garrod & Sanford, 1994; Marslen-Wilson & Tyler, 1980). Associated with this general view of processing is the intuitively plausible idea that the linking of a sentence to earlier discourse will somehow be more complex, and hence probably also slower, than the computation of sentence-internal semantic relations (e.g., Fodor, Ni, Crain, & Schankweiler, 1996; Kintsch, 1998; Perfetti, 1990; Till, Mross, & Kintsch, 1988). A closely related idea is the *literal meaning hypothesis,* which holds that language users always first compute the literal meaning of an utterance before they compute a contextually appropriate meaning (e.g., Searle, 1979; see Gibbs, 1984, for discussion). Under such accounts, a word that is difficult to integrate given the semantics of the wider discourse rather than the local sentence may very well give rise to a delayed N400 effect or perhaps even a qualitatively different ERP effect.

There is some initial evidence for discourse-semantic ERP effects. Earlier work has shown that if a semantically coherent sentence is presented in isolation, the amplitude of the N400 elicited by open-class words declines as a function of word position (e.g., Kutas et al., 1988). This N400 decline is generally thought to reflect the accumulation of semantic context: Words that come late in the sentence benefit from the semantic context established by the preceding part, but words that come early have little context and therefore elicit larger N400 amplitudes. Interestingly, Van Petten (1995) notes that no such N400 amplitude decline occurs in sentences embedded in coherent discourse. As argued by Van Petten, the reason might be that for sentences in discourse, strong contextual support is available right from the start, attenuating N400 amplitudes equally throughout the sentence. If this interpretation is correct, it means that sentential and discourse context both affect the N400 and do so in essentially similar ways.

Discourse-semantic N400 effects have also been reported by St. George, Mannes, and Hoffman (1994). St. George et al. asked their subjects to read paragraphs that only made sense if supplied with a title that expressed the global topic. Without the title, the paragraphs reduced to a relatively noncoherent series of sentences, each of which was by itself both syntactically and semantically acceptable. Earlier research had shown that the comprehension of these paragraphs degraded considerably when no title was supplied (Bransford & Johnson, 1972). St. George et al. therefore reasoned that if the amplitude of the N400 reflects the difficulty of semantic integration at both local and global levels, words in the untitled paragraphs should elicit larger N400 components than words in titled paragraphs. The ERP data, recorded at five scalp sites, confirmed this prediction, and St. George et al. therefore inferred that the N400 is sensitive to both local, sentence-semantic and global, discourse-semantic processing. The results of a second study (St. George, Mannes, & Hoffman, 1997) also showed that inferences based on prior discourse can attenuate the amplitude of the N400.[1]

The above findings suggest that it is possible to elicit a stable N400 effect in response to discourse-semantic manipulations. They also suggest that discourse context is involved in sentence processing at a very early point in time, within some 250 to 300 msec after word onset. But to assess to what extent this discourse-semantic N400 effect reflects the same underlying phenomenon as the standard N400 effect obtained with sentence-semantic manipulations, one would want to elicit both under comparable experimental conditions. To establish the identity of two ERP effects, it is also important to have somewhat more detailed information on their respective scalp distributions. Very similar topographies are compatible with the hypothesis that two ERP effects reflect largely or fully identical underlying sets of neural generators and hence presumably identical functional processes (cf. Kutas & Van Petten, 1994); very different topographies instead necessarily reflect largely different underlying sets of neural generators and are as such more compatible with different functional processes (but see Rugg & Coles, 1995).

We designed two ERP experiments to address these issues. In the first, we tried to elicit a discourse-semantic ERP effect. In the second study, we used sentence-semantic anomalies to elicit a standard N400 effect in an otherwise comparable paradigm, thus providing the basis for a systematic comparison of the two effects.

The logic of the two experiments can be illustrated with the example materials in Table 1 (see Methods section for details). For Experiment 1, we used stories that were three sentences long, and we recorded ERPs throughout the last sentence. In the **discourse-coherent** condition, this so-called carrier sentence contained a critical word that continued the discourse in a semantically acceptable way (e.g., *quick* in the example of Table 1). In the **discourse-anomalous** condition, we replaced this coherent critical word with an alternative that rendered the discourse semantically anomalous at that point (e.g., *slow*). Importantly, the discourse-anomalous critical word was chosen such that *in the local carrier sentence* it was acceptable, and approximately as coherent as the discourse-coherent critical word it replaced (see Methods section for details). This was done to ensure that any ERP effect elicited by a discourse-anomalous word could indeed be attributed to problems with integrating the anomalous word in the wider discourse, rather than to local factors.

Table 1. Example Materials for Experiments 1 and 2

Experiment 1	
Zoals afgesproken zou Jane om vijf uur 's ochtends haar zus en haar broertje wakker maken. Maar de zus had zich al gewassen, en het broertje had zich reeds aangekleed.	
(As agreed upon, Jane was to wake her sister and her brother at five o'clock in the morning. But the sister had already washed herself, and the brother had even got dressed.)	
Discourse-Coherent Word:	*Discourse-Anomalous Word:*
Jane vertelde het broertje dat hij bijzonder **vlot** was.	Jane vertelde het broertje dat hij bijzonder **traag** was.
(Jane told the brother that he was exceptionally **quick.**)	(Jane told the brother that he was exceptionally **slow.**)
Experiment 2	
(no discourse context)	
Discourse-Coherent Control Word:	*Discourse-Anomalous Control Word:*
Jane vertelde het broertje dat hij bijzonder **vlot** was.	Jane vertelde het broertje dat hij bijzonder **traag** was.
(Jane told the brother that he was exceptionally **quick.**)	(Jane told the brother that he was exceptionally **slow.**)
Sentence-Coherent Word:	*Sentence-Anomalous Word:*
In bedrukte stemming stonden de mannen rond het **graf** van de president.	In bedrukte stemming stonden de mannen rond het **potlood** van de president.
(Gloomily the men stood around the **grave** of the president.)	(Gloomily the men stood around the **pencil** of the president.)

Note: All critical words (CW) are shown in boldface, embedded in their (example) carrier sentence.

Because we did not know for certain whether we had successfully ruled out any differences in local sentence-semantic support for the critical words, we presented the same carrier sentences in Experiment 2 without their earlier discourse. The logic of these **discourse-coherent control** and **discourse-anomalous control** conditions was straightforward: To the extent that the ERP effect (e.g., N400 effect) elicited by the discourse-anomalous critical word really hinges on the wider discourse, it should disappear if the discourse context is removed. Ideally, the ERPs elicited by critical words in the discourse-anomalous control condition should not differ from those elicited by critical words in the discourse-coherent control condition.

In Experiment 2, these discourse-coherent and anomalous control trials were mixed with other single sentences designed to elicit a standard sentence-semantic N400 effect. In the **sentence-coherent** condition, these sentences contained a critical word that was semantically acceptable within the local sentence context up to that point, such as the word *grave* in *Gloomily the men stood around the grave of the president.* For the **sentence-anomalous** condition, this critical word was replaced by one that was semantically anomalous within the local sentence context, such as the word *pencil* in the above example. These sentence pairs were adapted from earlier studies (Hagoort & Brown, 1998), where they had elicited a standard N400 effect.

