ERPs reveal sensitivity to hypothetical contexts in spoken discourse

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We used event-related potentials to examine the interaction between two dimensions of discourse comprehension: (i) referential dependencies across sentences (e.g. between the pronoun 'it' and its antecedent 'a novel' in: 'John is reading a novel. It ends quite abruptly'), and (ii) the distinction between reference to events/situations and entities/individuals in the real/actual world versus in hypothetical possible worlds. Cross-sentential referential dependencies are disrupted when the antecedent for a pronoun is embedded in a sentence introducing hypothetical entities (e.g. 'John is considering writing a novel. It ends quite abruptly'). An earlier event-related potential reading study showed such disruptions yielded a P600-like frontal positivity. Here we replicate this effect using auditorily presented sentences and discuss the implications for our understanding of discourse-level language processing. *NeuroReport* 21:791–795 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

Real-time interpretation of linguistic utterances in discourse contexts depends on our ability to mentally represent individuals/entities referred to by nominal expressions. For example, understanding 'John is reading a book' is thought to involve the generation of a mental model of an event involving two entities: 'John' and 'a book' [1–3]. Subsequent sentences can introduce expressions, which serve to refer back to these entities, as with the pronoun 'it' in the sentence pair: 'John is reading a book. It ends quite abruptly'.

This investigation used event-related potentials (ERPs) to study the brain mechanisms supporting the processing of such cross-sentential dependencies by examining a case in which such pronoun–antecedent relationships are disrupted. Note that in the foregoing example, the first sentence makes a factual claim about the real/actual world, the truth of which depends on whether (at the time of utterance) there is, in fact, some individual named John presently engaged in the activity of reading some book or other. However, all human languages make available a variety of grammatical means for introducing entities in which existence is merely hypothetical (i.e. not real/actual). For example, in 'John is considering writing a book', the indefinite noun phrase 'a book' does not pick out an actual entity in the real world. As has long been observed [4–8] that grammatical structure does not allow for a pronoun in a subsequent sentence to refer back to 'a book', consider: 'John is considering writing a book'. #'It ends quite abruptly' (the impossibility of linking the pronoun 'it' to 'a book' is marked here and below with '#'). Further examples of structures that do not support pronominal reference include, for example, negation: 'John doesn't have a car. #It is black'; and modal auxiliaries: 'John may have a car. #It is black'. 'Existence' in these stimuli is wholly inferred by the grammatical structure used in discourse, not by participants' beliefs about the real world. In contrast to the knowledge of how the world works (conceptual semantic knowledge), meaning that is derived from grammatical structure is known as 'compositional semantic knowledge' [9], and stimuli that require such computation provide a rich test-bed for understanding neurocognitive processes in language processing.

In an earlier study [10] we used ERPs to test the 2×2 design illustrated in Table 1. The context sentences were either hypothetical (H) or not [control (C)] and continuation sentences either contained or lacked a modal auxiliary, that is, these were either nonfactual (NF) or factual (F). Note that there is no difficulty in linking the pronoun 'it' to the antecedent 'a book' when the continuation sentences contain modal auxiliaries (i.e. HNF and CNF in Table 1 thus served as further controls).

Consistent with earlier behavioral findings [8], we found ERP evidence that the #HF condition gave rise to processing difficulties relative to the other conditions, which was reflected by a sustained positive-going deflection with an anterior scalp distribution. This effect

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Table 1 Example stimuli

Control factual		
John is reading a novel	It ends quite abruptly	CF
Hypothetical factual		
John is considering writing a novel	It ends quite abruptly	#HF
Control nonfactual		
John is reading a novel	It might end quite abruptly	CNF
Hypothetical nonfactual		
John is considering writing a novel	It might end quite abruptly	HNF

Note that at the verb position, condition HF is, anomalous, marked as #.
CF, control factual; CNF, control nonfactual; HF, hypothetical factual; HNF, hypothetical nonfactual.

was interpreted as a member of the P600 family [11–14]. The atypical anterior scalp distribution was linked to suggestions made elsewhere [11,12] that frontal effects of this kind may reflect discourse-level processing complexity. However, as we earlier deployed the artificial word-by-word visual presentation used in most ERP reading studies, here we aimed to replicate and extend our earlier finding using more naturalistic auditory presentation of the paradigm in Table 1.

