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The role of structural prediction in rapid syntactic analysis

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Abstract

A number of recent electrophysiological studies of sentence processing have shown that a subclass of syntactic violations elicits very rapid ERP responses, occurring within around 200 ms of the onset of the violation. Such findings raise the question of how it is possible to diagnose violations so quickly. This paper suggests that very rapid diagnosis of errors is possible specifically in situations where the diagnosis problem is tightly constrained by specific expectations generated before the critical word is presented. In an event-related potentials (ERP) study of visual sentence reading participants encountered violations of a word order constraint (...*Max's of*...) that has elicited early ERP responses in previous studies. Across conditions the illicit sequence was held constant, while sentence context was used to manipulate the expectation for a noun following the possessor *Max's*, by manipulating the possibility of ellipsis of the head noun. Results showed that the anterior negativity elicited by the word category violation was attenuated when the availability of ellipsis reduced the expectation for a noun in the position of the offending preposition *of*, with divergence between conditions starting around 200 ms after the onset of the violation. This suggests a role for structural expectations in accounting for very fast syntactic diagnosis processes.

Keywords: Event-related potentials; Parsing; Syntax; ELAN; Ellipsis; Structural prediction

1. Introduction

It has been known for at least thirty years that some portion of syntactic structure building in language comprehension happens very quickly. Marslen-Wilson's speech-shadowing experiments (Marslen-Wilson, 1973, 1975) showed that people who were shadowing spoken sentences at latencies as short as 250 ms were able to make corrections to inappropriate syllables, and crucially, that the rate of success in correction depended on the syntactic and semantic congruency of the word with its context. Eye-tracking studies investigating the immediate effects of sentence processing on eye movements (e.g., Sussman & Sedivy, 2003), as well as studies of error-detection using speed-accuracy tradeoff paradigms and electrophysiological brain recordings (e.g., McElree & Griffith, 1995; Neville, Nicol, Barss, Forster, & Garrett, 1991) have provided further evidence for syntactic processes occurring within 300 ms of word onset.

The psycholinguistic evidence for rapid syntactic processing is consistent with the subjective experience of immediate language comprehension, and it has become common to assume that most syntactic processing occurs rapidly. However, while it is clear that some syntactic processing does occur very quickly, the scope and nature of these 'syntactic processes' has largely remained unspecified. The classic speech-shadowing studies do not specify whether all syntactic contexts were equally amenable to correction, or whether rapid correction was restricted to a subclass of contexts. In addition, there has been little work on the mechanisms that make such rapid processing possible. In the 200–300 ms estimate, very little time is left over for syntactic processing once time is allowed for low-level sensory processing, lexical access, and response planning, suggesting that the mechanisms employed in syntactic processing within 200–300 ms of a word onset must be highly constrained and specialized.

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In this paper, we seek to contribute to a more explicit account of early syntactic processes through an investigation of Event-related potentials (ERP) responses to grammatical category violations. We provide a more detailed description of which syntactic processes occur most rapidly, and use these findings to suggest how these processes are able to proceed so quickly.

Studies in both English (Neville et al., 1991) and German (e.g., Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999) have shown that grammatical category violations like those shown in (1a) and (2a) elicit an increased left anterior negativity with a latency of 100–250 ms, relative to grammatical sequences like (1b) and (2b). The critical word is italicized in each example. This early response component has come to be known as the *Early Left Anterior Negativity* (ELAN).

(1) (a) *The scientist criticized Max's *of* proof the theorem.
(b) The scientist criticized Max's proof *of* the theorem.

(2) (a) *Die Kuh wurde im *gefüttert*.
The cow was in-the fed.
(b) Die Kuh wurde im Stall *gefüttert*.
The cow was in-the barn fed.

The ELAN response has been elicited only in very specific contexts. To date it has primarily been elicited by the syntactic sequences illustrated in (1) and (2) and minor variants upon them in Spanish (Hinojosa, Martin-Loeches, Casado, Muñoz, & Rubia, 2003), French (Isel, Hahne, & Friederici, 2004), and German (Rossi, Gugler, Hahne, & Friederici, 2005). The specificity of the ELAN is unusual when compared to the several other ERP components that have been shown to be associated with syntactic anomalies, including the anterior negativity with an onset of about 300–500 ms and the relatively long-lasting late positivity with characteristic onset of about 500–900 ms. The anterior negativity is generally known as the *Left Anterior Negativity* (LAN), since it often has a left-lateralized distribution, and it has been observed in response to inflection/agreement violations in some studies (Coulson, King, & Kutas, 1998; Friederici et al., 1993; Gunter, Stowe, & Mulder, 1997; Kaan, 2002; Kutas & Hillyard, 1983; Münte, Matzke, & Johannes, 1997; Osterhout & Mobley, 1995), and in some instances of case violations (Münte & Heinze, 1994), word category violations (Friederici, Hahne, & Mecklinger, 1996; Hagoort, Wassenaar, & Brown, 2003), violations of constraints on wh-fronting (Kluender & Kutas, 1993a, 1993b), and syntactic garden-paths (Kaan & Swaab, 2003). The late positivity is generally known as the *P600* (alternatively 'Syntactic Positive Shift'), although its latency shows substantial variation across studies, and has been elicited by a wide range of syntactic anomalies, including category and agreement violations (Friederici et al., 1993; Hagoort, Brown, & Groothusen, 1993; Hahne & Friederici, 1999; Kaan, 2002), syntactic garden-paths (Friederici et al., 1996; Kaan & Swaab, 2003; Osterhout, Holcomb, & Swinney, 1994), and subcategorization violations (Friederici & Frisch, 2000; Osterhout & Holcomb, 1992). In recent years, the P600 has also been elicited in well-formed sentences in response to ambiguity (Frisch, Schlesewsky, Saddy, & Alpermann, 2002), the construction of long-distance dependencies (Fiebach, Schlesewsky, & Friederici, 2002; Kaan, Harris, Gibson, & Holcomb, 2000; Phillips, Kazanina, & Abada, 2005), and in cases of unexpected mappings between noun phrases (NPs) and thematic roles (Kim & Osterhout, 2005; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; van Herten, Kolk, & Chwilla, 2005). In light of the wide variety of manipulations that elicit the later syntax-related ERP components, the specificity of the ELAN is all the more interesting.

Subsequent to the original demonstrations of the ELAN in English (Neville et al., 1991) and German (Friederici et al., 1993), Friederici and colleagues have confirmed its robustness in a number of studies. In a study using the same materials with the MEG methodology a response peak with a similar latency was observed (Friederici, Wang, Herrmann, Maess, & Oertel, 2000). The ELAN appears not to be sensitive to task manipulations (Hahne & Friederici, 2002) or to the experiment-wide probability of the violation (Hahne & Friederici, 1999), in contrast to the P600 component, which is affected by both. In other work, it has been shown that an ELAN response is not observed in ambiguous sentences disambiguated to the less frequent structure, even when this structure is strongly dispreferred (Ainsworth-Darnell, Shulman, & Boland, 1998; Friederici et al., 1996). Thus, it appears that the early response is not elicited in cases where successfully integrating the item into a phrase structure is merely difficult or unlikely.