RESULTS

We report the results for discourse anomalies, discourse-anomaly controls, and sentence anomalies separately and describe additional comparisons as they become relevant. All figures display grand average ERP waveforms time-locked to the onset of the critical words (see Table 1 for examples); all analyses of variance (ANOVAs) involve mean amplitude in the typical N400 latency window of 300 to 500 msec after onset of the critical words.

Discourse Anomalies

Figure 1 displays the grand average waveforms elicited by a critical word that continued the discourse in a coherent or semantically anomalous way. The critical words in these two and all further conditions all elicit the N1-P2 complex that is typical for visually presented material, as well as a P1 component at occipital sites. Around 400 msec poststimulus, coherent as well as anomalous words also both elicit a clear negative deflection that has the characteristic morphology, time course, and distribution of an N400. Critically, at most sites the N400 elicited by discourse-anomalous words is substan-

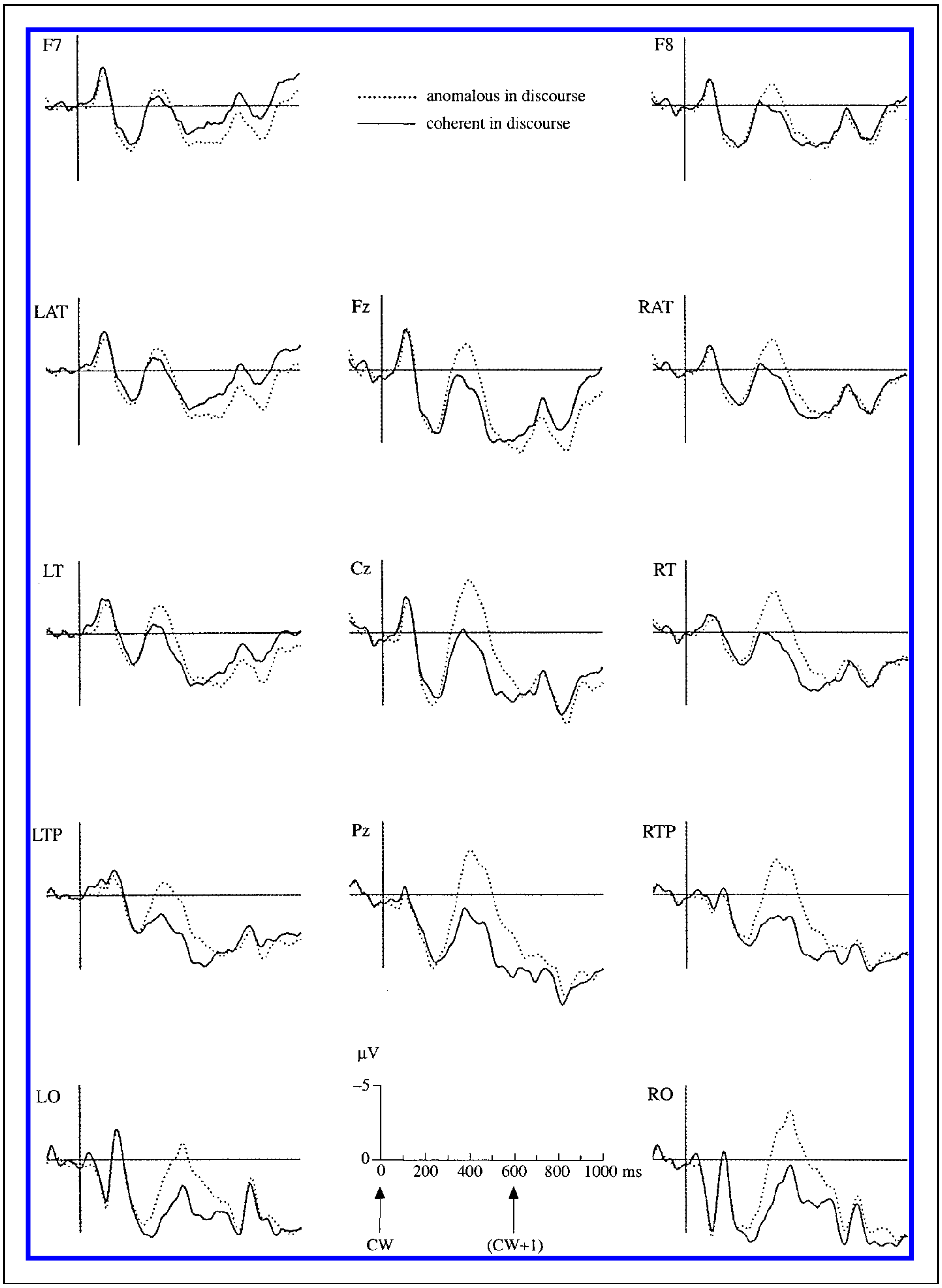


Figure 1. Discourse-semantic anomalies (Experiment 1). Grand average ERPs elicited by critical words that were semantically coherent (solid line) or anomalous (dotted line) with respect to the discourse context. In this and all following figures, negativity is plotted upward, the onset of the critical word (CW) is at 0 msec, and the next word (CW + 1), if any, follows at 600 msec. LAT, RAT = left, right anterior temporal, LT, RT = left, right temporal, LTP, RTP = left, right temporo-parietal, LO, RO = left, right occipital.

tially larger than the N400 elicited by coherent words. This N400 effect begins at about 200 to 250 msec after onset of the critical word, peaks at about 400 msec, has a centroparietal maximum, and is somewhat larger over the right hemisphere than over the left.

Table 2 reveals that our discourse coherence manipulation had a significant main effect on mean amplitude in the N400 latency range (corresponding to a 1.95-μV average amplitude difference) and also interacted with electrode site. Specific topographical analyses showed that the anomaly effect was significantly larger over posterior than anterior regions of the scalp and larger over the right hemisphere.

Discourse-Anomaly Controls

Figure 2 shows the results for the same critical sentences, now presented without their original discourse context to a new group of subjects. Although the critical words in these two conditions had been designed to be equally acceptable in the current local carrier sentence context, words that had previously been anomalous in wider discourse (discourse-anomalous controls) elicited a slighly larger N400 than words that had previously been coherent (discourse-coherent controls). As shown in Table 3, the discourse-coherence control factor had a small (0.88 μV) but significant main effect on mean amplitudes in the N400 latency range and also interacted significantly with hemisphere.

However, a comparison of Figures 1 and 2 clearly suggests that a substantial part of the N400 effect elicited by discourse-anomalous words is eliminated if the same words are presented in their local carrier sentence only. A joint ANOVA on mean amplitudes in the 300- to 500-msec latency range confirmed that the unexpected N400 effect in the discourse-anomaly control condition was significantly smaller than the predicted N400 effect in the critical discourse-anomaly condition (coherence × context interaction: $F(1, 38) = 4.23$; $MSE = 16.78$; $p = 0.047$). This suggests that the N400 effect observed for stories hinges to a substantial extent on how the critical words relate to earlier discourse (see Discussion, below).