Methods

Participants

Fourteen right-handed, monolingual native English-speaking adults (8 women; mean age = 22.4 years, SD = 3.03) participated. The participants were paid for participation. All the participants had normal or corrected-to-normal vision and were right handed, as assessed by a handedness inventory [15]. None of the participants reported any neurological impairments, history of neurological trauma, or use of neuroleptics. Electroencephalography (EEG) data from the two participants were discarded due to excessive artifacts. Thus all the data reported below are based on 12 participants (7 women; mean age = 22.5 years, SD = 3.3).

Materials

The auditorily presented sentence stimuli were identical to those used in the reading study reported in Ref. [10]. Five hundred two-sentence discourses produced by a male speaker were recorded using a Marantz (PMD670) digital recorder P(44.1 kHz sampling rate; 16-bit amplitude resolution). (Audio Acoustics, Inc., 800 N Cedarbrook Ave, Springfield, Missouri 65802, USA). The stimuli were composed of 400 target (100 for each condition in Table 1) and 100 filler discourses. Each two-sentence discourse consisted of a context sentence and a continuation sentence. In the continuation sentences, 20 high-frequency verbs were used with five different modals: may, might, should, would, and must. Trigger codes, marking the onset of each verb (i.e. "end") in the continuation sentences, were inserted into the wave files. The discourses then were pseudorandomized and evenly distributed across four blocks.

Procedure

During the EEG recording, the participants listened to four blocks (20 min each; order counter-balanced across the participants) through insertear-phones, while fixating on a cross displayed on a computer monitor. To monitor attention level, visually presented comprehension questions were inserted randomly within each block, at least once in every 3 minutes.

Electroencephalography recording and data processing

EEG was continuously recorded (500 Hz sampling rate; Neuroscan NuAmps amplifier Compumedics Neuroscan USA, 6605 West W.T. Harris Blvd Suite F, Charlotte, North Carolina 28269, USA) from 19 cap-mounted Ag/AgCl electrodes (10-20 system; Quick Cap) referenced to the right mastoid (impedance $< 5\,k\Omega$). Electrooculography was recorded using bipolar electrode arrays. EEG data were analyzed using EEProbe (ANT B.V. (Advanced Neuro Technology) Colosseum 227521 PT Enschede, The Netherlands). Single participant averages were computed separately for the four conditions (Table 1) after data preprocessing that included filtering (0.5 to 30 Hz bandpass) and artifact rejection. The number of trials surviving artifact rejection did not significantly differ between the conditions. Averages were computed for 1000 ms epochs beginning 100 ms before the onset of the target verb (−100 to 0 ms baseline).