An account of the ELAN must explain how the response can be generated so quickly as well as the reason why only a narrow set of contexts elicit the response. The earliness of the ELAN response is even more striking when the time needed for basic perceptual processes is subtracted out. For example, a rough estimate of the time needed for visual information about a word to reach the brain areas that process lexical information is 60 ms (Sereno & Rayner, 2003). Thus, in the ERP studies that found early responses using visual presentation, only around 100 ms is available for the necessary syntactic information associated with the word to be accessed. The time window for syntactic analysis narrows further when one considers that estimates in the literature for the earliest processes involved in lexical access often fall in the 200 ms range (Allopenna, Magnuson, & Tanenhaus, 1998; van Petten, Coulson, Rubin, Plante, & Parks, 1999).

Across studies, there is some variation in the latency of the anterior negativity elicited by grammatical category violations. The response has an onset in the 100–200 ms range in a number of studies, including the original report on English by Neville et al. (1991) and most of the German auditory-based studies by Friederici et al. in which the offending participle is clearly marked by the prefix *ge-*

and the suffix -*t* (e.g., Friederici et al., 1993; Hahne & Friederici, 1999). In other studies, however, the anterior negativity to category violations has an onset latency of 300 ms or longer. This includes studies in German (Friederici et al., 1996), Dutch (Hagoort et al., 2003), and Spanish (Hinojosa et al., 2003) that have used visual presentation and offending verb forms that are morphologically distinguished from other categories only by their suffix. Note that in the Dutch examples in (3) the sequence of words preceding the category violation is perfectly matched across the grammatical and ungrammatical conditions, although this means that the critical word categories are not matched. This helps to dispel the possible concern that the anterior negativity might reflect an artifact due to poorly matched baseline intervals in the comparisons illustrated in (1) and (2).

(3) (a) De houthakker ontweek de ijdele *schroef* op dinsdag.
The lumberjack dodged the vain propeller on Tuesday.
(b) *Do houthakker ontweek de ijdele *schroeft* op dinsdag.
The lumberjack dodged the vain propelled on Tuesday.

Friederici (1995) hypothesized that the ELAN is a response elicited by any incoming word whose grammatical category cannot be integrated into any possible elaboration of the existing phrase structure, for example, a preposition following a possessor in the English example in (1a), or a participle following a preposition/determiner combination in the German example in (2a). This view of the ELAN may be understood in terms of a parsing architecture in which an initial parsing stage considers only category information about the incoming lexical item (Friederici, 1995; Frazier, 1978, 1987, 1990; Frazier & Rayner, 1982). If only category information is available at the earliest stage of structure building, the prediction is that only category-level violations can be diagnosed at very short latencies. Under this approach the rapid diagnosis of the category-level violations in (1)–(3) is a consequence of the impoverished nature of initial parse trees, which places an extrinsic constraint on the diagnosis process. In other words, certain types of information are assumed to be withheld from the earliest stage of syntactic analysis. This account successfully distinguishes the contexts in (1) and (2) from most other syntactic errors studied in the ERP literature, but does not specify the processes that could allow the parser to determine well-formedness so quickly.

An alternative possibility is that early detection of violations reflects an intrinsic property of the diagnosis process, and that the category-level violations in (1)–(3) are special because the sentential context that precedes the violation makes diagnosis unusually straightforward. In all of the examples in (1)–(3) the category violation occurs in a sentential context where the preceding word clearly signals that the parser is constructing a noun phrase but has not yet encountered its head. Therefore, the parser should strongly predict an upcoming noun position even before the new word is presented, and can diagnose the grammaticality of the incoming word by considering only a small part of the parse tree. For example, a possessor like *Max's* strongly predicts an upcoming noun position. The parser can conclude that the following word *of* in (1a) is a violation merely by determining that it is not a noun and that it cannot appear to the left of the head of an NP. Likewise, in the German examples the preposition + determiner combination *im* strongly predicts an upcoming noun, and thus the impossibility of the following participle in (2a) can be diagnosed simply by determining that it is neither a noun nor a word that can occur to the left of the head of an NP.[1] Similar remarks apply to the Dutch examples in (3). In each of these examples, the prediction for an upcoming noun means that, in analyzing the incoming word, the parser is freed from considering any part of the structure beyond the predicted noun position.

In sum, based on current data, there are at least two possible accounts for rapid ERP responses to category violations. The first is that all syntactic structure is built very quickly based on word category information, and the ELAN response results from a situation in which it is impossible to integrate the word category of the current word into the syntactic structure that has been built so far. The alternative is that a strong structural prediction leads the reader to predict a certain word category, which narrows the task of diagnosing the grammaticality of the incoming word to one of determining whether the word matches the predicted category or can be a left-hand modifier of the predicted category. Under this account, the speed of the ELAN reflects the restricted nature of the diagnosis problem in cases like (1)–(3).

The aim of the current study was to further understand the syntactic processes underlying this response by directly comparing ungrammatical sentences in which the critical word and the preceding word were matched, but where the conditions for diagnosing the violation varied. Based on differences in the early response to the two violation types, we suggest a more specific interpretation of the processes underlying the early negativity, which may in turn contribute to the development of a timeline for early syntactic processing. We used the possibility of ellipsis to manipulate whether a possessor at the left edge of an NP created a strong prediction for an overt noun. We achieved

[1] As in English, participles in German can be productively used to derive adjectives, requiring only the addition of appropriate adjective agreement suffixes. It is therefore perhaps surprising that the German category violations elicit such rapid responses in studies using auditory presentation, since the critical word may be initially parsed as an adjective, at least until the end of the word is reached. This suggests that, for some reason, the adjective analysis is not initially considered by participants in these studies.

this by adding a preceding clause to the constructions that have previously been used to elicit ELAN in English. In English it is possible for the head of an NP to undergo ellipsis when its content can be recovered from a prominent NP in the discourse, as in sentences like *I don't like Bill's theory but I do like Max's*.

The experiment also included a pair of conditions that manipulated the correctness of verbal agreement marking, with the aim of providing a point of comparison with responses elicited by grammatical category violations. In previous studies, agreement violations have been associated with both LAN and P600 responses. A sample set of experimental conditions is presented in Table 1.