Sentence Anomalies

Figure 3 displays the grand average waveforms elicited by a critical word that continued a single isolated sentence in a coherent or semantically anomalous way. Sentence-anomalous words elicit a substantially larger N400 than sentence-coherent words. This standard N400 effect begins at about 250 to 300 msec after onset of the critical word, peaks at about 400 msec, and has a centroparietal maximum. Table 4 reveals that the sentence coherence manipulation had a significant main effect on mean amplitudes in the N400 latency range (corresponding to a 1.34-μV average amplitude difference), where it also interacted with the 13-level electrode site factor.

Table 2. Discourse Anomalies: Mean ERP Amplitude ANOVAs in the 300- to 500-msec Latency Range

Source	*df*	*F*	*MSE*	*p*
Omnibus ANOVA (13 electrodes)				
DC	1, 23	31.34	18.84	0.000^{***}
DC × El	12, 276	13.96	1.02	0.000^{***}
Midline ANOVA (3 electrodes)				
DC	1, 23	30.22	9.22	0.000^{***}
DC × El	2, 46	7.60	1.16	0.006^{**}
Lateral ANOVA (2 × 5 electrodes)				
DC	1, 23	28.67	12.02	0.000^{***}
DC × He	1, 23	6.86	3.61	0.015^{*}
DC × El	4, 92	30.72	0.77	0.000^{***}
DC × He × El	4, 92	1.01	0.20	0.382

Note: DC = discourse coherence; El = electrode; He = hemisphere. Table only displays ANOVA tests that involve DC.

* $p < 0.05$.

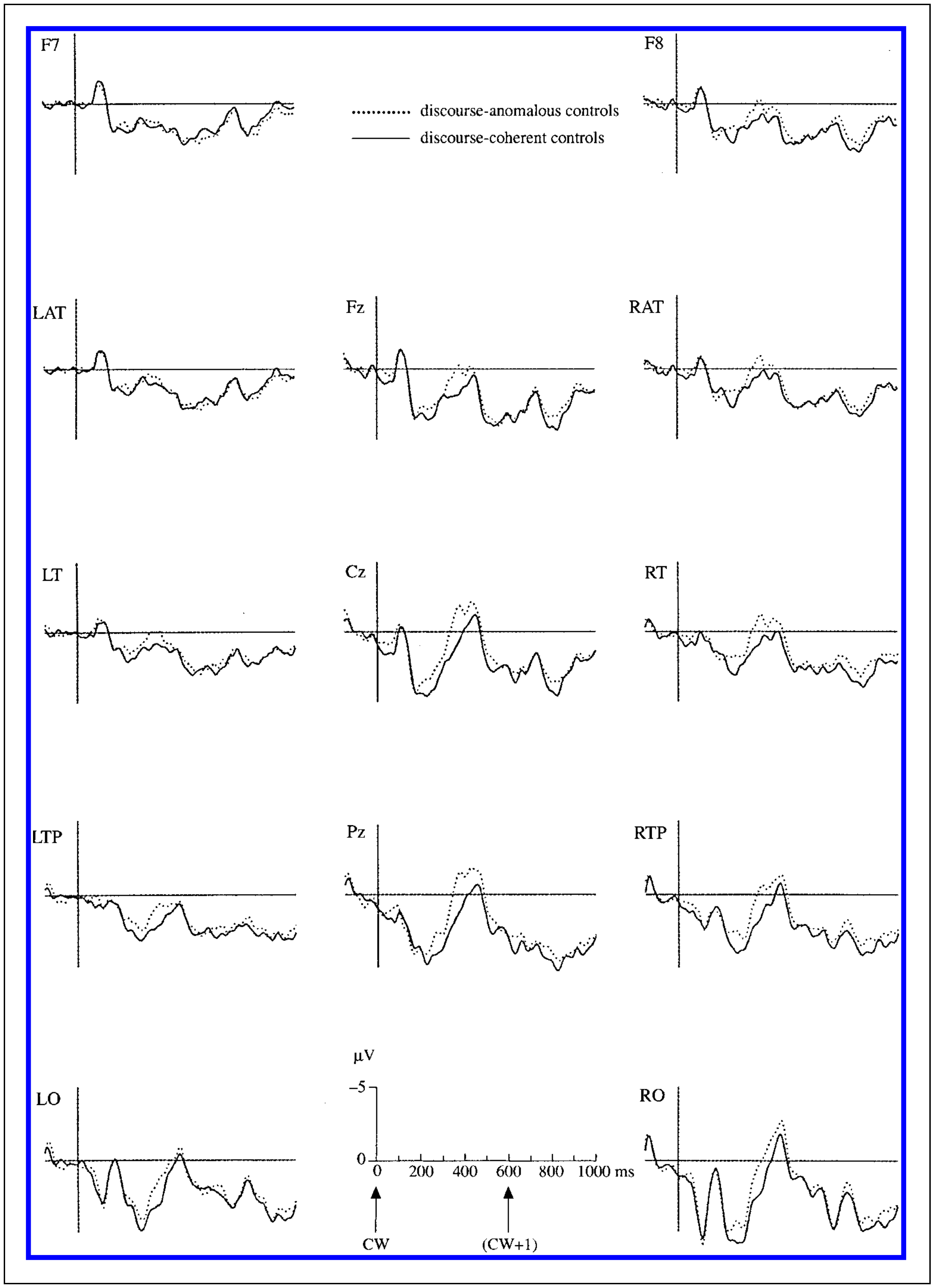
** $p < 0.01$.

*** $p < 0.001$.

A comparison of Figures 1 and 3 suggests that the earlier discourse-dependent semantic anomaly effect closely resembles the sentence-dependent semantic anomaly effect. In Figure 4, we display the corresponding difference waveforms together. Although the discourse anomaly effect appears to be somewhat larger than the sentence anomaly effect (but see below for statistics), the effects are very similar in overall morphology, time course, and scalp distribution.

A joint ANOVA on mean amplitudes in the 300- to 500-msec latency range revealed that the discourse-dependent N400 effect was not significantly larger than the sentence-dependent N400 effect (context × coherence $F(1, 38) = 1.23$; $MSE = 18.82$; $p = 0.274$). After the appropriate data transformations for testing differences in scalp distribution, a subsequent ANOVA revealed that the two N400 effects also did not differ significantly in scalp topography (context × coherence × electrode $F(12, 456) = 1.69$; $MSE = 0.37$; $p = 0.147$).[2] We statistically compared the onset of the two N400 effects by computing mean amplitude values in consecutive 10-msec latency ranges (i.e., 200 to 210 msec, 210 to 220 msec, etc.). The two effects differed significantly in the 280- to 290- and 290- to 300-msec latency ranges only (280 to 290 msec: $F(1, 38) = 5.03$; $MSE = 10.41$; $p = 0.031$; 290 to 300 msec : $F(1, 38) = 4.94$; $MSE = 14.14$; $p = 0.032$), reflecting a slightly delayed onset of the sentence-dependent effect at LO, RO, RTP, and (in the 290- to 300-msec range only) Pz.

Figure 2. Discourse-anomaly control effect (Experiment 2). Grand average ERPs elicited by critical words that were semantically coherent (solid line) or anomalous (dotted line) with respect to the original discourse context but have now been presented in their neutral carrier sentence only. LAT, RAT = left, right anterior temporal, LT, RT = left, right temporal, LTP, RTP = left, right temporo-parietal, LO, RO = left, right occipital.