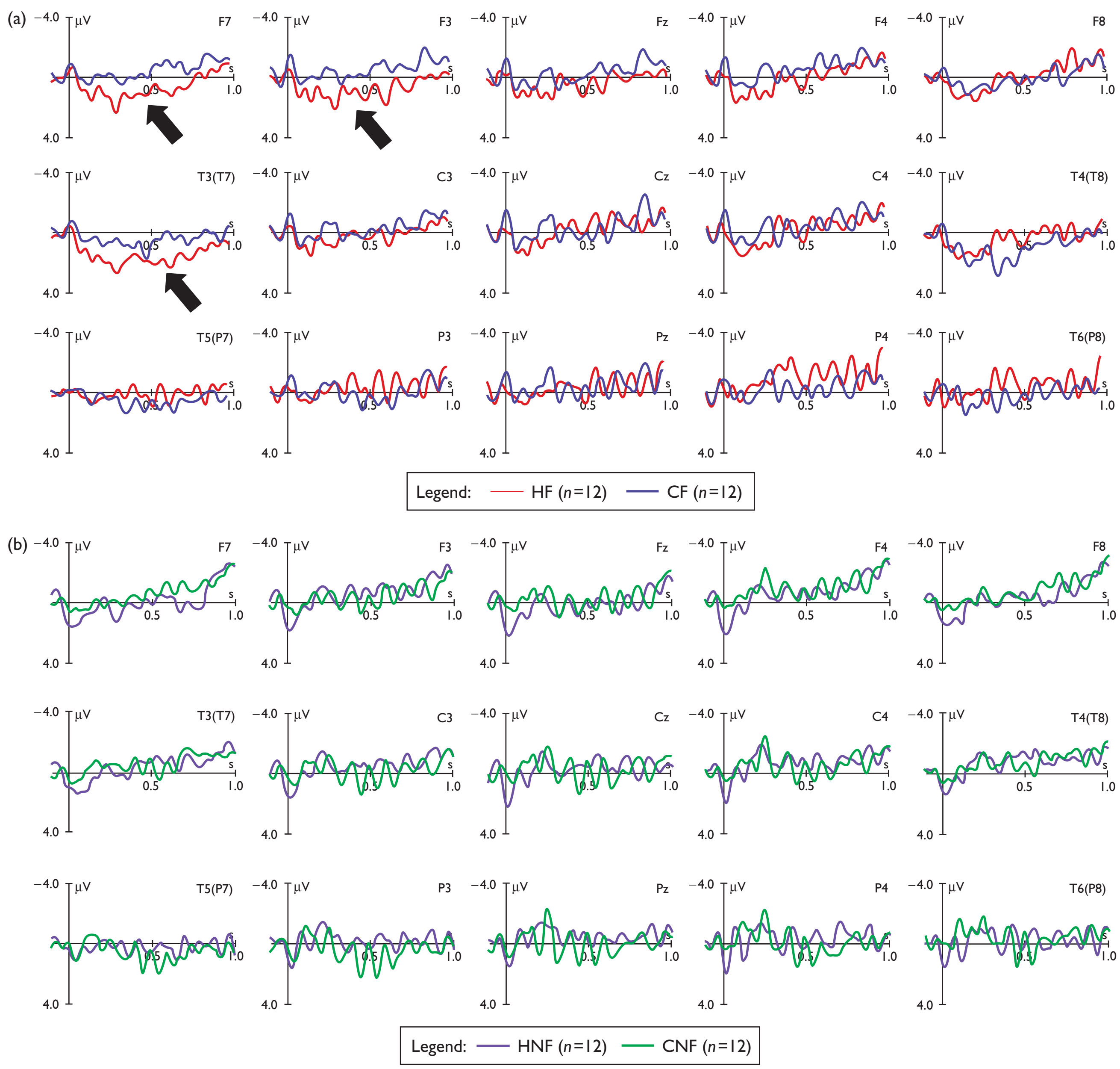
Statistical analyses

Statistical analyses were conducted over six regions of interest (ROIs), each composed of an averaged electrode pair: F3/7, F4/8, C3/T3, C4/T4, P3/5, P4/T6. (Note: midline analyses over Fz/Cz/Pz were also conducted, but as these did not show any ERP effects that were not already evident in the lateral analyses, they are not reported here). Repeated measures analyses of variance with mean amplitude as the dependent measure were conducted for four standard 200 ms time-windows (i.e. 100–300, 300–500, 500–700, and 700–900 ms), based on earlier literature and visual inspection. Two separate global analyses were conducted for the matched factual [hypothetical factual (#HF) vs. control factual (CF)] and nonfactual [hypothetical nonfactual (HNF) vs. control nonfactual (CNF)] conditions including the two-level factor context (hypothetical vs. control), and two electrode position factors (anterior/posterior: three-levels; hemisphere: two-levels) covering the six ROIs. Greenhouse–Geisser corrections for violations of sphericity were applied to analyses where appropriate (we report original degrees of freedom and Greenhouse–Geisser-corrected P values).

Results

Our findings were straightforward. Grand average ERP waveforms for the critical #HF/CF and control HNF/CNF comparisons are shown in Fig. 1a and b, respectively, at the verb position. The corresponding results of repeated measures analyses of variance are shown in Table 2.

Fig. 1



(a) Grand average waveforms for the factual conditions (hypothetical/#HF vs. control/CF). Arrows indicate electrodes of interest. (b) Grand average waveforms for the nonfactual conditions (hypothetical/HNF vs. control/CNF). CF, control factual; CNF, control nonfactual; HF, hypothetical factual; HNF, hypothetical nonfactual.

As predicted based on our reading study [10], the anomalous #HF condition elicited a positive-going deflection relative to the matched CF condition over the anterior left hemisphere recording sites (see Fig. 1a). Note that although the waveform for the anomalous #H-F condition showed an early departure (100–300 ms) from the matched CF condition, this yielded only borderline interactions (Table 2) of context with anterior/posterior (100–300 ms) and hemisphere (300–500 ms). Significant interactions of context with both anterior/posterior and hemisphere (see Table 2) did emerge though in the final two (500–700 and 700–900 ms) time-windows (i.e. in typical time windows associated with P600 effects).