The second clause of the grammatical and ungrammatical conditions has the same structure as the control and phrase structure violation conditions used by Neville et al. (1991). The difference in the current study is that the addition of a preceding clause makes it possible to manipulate the availability of ellipsis of the noun following the possessor in the second clause. In the +ellipsis conditions the first clause ends in an NP containing a possessor and a noun, and the two clauses have a form that makes it easy to understand them as encoding contrastive propositions. Together, these two properties should allow for an elliptical interpretation of the noun position following the possessor *Dana's* in the second clause. In this case the sentence would be grammatical if it ended at the word *Dana's* (e.g., *Although Erica kissed Mary's mother, she did not kiss Dana's*). If no overt noun is predicted following the possessor, then the task of evaluating the appropriateness of a subsequent incoming word is made more open-ended, because the possible attachment sites are no longer restricted to the noun position and left-hand modifiers of the noun. In contrast, in the −ellipsis conditions the first clause is minimally modified such that it no longer provides a possessor + noun combination that could license ellipsis in the second clause. Therefore, the possessor *Dana's* should trigger a prediction for a following noun, just as in examples like (1)–(3), and the sentence would be ungrammatical if it ended at *Dana's*. Thus, the clause containing the category violation is identical in the two incorrect conditions, but the contextual manipulation varies the strength of prediction for an overt noun following the possessor *Dana's*. If a strong prediction for an upcoming noun plays a key role in explaining the early anterior negativity, then we predict attenuation of the anterior negativity in the +ellipsis ungrammatical condition, relative to the −ellipsis ungrammatical condition. On the other hand, if all structure is built very quickly and the ELAN is a response to the impossibility of attaching *of*, we expect the ERP responses to the two ungrammatical conditions to be identical.

2. Methods

2.1. Participants

Forty-one members of the University of Maryland community participated in the ERP study. None had participated in testing of materials (described below). Data from six participants were excluded due to technical problems and data from three participants were excluded due to high levels of artifacts in the EEG recordings. All 32 remaining participants (20 female; mean age 20.7; range 18–37 years) were healthy, monolingual native speakers of English with normal or corrected to normal vision, and all were classified as strongly right-handed based on the Edinburgh handedness inventory (Oldfield, 1971). All participants gave informed consent and were paid $10/hour for their participation, which lasted around $2\frac{1}{2}$ h, including set-up time.

2.2. Materials

To confirm that our contextual manipulation successfully modulated the strength of the prediction for an overt noun following a possessor we conducted a preliminary off-line sentence completion study. Fourteen participants from the University of Maryland community were asked to supply completions to fragments like (4a and b), corresponding to the first 10 words of the syntactically incorrect conditions in Table 1. The +antecedent condition (4a) contained a noun phrase with a possessor in direct object position of the first clause, which served as a potential antecedent for ellipsis in the second clause and allowed the string to stand complete without further elaboration. The −antecedent condition (4b) served as the baseline condition, since the first clause contained no antecedent for ellipsis, and therefore the fragment had to be completed with a noun. Participants were instructed to insert suitable words to complete the sentence naturally, and were told that they could insert a period if they felt that no additional words were needed to complete the sentence. Six items were presented from each of the two conditions, within a questionnaire that included 48 filler items, all of which used a similar two-clause form.

Table 1
Sample set of conditions used in the ERP experiment

+Ellipsis	Grammatical	Although Erica kissed Mary's mother, she did not kiss the daughter *of* the bride
	Ungrammatical	*Although Erica kissed Mary's mother, she did not kiss Dana's *of* the bride
−Ellipsis	Grammatical	Although the bridesmaid kissed Mary, she did not kiss the daughter *of* the bride
	Ungrammatical	*Although the bridesmaid kissed Mary, she did not kiss Dana's *of* the bride
Agreement	+Agree	Although Matt *followed* the directions closely, he had trouble finding the theater
	−Agree	*Although Matt *follow* the directions closely, he had trouble finding the theater

Table 2
Frequency of completion types in the offline completion task ($n = 14$)

Fragment type	Noun		Period	Error
	Novel	Repeat		
+Antecedent (4a)	26	22	33	3
−Antecedent (4b)	83	n/a	1	0

(4) (a) Although Erica kissed Mary's mother, she did not kiss Dana's...
(b) Although the woman kissed Mary, she did not kiss Dana's...

A summary of results from the completion study is presented in Table 2. The results showed that there was a significant difference in the pattern of completions for the two conditions ($\chi^2 = 37.759$, $p < .001$). As expected, in the −antecedent condition participants supplied a grammatical continuation with an overt noun in 99% of trials. In contrast, in 39% of the +antecedent trials participants simply ended the sentence with a period, indicating an elliptical interpretation for the object of the second clause. Additionally, in 26% of +antecedent trials participants supplied a noun that matched the noun in the first clause, suggesting that they constructed the same interpretation used in the elliptical completions. These results provide evidence that the contextual manipulation used in the ERP study is indeed able to weaken the prediction for a novel noun following the possessor, although it remains likely that a novel noun was still predicted on some proportion of the +ellipsis trials in the ERP study.

The materials for the ERP study consisted of sentence quadruples organized in a 2 × 2 factorial design and corresponding to the first four conditions in Table 1, plus pairs of sentences corresponding to the grammatical and ungrammatical agreement conditions. In all four category violation conditions, the sentences consisted of a subordinate clause followed by a main clause; within each set, the two factors varied were the availability of ellipsis (presence vs. absence of a possessive NP in the first clause) and grammaticality (full NP vs. possessor preceding the preposition in the second clause). To facilitate a contrastive interpretation of the two clauses and thereby favor ellipsis, the second clause always contained the same verb as the first clause, and the second clause showed the opposite polarity of the first clause, i.e., the second clause was negated. To balance the number of words and the number of common nouns in the first clause across conditions, the subject of the first clause was a proper name in the +ellipsis conditions and a two word NP in the −ellipsis conditions. Within each level of the grammaticality factor, the sequence of words preceding the critical word *of* was identical across a span of at least five words.

The common noun in the second clause (e.g., *daughter*) was chosen to freely allow a following argument or modifier prepositional phrase (PP) headed by *of*. On the other hand, the choice of common noun in the possessive NP in the first clause was constrained in order to resist combination with the preposition *of*, and thereby to ensure that the possessor+ *of* sequence in the second clause would be equally unacceptable in the two grammatically incorrect conditions. Some speakers of English find it marginally acceptable to elide the head noun to create a possessor+ *of* sequence when an appropriate antecedent is available and the possessor may be construed as the agent of the event denoted by the noun (5). In cases where the possessor has a true genitive interpretation this ellipsis is fully impossible (6).

(5) (a) ?John's description of the crime and Mary's of the leading suspects.
(b) ?John's news of the earthquake and Mary's of the relief effort.
(c) ??The barbarians' destruction of the city and the peasants' of the surrounding countryside.

(6) (a) *John's vase of crystal and Mary's of solid silver.
(b) *Manchester United's director of coaching and Chelsea's of marketing.
(c) *Sue's friend of 15 years, and Sally's of six months.

One hundred and twenty eight sets of items for the category violation conditions were distributed across four presentation lists in a Latin Square design, such that each list contained 32 items per condition. In addition, 64 pairs of agreement items were distributed across two presentation lists in a Latin Square design. Each list of category violation items was combined with one of the agreement lists and 192 filler items to create four lists with 384 items each. The filler items were similar to the experimental items in maintaining a subordinate–main clause format, and were all grammatically correct. Thus, items from the four category violation conditions were outnumbered 2:1 by other items, and the ratio of grammatical to ungrammatical sentences was 3:1. Furthermore, since the grammatical violations occurred in either the first clause (agreement conditions) or the second clause (category prediction conditions), participants needed to pay attention to the entire sentence in order to accurately judge the well-formedness of the sentence. A full set of experimental materials is available at http://www.ling.umd.edu/colin.