DISCUSSION

We conducted two event-related brain potential studies to investigate how and when the language comprehension system relates an incoming word to semantic representations of the unfolding local sentence and the wider discourse. In the first experiment, subjects were presented with short stories, of which the last sentence occasionally contained a critical word that was semantically anomalous with respect to the wider discourse (e.g., *Jane told the brother that he was exceptionally slow* in a discourse context where he had in fact been very quick). Relative to a discourse-coherent counterpart (e.g., *quick*), these discourse-anomalous words elicited a large N400 effect (i.e., a monophasic negative shift in the ERP that began at about 200 to 250 msec after word onset and peaked around 400 msec, with a centro-parietal maximum). Also consistent with earlier N400 findings for visually presented words, the current effect was somewhat larger over the right hemisphere than over the left.

To establish that the N400 effect indeed depended on earlier discourse, the same critical sentences were presented without their original discourse context in a

Table 3. Discourse-Anomaly Controls: Mean ERP Amplitude ANOVAs in the 300- to 500-msec Latency Range

Source	*df*	*F*	*MSE*	*p*
Omnibus ANOVA (13 electrodes)				
DCC	1, 15	5.90	13.61	0.028*
DCC × El	12, 180	2.00	0.83	0.141
Midline ANOVA (3 electrodes)				
DCC	1, 15	5.37	7.28	0.035*
DCC × El	2, 30	1.36	0.67	0.273
Lateral ANOVA (2 × 5 electrodes)				
DCC	1, 15	5.58	8.27	0.032*
DCC × He	1, 15	5.73	1.17	0.030*
DCC × El	4, 60	1.40	1.13	0.259
DCC × He × El	4, 60	0.08	0.24	0.906

Note: DCC = discourse-coherence control; El = electrode; He = hemisphere. Table only displays ANOVA tests that involve DCC.
* $p < 0.05$.

second experiment. This control was necessary because although we had made every attempt to select critical word pairs that were approximately equally coherent in the local context, the results of one of our pretests indicated that we had perhaps not been completely successful. The critical words of a pair had been matched on the probability that, when given the preceding carrier sentence fragment, subjects used that particular word to complete the sentence (cloze probability). But when given the complete sentence pairs for comparison, subjects nevertheless considered those with a discourse-anomalous critical word as somewhat less plausible than those with a coherent alternative (see Methods section for details).

The fact that the discourse-anomalous control condition of Experiment 2 elicited a small N400 effect suggests that the critical word pairs did to some extent indeed accidentally differ in terms of local coherence. However, what is critical for current purposes is that this unexpected N400 effect is much (and significantly) smaller than the effect obtained in Experiment 1, where the same words had been presented in discourse context. This suggests that at least a substantial part of the latter effect hinged on how a critical word related to the wider discourse and not on how well it continued the local sentence in which it was embedded.

Earlier research had already established that the amplitude of the N400 is equally sensitive to the semantic context established within a sentence and the semantic context established by a single prime word (Kutas, 1993; Van Petten, 1993). The more recent work of St. George et al. (1994, 1997) and Van Petten and colleagues (see Van Petten, 1995) provided a first indication that, beyond such local contexts, global semantic manipulations at the level of the discourse also affect the N400. In the present study, we elicited discourse- and sentence-semantic anomaly effects under comparable experimental conditions. Our results show that the ERP effects elicited by both types of anomalies are indeed highly similar. Relative to their coherent counterparts, discourse- and sentence-anomalous critical words elicited an N400 effect with the same overall morphology, overall time-course, and distribution across the scalp. The similarity of these effects, particularly in polarity and scalp distribution, is compatible with the claim that they reflect the activity of a largely overlapping or identical set of underlying neural generators, indicating similar functional processes (cf. Kutas & Van Petten, 1994).

As most clearly displayed by the difference waveforms of Figure 4, the results also reveal that the processing consequences of a discourse-dependent semantic anomaly and those of a sentence-dependent anomaly show up in the ERP record at about the same time (i.e., within about 200 to 300 msec after onset of the anomalous word). There is no indication whatsoever that the system is slower in relating a new word to the semantics of the wider discourse than in relating it to local sentence context. If anything, Figure 4 suggest the opposite. We think it would be premature to conclude from our data that discourse-dependent N400 effects generally have an *earlier* onset than sentence-dependent N400 effects. On the other hand, our data clearly also do not support the idea that new words are related to the discourse model *after* they have been evaluated in terms of their contribution to local sentence semantics.

The speed with which discourse context affects processing of the current sentence in our study appears to be at odds with recent estimates of how long it would take to retrieve information about prior discourse from long-term memory. In our materials, the relative coherence of a critical word usually hinged on rather subtle information that was implicit in the discourse and that required considerable inferencing about the discourse topic and the situation it described. Kintsch and his collaborators (Kintsch, 1998; Ericsson & Kintsch, 1995; Till et al., 1988) have suggested that during on-line text comprehension, such subtle discourse information is not immediately available and must be retrieved from "long-term working memory" when needed. This is estimated to take some 300 to 400 msec at least. However, the results of Experiment 1 suggest that the relevant discourse information can be brought to bear on local processing within at most 200 to 250 msec.

All findings discussed so far were obtained by averaging across critical words in sentence-medial and sentence-final positions. It is important to note, though, that as illustrated for one electrode in Figure 5, the results