Follow-up analyses over the individual ROIs for the 500–700-ms time-window showed that the positivity for the #HF condition was significant relative to the CF condition only over F3/F7 [$F(1,11) = 5.66$, $P < 0.05$] and

Table 2 ANOVA results

	d.f.	Latency range			
		100–300	300–500	500–700	700–900
#HF/CF					
Context	(1, 11)	–	–	–	–
C × A/P	(2, 22)	3.12[b]	–	3.04[b]	–
C × H	(1, 11)	–	3.13[b]	4.47[b]	–
C × A/P × H	(2, 22)	–	–	4.44[a]	5.52[a]
HNF/CNF					
Context	(1, 11)	–	–	–	–
C × A/P	(2, 22)	–	–	–	–
C × H	(1, 11)	–	–	–	–
C × A/P × H	(2, 22)	–	–	–	–

ANOVA, analysis of variance; A/P, anterior/posterior; C, context; CF, control factual; CNF, control nonfactual; H, hemisphere; HF, hypothetical factual; HNF, hypothetical nonfactual.
[a]$P < 0.05$.
[b]$P < 0.10$.

C3/T3 [$F(1,11) = 5.43$, $P < 0.05$] (for all other ROIs, all Fs < 1). In the subsequent 700–900 ms window, this relative positivity dissipated, as the follow-up analyses showed only a borderline effect at F3/F7 [$F(1,11) = 3.33$, $P = 0.095$] (for other ROIs Fs < 1 or P's > 0.15).

In contrast, the nonfactual (HNF vs. CNF) comparison did not show any significant differences in any latency range (Fig. 1b).

Discussion and conclusion

This study replicated the atypical frontal positivity found in our earlier reading study [10], thus extending this result to more naturalistic speech stimuli. One important aspect of the consistency of this finding is that this type of semantic/discourse level mismatch did not elicit the N400-type effect typically associated with conceptual semantic anomaly [16–19]. Unlike typical cases which elicit modulations of the N400 (e.g. John ate #democracy), the semantic mismatch studied here gives rise not to a clash in the fit between concepts, but rather to a logical contradiction with regard to the ontological status of an entity (a book) in participants' discourse representations [6,7]. In the critical (#HF) condition in which the antecedent has only a 'hypothetical' status and the pronoun (it) is followed by a present tense verb (It ends …), a logical conflict results: things cannot be both 'actual'/existent and 'hypothetical'/nonexistent at the same time.

Interestingly, an earlier study [20] examining cases of outright contradiction (e.g. Jane does not eat any meat at all, and instead, she eats lots of #BEEF and vegetables) also found a P600-like effect (and no N400). Further, other cases in which the linguistics literature link to contradiction (e.g. John has ever been to Paris) have also been shown to elicit P600-like effects [21–23]. However, in all of these plausibly related cases, the distribution of the positivities has been posterior, and not left/anterior as the effect found here (and in Ref. [10]). Thus, though our findings add to the growing literature showing P600-like effects for meaning related anomalies, which are not primarily 'conceptual' in nature [22,23], the left/frontal distribution of our effect stands out.

The distribution of the positivity observed here may reflect a particular aspect of our stimuli: this work (as in Refs [8,10]) manipulates logical semantic anomaly (vs. syntactic or conceptual anomaly) at the discourse level. Earlier studies that elicited P600 effects for logical contradiction occurred within, not across, sentences and furthermore could not be repaired by revision. Thus, we understand the left/frontal distribution as follows. First, the frontal distribution of this P600 effect bolsters the claims made in [11] in which, however, frontal positivity 'reflects only a subtype of revision, namely revision of the preceding phrase structure' (Ibid., p. 634). In contrast, in this work it is the preceding discourse structure that would need to be revised to resolve the logical contradiction. Our current hypothesis is that this distinct type of discourse-related re-analysis may also explain the rather atypical left-lateralization of the frontal effect. Alternatively, the distribution of the positivity could be due to the nature of the predictive reasoning that is generated while processing information of a hypothetical nature [24]. Further research in the domain of logical contradictions is required to tease apart the issues raised above. In sum, our ERP findings support recent claims with regard to the nonunitary functional view of the P600 component, in which anterior effects may be understood in terms of revision of discourse structure.

Finally, these findings (also see Refs [8,25]) shed light on models of discourse comprehension [1–3] that incorporate conceptual semantic information, as we have shown that rather than relying exclusively on a notion of meaning as defined by conceptual or real-world knowledge, grammatical structure also plays a role at the discourse level. Our results indicate that the mind/brain is sensitive to compositional semantic meaning, and that this meaning influences the interpretation of pronouns that occur in later sentences.

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