2.3. Procedure

Participants were comfortably seated in a dimly lit testing room around 100 cm in front of a computer monitor. Sentences were presented one word at a time in black letters on a white screen in 30 pt font. Each sentence was preceded by a fixation cross. Participants pressed a button to initiate presentation of the sentence, which began 1000 ms later. Each word appeared on the screen for 300 ms, followed by 200 ms of blank screen. The last word of each sentence was marked with a period, and 1000 ms later a question mark prompt appeared on the screen. Participants were instructed to read the sentences carefully without blinking and to indicate with a button press whether the sentence was an acceptable sentence of English. Feedback was provided for incorrect responses. This task is similar to the task used in previous studies of responses to category violations. Each experimental session was preceded by a 12 trial practice session that included both grammatical and ungrammatical sentences. Participants received feedback and were able to ask clarification questions about the task at this time. The experimental session itself was divided into six blocks of 64 sentences each.

2.4. EEG recording

EEG was recorded from 30 Ag/AgCl electrodes, mounted in an electrode cap (Electrocap International): midline: Fz, FCz, Cz, CPz, Pz, Oz; lateral: FP1/2, F3/4, F7/8, FC3/4, FT7/8, C3/4, T7/8, CP3/4, TP7/8, P4/5, P7/8, and O1/2. Recordings were referenced online to the linked average of the left and right mastoids, and re-referenced offline to the common average reference, as discussed further in Section 3. Additional electrodes were placed on the left and right outer canthus, and above and below the left eye to monitor eye movements. EEG and EOG recordings were amplified and sampled at 1 kHz using an analog bandpass filter of 0.1–70 Hz. Impedances were kept below 5 kΩ.

2.5. EEG analysis

All comparisons were made based upon single word epochs, consisting of the 100 ms preceding and the 1000 ms following the critical words. Epochs with ocular and other large artifacts were rejected from analysis based on visual screening. This affected 10.9% of trials, ranging between 9.1 and 13.8% across conditions. The waveforms of the individual trials were normalized using a 100 ms prestimulus baseline. Averaged waveforms were filtered offline using a 10 Hz low-pass filter for presentation purposes, but all statistics are based on unfiltered data. The following latency intervals were chosen for analysis, based on the intervals used in the literature and on visual inspection: 0–200 ms, 200–400 ms (ELAN), 300–500 ms (LAN), and 600–1000 ms (P600).

To test for lateral effects, four quadrants of electrodes were defined as follows: left anterior (F7, FT7, F3, and FC3), right anterior (F4, FC4, F8, and FT8), left posterior (TP7, P7, CP3, and P3), and right posterior (CP4, P4, TP8, and P8). ANOVAs were performed hierarchically, using the within-subjects factors ellipsis (ellipsis available/unavailable), grammaticality (grammatical/ungrammatical), hemisphere (left/right), anteriority (anterior/posterior), and electrode (four per region). In addition, ANOVAs were performed separately on the midline electrodes, with two regions, anterior (Fz, FCz, and Cz) and posterior (CPz, Pz, and Oz), and the factors ellipsis, grammaticality and anteriority. All *p*-values reported below reflect the application of the Greenhouse-Geisser correction where appropriate, to control for violations of the sphericity assumption (Greenhouse & Geisser, 1959), together with the original degrees of freedom. Due to the large number of possible interactions in this design, we report as significant only those interactions for which follow-up analyses yielded significant contrasts within the levels of the interacting factors.

3. Results

3.1. Comprehension question accuracy

Overall accuracy on the behavioral grammaticality judgment task for the four category violation conditions was 95.4%. The agreement conditions showed an overall accuracy that was somewhat lower, 88.4%. Average accuracy for the ungrammatical agreement condition was only 82.5%, suggesting that participants either experienced some difficulty in detecting these violations, or were less attentive to these violations, perhaps because they were less striking than the category violations or because they appeared earlier in the sentence.

3.2. ELAN comparison

3.2.1. Pre-critical word

Visual inspection of the responses to the grammatical and ungrammatical conditions suggested that the waveforms already diverged at the word preceding the critical word *of*. This is perhaps not surprising in light of the lexical differences between conditions in this position. Pre-existing differences in the responses to grammatical and ungrammatical conditions could bias the analysis of responses to the preposition *of*. To statistically test for pre-existing differences, an ANOVA was performed on the 300–500 ms interval following presentation of the word preceding *of*, which falls immediately before the presentation of the critical word. At this interval the ungrammatical conditions were more negative at anterior scalp regions and slightly more positive at posterior regions, relative to the grammatical conditions. This yielded a main effect of grammaticality, $F(1,31) = 10.62$, $p < .01$, and interactions between grammaticality and hemisphere, $F(1,31) = 4.25$, $p < .05$, and between grammaticality and anteriority, $F(1,31) = 18.41$, $p < .001$. The ANOVAs comparing grammatical and ungrammatical conditions within each level of the ellipsis factor showed similar patterns within both the +ellipsis and −ellipsis pairs. The +ellipsis ungrammatical condition showed a more negative response than the +ellipsis grammatical condition at anterior scalp regions, including the left anterior quadrant, $F(1,31) = 11.52$, $p < .01$, the right anterior quadrant, $F(1,31) = 4.16$, $p < .06$, and the anterior midline region, $F(1,31) = 14.88$, $p < .01$, but showed a more positive response than the grammatical condition in the right posterior quadrant $F(1,31) = 7.52$, $p < .05$. The response to the −ellipsis ungrammatical condition was more negative than the response to the −ellipsis grammatical condition in the left anterior quadrant, $F(1,31) = 14.61$, $p < .01$, and in the anterior midline region, $F(1,31) = 13.74$, $p < .01$. The effects of grammaticality are unsurprising, since the comparison involves different words with different grammatical roles: in the grammatical condition the word before *of* is a noun (e.g., *director*), while in the ungrammatical condition the word before *of* is a possessor (e.g., *John's*) that precedes the anticipated noun. Due to the differences in ERP responses at the preceding word, it was difficult to establish a reliable baseline interval or to reliably identify effects of the processing of the word *of*. Therefore, in what follows we only report comparisons within each level of the grammaticality factor. Although this means we cannot directly evaluate the effect of grammaticality, the advantage of this approach is that all comparisons are based on conditions that are lexically very well matched and that are also identical through at least the five regions preceding the critical word *of*.