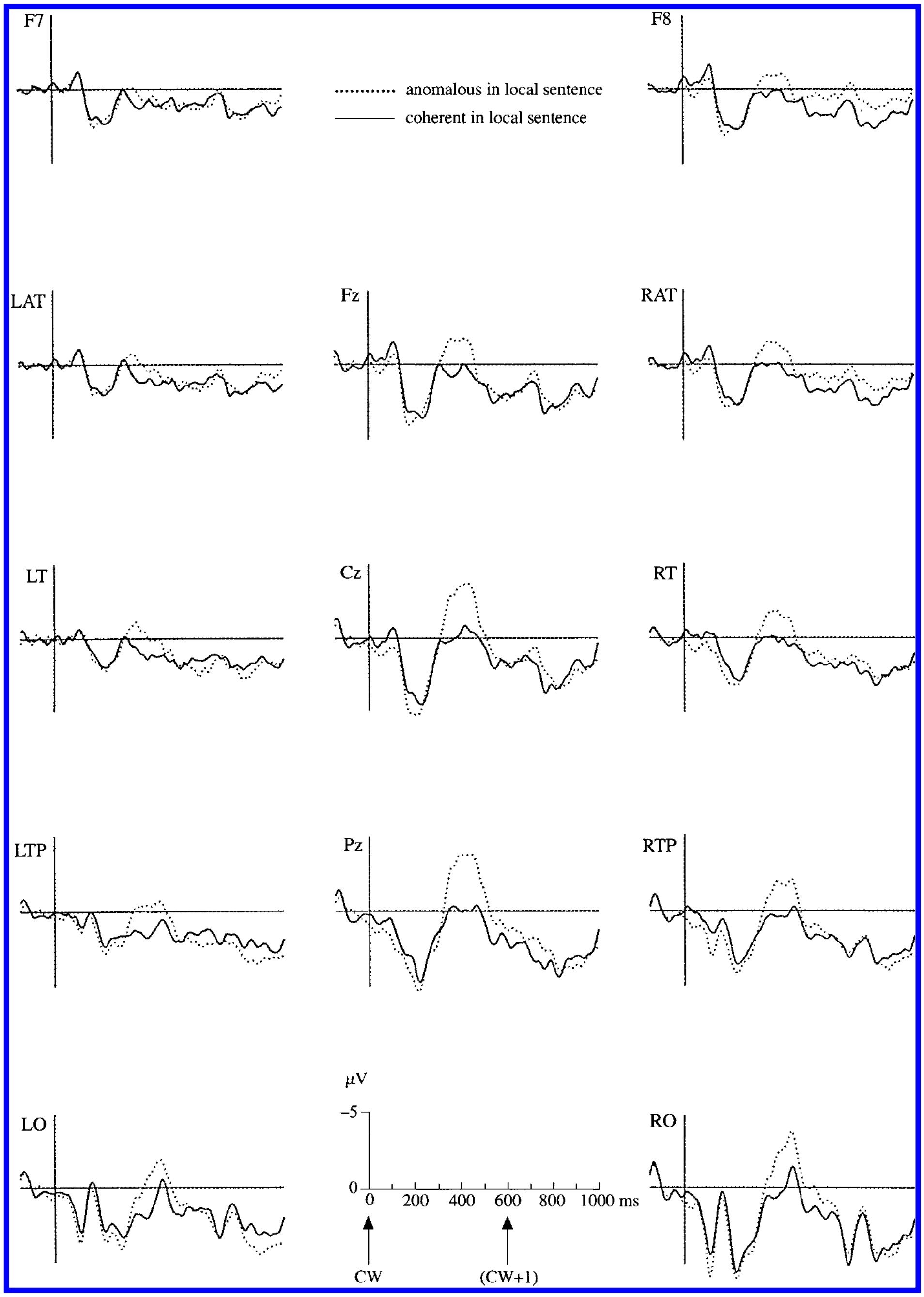


Figure 3. Sentence-semantic anomalies (Experiment 2). Grand average ERPs elicited by critical words that were semantically coherent (solid line) or anomalous (dotted line) with respect to the isolated carrier sentence. LAT, RAT = left, right anterior temporal, LT, RT = left, right temporal, LTP, RTP = left, right temporo-parietal, LO, RO = left, right occipital.

hold regardless of whether critical words are in the middle or at the end of their carrier sentence.[3] As for the isolated sentences, we thus replicate the findings of Kutas and Hillyard (1983), who were the first to compare sentence-medial and sentence-final N400 effects. The fact that a *discourse*-dependent semantic violation also has an immediate effect at critical words in sentence-medial position, however, has important theoretical implications. In models where the integration of new input into a representation of the wider discourse is delayed until, say, the current clause has been encoded, a sentence-*final* discourse effect can be accounted for in terms of special clause-final wrap-up processes. But such models cannot easily explain why critical words in sentence- (and clause-) *medial* position also elicit a rapid discourse-dependent anomaly effect. In line with the results of several reaction time studies (e.g., Hess, Foss, & Carroll, 1995; Marslen-Wilson & Tyler, 1980), this latter finding suggests that language users immediately relate *every* new word to the global discourse.

The observed similarity of discourse- and sentence-dependent anomaly effects is most naturally accounted for if, in terms of an on-line processing architecture, we abandon the distinction between sentence- and dis-

Table 4. Sentence Anomalies: Mean ERP Amplitude ANOVAs in the 300- to 500-msec Latency Range

Source	*df*	*F*	*MSE*	*p*
Omnibus ANOVA (13 electrodes)				
SC	1, 15	9.89	18.78	0.007**
SC × El	12, 180	3.20	0.87	0.034*
Midline ANOVA (3 electrodes)				
SC	1, 15	8.43	11.89	0.011*
SC × El	2, 30	2.97	1.00	0.095
Lateral ANOVA (2 × 5 electrodes)				
SC	1, 15	10.55	9.58	0.005**
SC × He	1, 15	1.48	1.08	0.242
SC × El	4, 60	2.36	1.01	0.135
SC × He × El	4, 60	0.98	0.14	0.379

Note: SC = sentence coherence; El = electrode; He = hemisphere. Table only displays ANOVA tests that involve SC.
* $p < 0.05$.
** $p < 0.01$.

course-level semantic integration. One possibility is to take seriously the notion of *common ground,* first proposed by Stalnaker (1978) and recently elaborated by, among others, Clark (1996). The analysis of Clark clearly demonstrates that the meaning of linguistic utterances cannot be determined without taking into account the knowledge base that the speaker and the listener (or writer and reader) share and mutually believe they share. This common ground includes a model of the discourse itself, which is continually updated as the discourse unfolds. But the common ground also contains the linguistic conventions that the interlocutors share, including the grammar and lexicon of their language. Moreover, it contains information based on shared personal experiences (including the setting in which the current discourse takes place) as well as information based on the cultural communities to which a person is believed to belong. All this forms the background against which every utterance is interpreted (and composed).

If listeners and readers always immediately evaluate new words relative to the discourse model and the associated information in common ground (i.e., immediately compute "contextual meaning"), the identity of the ERP effects generated by sentence- and discourse-dependent semantic anomalies has a natural explanation. With a single sentence, the relevant common ground only includes whatever discourse and world knowledge has just been activated by the sentence fragment presented so far (by this particular speaker or writer, in this physical context, task setting, culture, etc.). With a sentence presented in discourse context, the relevant common ground will be somewhat richer, now also including information elicited by the specific earlier discourse. But the process that maps incoming words onto the relevant common ground can run into trouble either way. We suggest that the two N400 effects observed in this study reflect the activity of this one unified integration process.

Of course, this is not to deny the relevance of sentential structure for semantic interpretation. In particular, how the incoming words are related to the discourse model is ultimately constrained by sentence-level syntactic devices (such as word order, case marking, local phrase structure, or agreement). The associated rules of semantic composition cause *a chair* to differ from *the chair*, and *dogs like people* from *people like dogs*. What we suggest, though, is that there is no functionally distinct separate stage during which such compositionally constrained word meaning is exclusively evaluated with respect to "local sentence meaning," independent of the context in which that sentence occurs (cf. Marslen-Wilson & Tyler, 1980; see Chambers, Tanenhaus, Eberhard, Carlson, & Filip, 1998, McElree, 1998, Murray & Rowan, 1998, and Van Petten, 1995, for comparable suggestions).

In all, our findings support three related conclusions about sentence processing in discourse. First, we have found that words that are acceptable in a single sentence but semantically anomalous given a wider discourse elicit an N400 effect in event-related brain potentials. This shows that incoming words are very rapidly related to the semantics of the wider discourse. Because this effect can be elicited by words in sentence-final as well as sentence-medial position, our findings also suggest that sentence processing is incremental all the way up to the discourse level. Finally, the N400 effect elicited in discourse is indistinguishable from the standard N400 effect elicited by words that are anomalous given the "local" semantics of a single sentence. This accords well with models of language comprehension in which there is no fundamental processing distinction between the integration of a word in its local (sentence-level) and its global (discourse-level) semantic context.

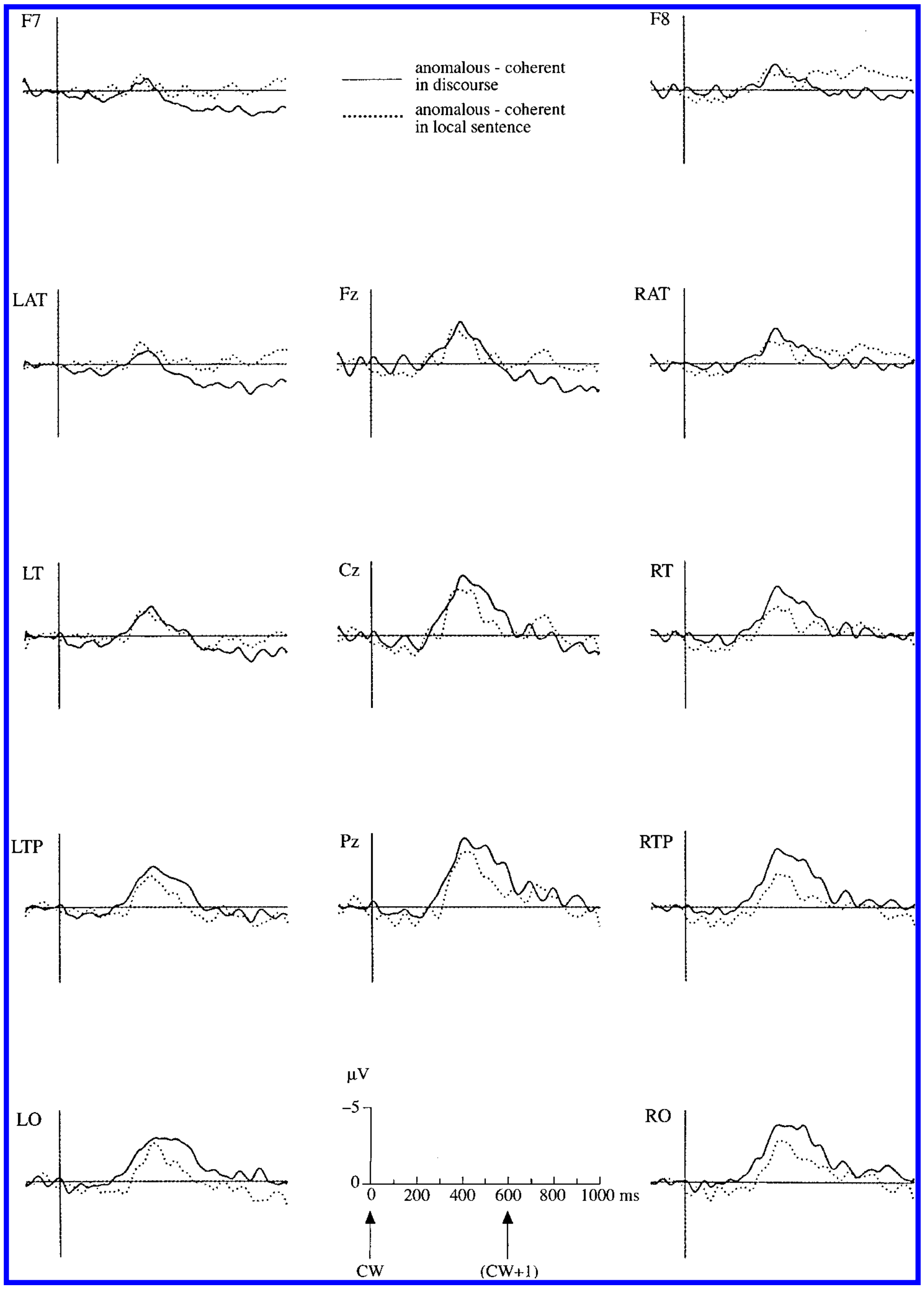
METHODS

Experiment 1

Subjects

Experiment 1 was conducted with 24 native speakers of Dutch (20 female, mean age 24, range 21 to 26 years), recruited from the Max Planck Institute subject pool. All had normal or corrected-to-normal vision and were right handed (10 subjects reported having left-handed relatives). None of the subjects had any neurological impairment, had experienced any neurological trauma, or used neuroleptics. Also, none of them had participated in any of the pretests (see below).

Figure 4. Difference waveforms for discourse anomalies (anomalous − coherent; solid line) and for sentence anomalies (anomalous − coherent; dotted line). LAT, RAT = left, right anterior temporal, LT, RT = left, right temporal, LTP, RTP = left, right temporo-parietal, LO, RO = left, right occipital.



Materials

Discourse Anomalies. We created 80 Dutch stories that, although very short, coherently described realistic or imaginary situations and events (see Table 1 for an example; the complete set of materials can be obtained from the authors). Each story consisted of three sentences, the last of which was the so-called carrier sentence that contained a critical word (CW). *Discourse-coherent* CWs were chosen to be a good continuation of the earlier discourse, and each coherent CW had a *discourse-anomalous* CW alternative that did not continue the discourse in a semantically acceptable way. The difference in coherence between two CWs usually hinged on considerable inferencing about the discourse topic and the situation it described. To avoid a sentence-semantic confound, each discourse-anomalous CW was chosen such that within the local carrier sentence it was roughly as acceptable as its discourse-coherent CW counterpart. Also, neither word was used in the preceding context.

Two written questionnaire pretests were conducted to assess the degree of sentence-semantic acceptability of these discourse-coherent and discourse-anomalous CWs. In the first pretest, 24 subjects were asked to