In addition to the effect of grammaticality, the ANOVA revealed that in the 300–500 ms interval after the word preceding the critical word *of* there was a main effect of ellipsis, $F(1,31) = 7.69$, $p < .01$, with no significant or marginally significant interactions between ellipsis and any other factors. However, the difference in amplitude was small, with the average response to +ellipsis conditions being 0.12 μV more negative than the response to −ellipsis conditions. Visual inspection suggested that this effect arose from a difference between the grammatically correct +ellipsis and −ellipsis conditions, and that the two ungrammatical sentences were closely matched. The statistics confirmed this: an ANOVA comparing the +ellipsis grammatical and −ellipsis grammatical conditions yielded a significant effect of ellipsis, $F(1,31) = 9.13$, $p < .01$, with no significant or marginally significant interactions between ellipsis and any other factor. Again, the amplitude difference was small; the response to the +ellipsis grammatical condition was 0.17 μV more negative than the response to the −ellipsis grammatical condition. This effect is a concern since effects of the ellipsis manipulation were not anticipated at this point in the sentence. However, since the amplitude difference was small and non-focal, relative to the approximately 1 μV focal ELAN effect at the critical word (see Section 3.2.2), we assume that the difference at the pre-critical word in the grammatical conditions does not compromise our main conclusions. Importantly for the main topic of our study, there was no difference between the +ellipsis ungrammatical and the −ellipsis ungrammatical conditions.

3.2.2. Critical word

Due to pre-existing differences in the grammaticality factor at the pre-critical word, as discussed above, subsequent analyses focus on comparisons within each level of the grammaticality factor. In the comparison of responses to the word *of* in the two ungrammatical conditions (Fig. 1 and Table 3), there was an effect of ellipsis in the 0–200 ms interval; the +ellipsis condition showed a slightly greater negativity than the −ellipsis condition, although this difference was not significant in any individual region. In the 200–400 ms interval, the interval in which we expected to see modulation of the ELAN effect, the response to the −ellipsis condition in the left anterior scalp quadrant was significantly more negative than in the +ellipsis condition. There was also a significant effect of ellipsis in the right posterior quadrant, due to a slightly more negative response to the +ellipsis condition than to the −ellipsis condition. In the 600–1000 ms window there were no differences that would be characteristic of a P600. Although this could in principle reflect a lack of P600 in both conditions, this is unlikely and it is more likely that it reflects an equivalent late positive effect in both conditions.

Note that the analyses presented in this study are based upon data that used a common average reference, in which individual electrodes are referenced to the average of all electrode voltages. Although electrophysiological studies of sentence comprehension have by convention used a mastoid reference, the average reference is widely used in some areas of ERP research. Given a standard model of scalp potentials generated by a dipolar source (Brody, Terry, & Ideker, 1973), the focal distribution of the difference wave based on the average reference (Fig. 1) is more plausible than the distribution based on the mastoid reference (Appendix: Fig. 4), which shows a weak effect distributed evenly across most of the scalp and a focal absence of differences at left anterior electrodes. A potential drawback to using the mastoid reference is that this method assumes that the mastoids do not pick up any electrical activity that correlates with the experimental measure, because this activity will be subtracted from the voltages measured at all electrodes (Dien, 1998). The pattern observed with the mastoid reference may reflect a violation of this assumption. Use of an average reference avoided this potential confound. Note that the comparison of the ungrammatical −ellipsis and +ellipsis conditions shows a more negative response at left anterior electrodes than at other regions for either choice of reference.

We predict that manipulation of ellipsis should not affect responses to the word *of* in the grammatical conditions, since the two conditions were identical in the preceding five words and since the contextual manipulation did not affect the acceptability of these conditions or the possible anticipated continuations at the word preceding *of*. The relevant results are shown in Fig. 2 and Table 4.

Responses to the word *of* in the grammatically correct conditions showed a significant three-way interaction of ellipsis with hemisphere and anteriority in the 0–200 ms interval. This interaction was due to a marginally significant effect of ellipsis at the right anterior region, due to a small negativity (0.14 μV) in the −ellipsis grammatical condition. In the 200–400 ms interval there was a marginally significant interaction between ellipsis and hemisphere, but the effect of ellipsis was neither significant nor margin-

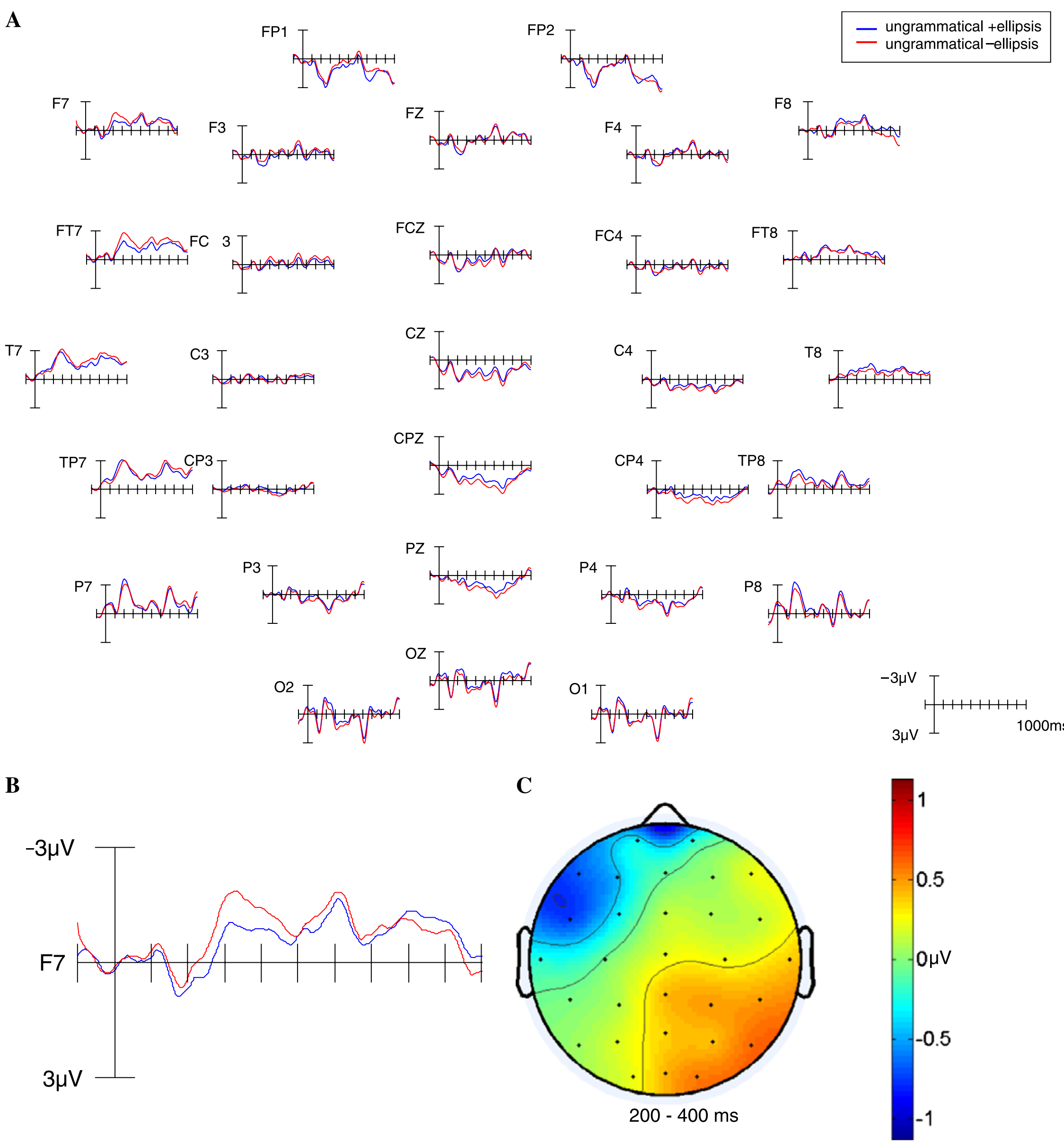

Fig. 1. Grand average responses in the ungrammatical +ellipsis (blue) and ungrammatical −ellipsis (red) conditions, average reference, showing (A) all electrodes and (B) left anterior electrode F7. (C) Topographic plot of the difference in average potential from 200 to 400 ms latency for the two ungrammatical conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

ally significant at any individual region, suggesting that the effect was spurious. In the 300–500 ms interval, the +ellipsis grammatical condition showed a more negative response than the −ellipsis grammatical condition in the right posterior quadrant. There were no other significant effects of ellipsis at any quadrant in any time interval. The scarcity of reliable contrasts in the grammatical conditions suggests that the manipulation of ellipsis in the first clause did not appreciably affect the reading of the word *of* in the second clause in the two grammatical conditions.

3.3. Agreement violation

There was no effect of grammaticality in any of the early intervals: 0–200 and 200–400 ms (Fig. 3A). Nor was there any significant effect in the LAN interval of 300–500 ms. In the 600–1000 ms interval, there was a pattern of a posterior positivity and a corresponding anterior negativity, a pattern that is the average reference counterpart of the posterior positivity observed when using a mastoid reference. The topographic map in Fig. 3B shows that the response to the agreement violation had a typical scalp distribution.

4. Discussion

The aim of this study was to contrast two ways of understanding the parsing mechanisms that underlie rapid ERP responses to category violations such as *Max's of...* and related violations in other languages. Assuming that some

Table 3
Ungrammatical +ellipsis vs. −ellipsis: ANOVA *f*-values at the critical word *of*

	0–200 ms	200–400 ms	300–500 ms	600–1000 ms
Overall ANOVA—four quadrants				
Ellip (1,31)	5.11*	—	—	—
Ellip x lat (1,31)	—	7.60*	5.43*	4.95*
Ellip x ant (1,31)	—	—	—	—
Ellip x lat x ant (1,31)	—	—	3.49**	—
Overall ANOVA—midline				
Ellip (1,31)	—	—	—	—
Ellip x ant (1,31)	—	—	—	—
Anterior regions				
Left Ellip (1,31)	—	6.60*	3.68**	—
Mid Ellip (1,31)	—	—	—	—
Right Ellip (1,31)	—	—	—	—
Posterior regions				
Left ellip (1,31)	—	—	—	—
Mid ellip (1,31)	—	—	—	—
Right ellip (1,31)	—	5.85*	2.90**	—

* <.05.
** <.1.

amount of time is needed for basic auditory or visual processing and for lexical access, the 100–300 ms onset latency of the response elicited by these violations leaves little time for processes of grammatical analysis and diagnosis. Under one approach, rapid responses to category violations reflect an initial stage of structure building that is based on purely syntactic category information, suggesting that any similar illicit sequence should yield a response with a similar latency. Under an alternative approach, the early response to category violations reflects specific situations in which a strong local prediction for an upcoming noun dramatically narrows the space of possibilities that must be evaluated in order to diagnose a violation. Previous studies could not decide between these two accounts, since the presence of a category violation and the presence of a strong local prediction consistently covaried. The current study aimed to distinguish the two accounts by manipulating the possibility of ellipsis following a possessor and thereby controlling the presence or absence of a strong local prediction for a following noun.

In a comparison of responses to identical possessor + preposition violations we found that the presence of a context that licensed ellipsis led to differential ERP responses, starting at a latency of around 200 ms. Specifically, a left anterior negativity was reduced in the ungrammatical ellipsis condition, as was a simultaneous right posterior positivity. In this comparison all words in the critical clause are identical and the violation is the same, but the response to the violation differs depending on the strength of constraint provided by the context. This finding suggests that not all word category violations are diagnosed in the same fashion. Furthermore, it suggests that the very rapid detection of category violations observed here and in other studies may reflect situations where category predictions make the diagnosis of illicit incoming words particularly straightforward. This may account for the speed of early electrophysiological responses to syntactic anomalies, without the need to appeal to an initial parse stage that encodes just syntactic category information.

We should point out certain advantages and disadvantages of the specific comparison presented here, and how

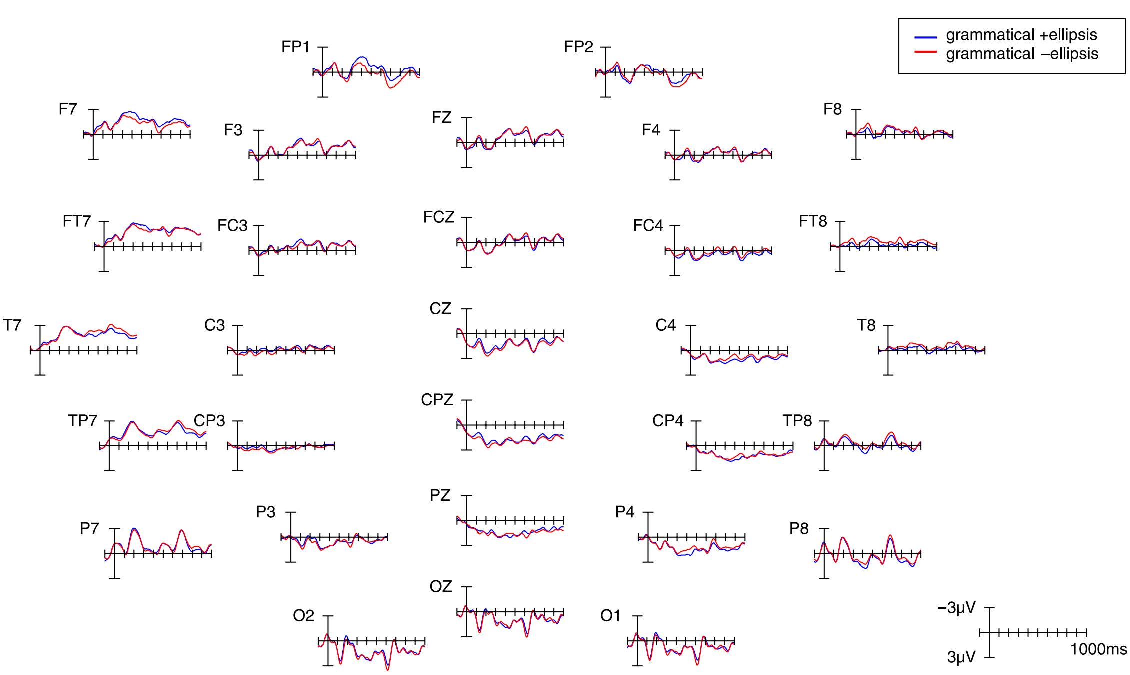

Fig. 2. Grand average responses in the grammatical +ellipsis (blue) and ungrammatical −ellipsis (red) conditions, average reference. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