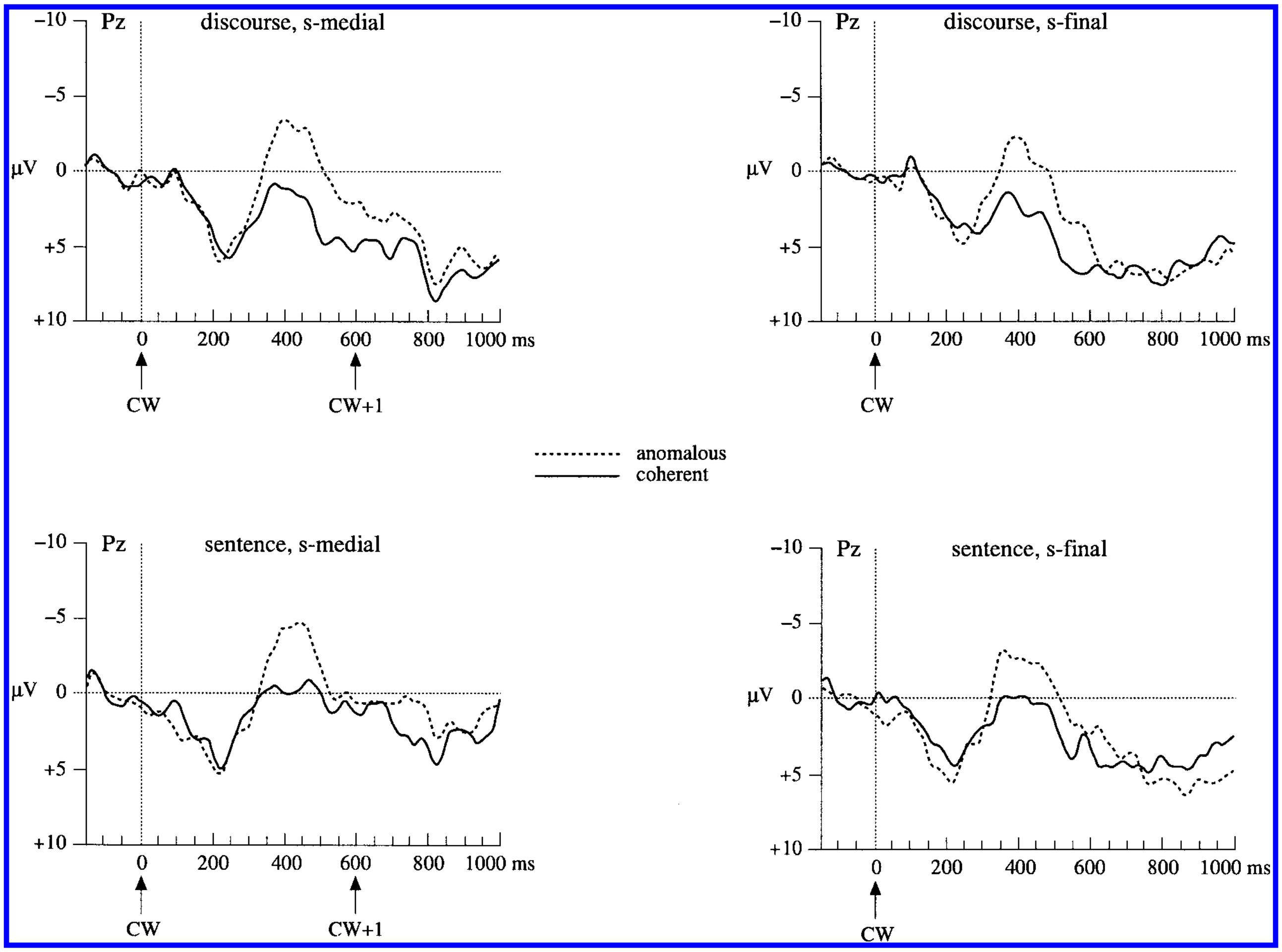


Figure 5. Semantic anomaly effects for different critical word positions. Grand average ERPs, at Pz, elicited by sentence-medial (left) and sentence-final (right) critical words that were coherent (solid line) or anomalous (dotted line) in a discourse (top) or in a single sentence (bottom).

complete all 80 isolated carrier sentences, which had been truncated right before the CW and randomly intermixed with 59 truncated filler sentences in two different random orders. In the second pretest, 24 different subjects were asked to select, for each of the 80 carrier sentence pairs, the most plausible sentence of the two. The sentence pairs were randomly intermixed with 65 filler sentences in two different random orders, such that half of the pairs in each rating list had the carrier sentence with the (in discourse context) anomalous CW first and the sentence with the coherent CW second, half had the reverse order, and every carrier sentence pair was presented in both orders across lists.

The sentence completion pretest revealed that the discourse-coherent and discourse-anomalous CWs had approximately equal cloze probability in the local carrier sentence context: On average, people spontaneously completed the sentence fragment (e.g., *Jane told the brother that he was exceptionally* _____) with the coherent story CW (e.g., *quick*) in 1.9% of the occasions (*SD* = 4.3; range = 0 to 21%) and with the anomalous story CW (e.g., *slow*) in 1.1% of the occasions (*SD* = 3.4; range = 0 to 21%). The relative plausibility rating pretest showed, however, that when asked to make a comparative evaluation of the complete carrier sentence variants, an average of 42% (*SD* = 20) of the subjects rated the carrier sentence with the discourse-coherent CW (e.g., *quick*) as the more plausible one, whereas 30% (*SD* = 21) of the subjects rated the carrier sentence with the discourse-anomalous CW (e.g., *slow*) as the more plausible one, with 28% (*SD* = 15) of the subjects expressing no preference either way. Because of other rather stringent constraints on the materials of this study (see van Berkum, Brown, & Hagoort, 1999, for details), we chose to control for any effects of this asymmetry by means of additional control conditions in the second experiment.

The 80 discourse-coherent and 80 discourse-anomalous CWs were pairwise equated on word class and inflection (e.g., both were plural nouns) and setwise matched on average length (7.7 and 7.5 letters respectively, with no CW over 10 letters) and frequency [46 and 42 occurrences on a million respectively, using a 42 million word corpus of Dutch (CELEX, 1990)]. Of the 80 carrier sentences, 35 had sentence-final CWs, and 45 had sentence- (and clause-) medial CWs.

To minimize eye-movement artifacts in the electroencephalogram (EEG), and to provide good time-locking for later ERP analysis and interpretation, the sentences were presented with serial visual presentation (see below). To attenuate the visual strain imposed by this mode of presentation, the context stories were presented auditorily. They were recorded by a female native speaker, using normal speaking rate and intonation. The recordings were subsequently sampled at 16 kHz mono and stored on disk for use in the experiment.

Randomization. Two trial lists were used for half of the subjects each. For the first list, 40 discourse-coherent and 40 discourse-anomalous critical trials were pseudorandomly mixed with another 160 filler trials such that neither coherent nor anomalous CW trials occurred more than four times consecutively and such that trials of each type were matched on average list position. The second list was derived from the first by replacing all discourse-coherent CWs by their anomalous counterparts and vice versa.

Procedure

Subjects were tested individually in a dimly lit sound-attenuating booth. They were seated in a comfortable reclining chair, instructed to move as little as possible, and told that they would be presented with a series of short episodes, with the first part of each played over headphones, and the last sentence shown word by word on a computer screen. Subjects were asked to process each episode for comprehension. They were free to blink and move their eyes during the spoken part of each episode but were instructed to fixate on the screen and avoid all movement during the written part. No additional task demands were imposed.

Each trial began with a 300-msec warning tone over headphones, followed after 700-msec silence by a spoken story context. At 1000 msec after offset of the spoken part, the visual presentation of the critical carrier sentence began, word by word in white lowercase Arial letters (the first word of each sentence began with a capital letter) against a dark background, in the center of a VGA computer screen. Viewing distance was approximately 110 cm, and the largest word subtended a visual angle of about 3.1° horizontally and 0.5° vertically. Each word was presented for 300 msec, followed by a blank screen for another 300 msec, after which the next word appeared. The final word was presented together with a period, and 2500 msec after its offset the next trial began. To inform subjects when they were allowed to blink and move their eyes, an asterisk was displayed throughout this noncritical interval, from 1600 msec after written sentence offset to the offset of the next trial's spoken context story. After a short practice, the trials were presented in five blocks of approximately 15 min.

EEG Recording and Analysis

The EEG was recorded from 13 tin electrodes in an electrode cap, each referred to the left mastoid. Three electrodes were placed according to the international 10-20 system over midline sites at Fz, Cz, and Pz locations. Ten electrodes were placed laterally over symmetrical positions: left and right frontal (F7, F8), anterior temporal (LAT, RAT, halfway between F7-T3 and F8-T4 respectively), temporal (LT, RT, laterally to Cz, at 33% of the interaural distance), temporo-parietal (LTP, RTP, posterior to Cz by 13% of the nasion-inion distance, and laterally by 30% of the interaural distance each), and occipital (LO, RO, halfway between T5-O1 and T6-O2 respectively). Vertical eye movements and blinks were monitored via a supra- to suborbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine if there were differential contributions of the experimental variables to the two presumably neutral mastoid sites (no such differential effects were observed here, or in Experiment 2). The EEG and electrooculogram (EOG) recordings were amplified with Nihon Kohden AB-601G bio-electric amplifiers, using a hi-cut of 30 Hz and a time constant of 8 sec. Impedances were kept below 5 and 3 kΩ for EOG and all other electrodes, respectively. The EEG and EOG signals were digitized on-line with a sampling frequency of 200 Hz.

Prior to off-line averaging, all single-trial waveforms were screened for eye movements, electrode drifting, amplifier blocking, and EMG artifacts in a critical window that ranged from 150 msec before onset of the word immediately preceding the CW to 1200 msec after onset of the CW itself. Trials containing such artifacts were rejected (10.8% in experiment 1, 15.4% in Experiment 2). For each subject, average waveforms were computed across all remaining trials per condition after normalizing the waveforms of the individual trials on the basis of the 150-msec pre-CW baseline. Subsequent ANOVAs used mean amplitude values computed for each subject in the typical N400 latency window of 300 to 500 msec after onset of the CW. Univariate F tests with more than 1 degree of freedom in the numerator were adjusted by means of the Greenhouse-Geisser/Box's epsilon hat correction (Maxwell & Delaney, 1989, pp. 475–479). All results were first evaluated in an omnibus ANOVA that crossed the coherence factor (anomalous, coherent) with a 13-level electrode factor. The scalp distribution of the anomaly effect was subsequently explored in two separate ANOVAs, one with a three-level midline-electrode factor (Fz, Cz, Pz) and the other with a hemisphere (left, right) by lateral-electrode (F7/F8, LAT/RAT, LT/RT, LTP/RTP, LO/RO) design.

Experiment 2

Subjects

Experiment 2 was conducted with 16 native speakers of Dutch (8 female, mean age 24, range 18 to 36 years) recruited from the same subject pool. All subjects had normal or corrected-to-normal vision, and were right handed (four subjects reported having left-handed relatives). Again, none of these subjects had any neurological impairment, had experienced any neurological trauma, or used neuroleptics. Also, none of them had participated in Experiment 1 or its pretests.

Materials

Discourse-Anomaly Controls. In Experiment 2, we presented all 80 critical carrier sentences of Experiment 1 in isolation (i.e., without their two-sentence discourse context).

Sentence Anomalies. To obtain a standard sentence-semantic N400 effect, we adapted 80 additional sentence pairs from the materials of an earlier study (Hagoort & Brown, 1998; Experiments 1 and 2). One member of each pair contained a *sentence-coherent* CW, which continued the sentence in a semantically acceptable way. In the other sentence of a pair, this coherent CW was replaced by a *sentence-anomalous* CW, which did not continue the sentence in a semantically acceptable way. An example item is shown in Table 1 (the full set of items can be obtained from the authors).

The 80 sentence-coherent and 80 sentence-anomalous CWs were pairwise equated on word class and inflection and setwise matched on average length (4.8 and 5.2 letters respectively, with no CW over 10 letters) and frequency (45 and 40 occurrences on a million, respectively). As in the discourse and discourse-control conditions, 35 of the 80 current carrier sentences had sentence-final CWs, and 45 had sentence-medial CWs.

Randomization. In addition to the above 80 critical discourse-anomaly controls and 80 critical new sentences, Experiment 2 presented the (semantically coherent) last sentences of the 160 filler stories used in Experiment 1, as well as 96 additional new sentences. Of the latter, half were semantically nonsensical (e.g., *The seasick exercises are very undertaking*), and half contained an additional syntactic anomaly (e.g., *The seasick exercising* are very undertaking*). Two different trial lists were used, each for half of the subjects. The first list contained 40 discourse-coherent control trials and 40 discourse-anomalous control trials, 40 sentence-coherent and 40 sentence-anomalous trials, and another 256 (160 + 96) filler trials, pseudorandomly mixed such that no trials of any critical type occurred more than four times consecutively and such that trials of each type were matched on average list position. The second stimulus list was derived from the first by replacing all coherent CWs by their anomalous counterparts and vice versa.

Procedure

The procedure of Experiment 2 was identical to that of Experiment 1, with the following exceptions pertaining to item presentation (which no longer involved a spoken context). Each trial began with an asterisk displayed for 2500 msec, during which subjects were free to blink and move their eyes. At 650 msec after offset of this signal, the critical sentence was presented by means of serial visual presentation (300-msec word, 300-msec blank screen, etc.). The next trial began 800 msec after sentence end.

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Notes

1. Two other N400 studies (Kutas & Hillyard, 1983; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991) also embedded their critical sentences in running text. Because these studies did not specifically address the processing of sentential- versus discourse-semantic constraints, however, their design did not separate these two factors.
2. Following Rösler, Heil, and Glowalla (1993; see also McCarthy & Wood, 1985), each subject's electrode- and condition-specific mean amplitude value was z transformed with respect to that subject's distribution of condition values across electrodes.
3. Although we had not designed these experiments to systematically compare the discourse- and sentence-dependent N400 effects for critical words in sentence-medial and sentence-final position, a post hoc analysis revealed a similar overall pattern of results at each position (context × coherence × CW-position: $F(1, 38) = 0.00$; $MSE = 30.25$; $p = 0.980$; context × coherence × electrode × CW-position: $F(12, 456) = 0.21$; $MSE = 0.44$; $p = 0.937$). Neither critical test comes close to significance. Also, as illustrated in Figure 5, there were no obvious qualitative differences between discourse- and sentence-dependent N400 effects at the two CW positions. Note, furthermore, that in these post hoc analyses, which had an additional

CW-position factor orthogonal to the main design, the basic pattern of results reappeared. There were significant coherence main effects in discourse ($F(1, 23) = 28.06$; $MSE = 36.63$; $p < 0.001$) and single sentences ($F(1, 15) = 8.79$; $MSE = 38.50$; $p = 0.010$), and the two did not interact ($F(1, 38) = 0.97$; $MSE = 37.37$; $p = 0.330$). Also, the N400 effect in discourse was significantly larger than the corresponding N400 control effect for the same critical sentences presented without the original discourse ($F(1, 38) = 4.26$; $MSE = 33.60$; $p = 0.046$). In this analysis, the latter control effect was only marginally significant ($F(1, 15) = 3.98$; $MSE = 28.94$; $p = 0.064$).

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