Table 4
Grammatical +ellipsis vs. −ellipsis: ANOVA *f*-values at the critical word *of*

	0–200 ms	200–400 ms	300–500 ms	600–1000 ms
Overall ANOVA—four quadrants				
Ellip (1, 31)	—	—	—	—
Ellip x lat (1, 31)	—	3.25**	4.40*	—
Ellip x ant (1, 31)	—	—	—	—
Ellip x lat x ant (1, 31)	4.61*	—	—	—
Overall ANOVA—midline				
Ellip (1, 31)	—	—	—	—
Ellip x ant (1, 31)	—	—	—	—
Anterior regions				
Left ellip (1, 31)	—	—	—	—
Mid ellip (1, 31)	—	—	—	—
Right ellip (1, 31)	4.01**	—	—	—
Posterior regions				
Left ellip (1, 31)	—	—	—	—
Mid ellip (1, 31)	—	—	—	—
Right ellip (1, 31)	—	—	7.62*	—

* <.05.
** <.1.

this impacts the conclusions that may be drawn from our results, particularly in relation to the functional nature of the ELAN component. A clear advantage of comparing two types of closely matched ungrammatical sentences is that we can be confident that the effects of the ellipsis factor in the 200–400 ms time interval are unlikely to be artifacts caused by mismatched preceding words. In contrast, it is difficult to exclude the possibility that the standard ELAN responses elicited in English and German might be affected by lexical differences at the region that immediately precedes the critical word. Note that this concern does not arise in the category violation study of Dutch (Hagoort et al., 2003) where preceding contexts were fully matched, although the target words in that study were imperfectly matched.

A disadvantage of the direct comparison of two grammatically incorrect conditions is that it differs from the comparison of correct and incorrect conditions that has standardly been used in studies of category violations (e.g., Friederici et al., 1993; Hahne & Friederici, 1999; Neville et al., 1991). It was not possible to make this comparison, due to the concerns about the baseline interval discussed in the Section 3. There are a number of possible explanations of why the materials used in this study did not yield closely matched baseline intervals for the grammatical–ungrammatical comparison. First, the region preceding the critical preposition *of* involves different words with different grammatical functions: in the grammatical condition it is a noun (e.g., *director*) whereas in the ungrammatical condition it is a possessor (e.g., *John's*). Since most other studies of category violations have also had mismatched words at the region preceding the violation, it is perhaps surprising that baseline differences have not been more widely reported. Second, in three of the four category prediction conditions, the word immediately preceding the violation is a potential end-of-sentence. Only in the ungrammatical −ellipsis condition is that position not a possible end-of-sentence. This raises the possibility of sentence-final wrap-up effects, which sometimes elicit additional activity that is not specific to the processing of the current word (Hagoort et al., 1993; Osterhout, 1997; Osterhout & Holcomb, 1992). This, in turn, raises the possibility that the responses to words in the comparison of the grammatical and ungrammatical −ellipsis condition, i.e., *daughter* versus *Dana's*, might have been different because one might encompass wrap-up effects.

Since it was not possible to make the standard comparison between grammatical and ungrammatical responses, our results allow us to conclude that the anterior negativity was diminished in the ungrammatical +ellipsis condition relative to its −ellipsis counterpart, but do not allow us to determine whether our manipulation eliminated the early response to the violation, or merely attenuated the response. Thus, we can conclude that the early response to the detection of the violation was modulated by our manipulation of context, but we cannot firmly conclude that the violation is simply not detected in the early time interval in the +ellipsis condition. Also, results from the off-line completion study suggested that overt novel nouns were predicted on a significant proportion of +ellipsis trials, and this may also have led to a merely attenuated early negativity. Furthermore, our conclusions about when a violation was diagnosed are always limited by the fact that EEG responses merely provide an upper bound on when a given cognitive process must have begun, and do not necessarily indicate the precise moment at which the underlying process occurred.

In previous studies of category violations the ELAN response has typically been followed by the late posterior component known as the P600. This is unsurprising, since the P600 has been elicited by a very wide range of syntactic and morphological anomalies. In the current study, the presence of a P600 effect was not confirmed, due to the absence of a grammatical–ungrammatical comparison. In addition, comparison of the two ungrammatical conditions showed no differences in the time interval associated with the P600. This suggests either that neither condition showed a P600, or that both conditions elicited an equivalent P600 effect. In light of the fact that participants showed 95.4% accuracy in detecting the category violations and that syntactic violations consistently elicit a P600 response in other studies, including previous studies that have observed an ELAN response (e.g., Neville et al., 1991), the most likely interpretation is that both ungrammatical conditions elicited a highly similar P600 response.

Another point of comparison between the current findings and previous studies of category violations involves the latency of the anterior negativity. We observed a difference between the two ungrammatical conditions in the 200–400 ms interval, and the difference had an onset at around 200 ms. This latency is later than some reports

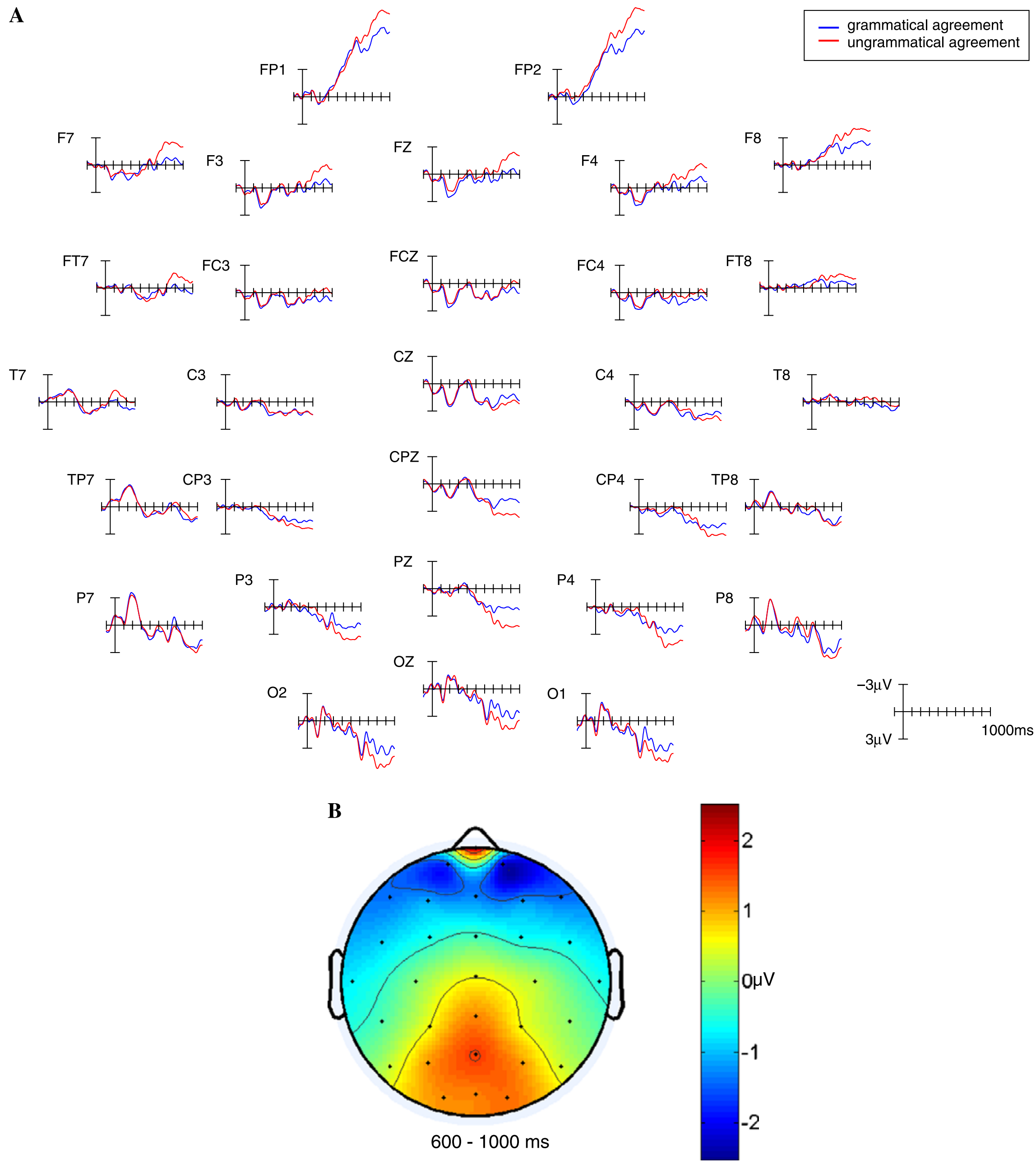

Fig. 3. Grand average responses in the grammatical (blue) and ungrammatical (red) agreement conditions, average reference, showing (A) all electrodes and (B) a topographic plot of the difference in average potential from 600 to 1000 ms latency. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

of the ELAN, which show onsets in the 100–150 ms range (Friederici et al., 1993; Hahne & Friederici, 1999; Neville et al., 1991), but is consistent with the latencies observed across a broader range of studies of category violations, which include onset latencies of up to 350 ms (Friederici et al., 1996; Hagoort et al., 2003). It is possible that this latency variation may reflect two qualitatively different phases in sentence processing, the first of which reflects word category identification and phrase structure building, and the second of which reflects the integration of semantic and morphosyntactic information (Friederici, 1995, 2002). Alternatively, the latency variation may simply reflect differences in the salience and position of the morphological cues to the violation (Hagoort et al., 2003). The negativity that we observed in the ellipsis comparison began at a latency of around 200 ms and peaked around 300 ms. This slight delay relative to other reports of early negativities may cast doubt on the notion that this response is the same as the 'traditional' ELAN response, as does the finding of a small but significant positivity in the right posterior region at the same latency, which is not part of the typical ELAN profile. As a consequence, our conclusions about the relationship between our results and other reports of early anterior negativities must remain tentative at present. Nevertheless, what is important for our hypothesis is that the ellipsis manipulation resulted in different electrophysiological responses to the same violation, showing that the same local category violation is processed differently as a function of the global syntactic and semantic context.

In light of the questions about the meaning of latency variation of anterior negativities, we included in our study a pair of conditions that manipulated subject–verb agreement, in addition to our category violation manipulation. These conditions were included in order to allow comparison of responses to morphosyntactic violations with responses to category violations. The agreement violation elicited a P600 response, but no anterior negativity. This contrasts with some studies that have reported that agreement violations elicit both a LAN and a P600 response (Coulson et al., 1998; Hagoort & Brown, 2000), but is consistent with other studies that have observed only a P600 in response to verb agreement or tense violations (Gunter & Friederici, 1999; Hagoort et al., 1993; Osterhout & Nicol, 1999). Thus, our results indicate that category violations and agreement violations elicit clearly different response components, but do not allow us to directly evaluate the suggestion that different types of violations elicit qualitatively different anterior negativities with different latencies.

In summary, the important findings of Friederici et al. on the early negativity elicited by syntactic category violations are consistent with the hypothesis that all syntactic category violations should elicit the same ELAN response. Our results show that a more detailed account is needed, since there exist syntactic contexts in which the same illicit sequence does not elicit the same ELAN response.

Notwithstanding the caveats raised here about the relation between our findings and previous demonstrations of the ELAN response, there are at least two alternative accounts of early anterior negativities that are consistent with current and previous findings. Both accounts rely on the assumption, motivated here, that the ELAN is specifically associated with violations that contradict a strong local prediction for an upcoming syntactic category. On one account, the ELAN could be understood as a kind of 'mismatch' response, elicited when the incoming word category mismatches with a predicted word category. It is computationally less demanding to check whether an incoming word matches the predicted word category than to determine whether there is any possible way to incorporate the incoming word into the existing parse tree. In this approach, the early latency of the ELAN reflects the fact that it occurs in situations where the task of grammatical analysis is essentially reduced to the task of grammatical category identification. However, on this account we would also expect ELAN responses to be elicited by fully grammatical sequences in which the incoming word does not match the predicted head, for example, in phrases with pre-nominal modifiers like *Max's clever proof*. Such cases clearly do not elicit the same conscious surprise as the category violations, but they might nevertheless be associated with an ELAN response. However, a recent study by Austin and Phillips (2004) investigated the ERP responses to such situations, comparing responses to pre-nominal adverbs such as *really* in situations where they conflict with a prediction for a noun following a possessor, as in (7a) to situations where there is no corresponding prediction (7b). No ELAN response was found in the comparison of these two conditions, suggesting that the response is specifically associated with syntactically impossible sequences.

(7) (a) The boy embraced Anne's *really* nervous cousin.
(b) The boy embraced Anne *really* nervously.

An alternative possibility is that the ELAN response is associated with cases in which ungrammaticality can be detected quickly. In other words, the increase in negativity is not associated with a certain *type* of violation, but is simply limited by whether the ungrammaticality can be detected by the time that the component occurs. Applied to our results, this account predicts that the ellipsis context makes it more difficult to diagnose ungrammaticality, since it broadens the space of alternatives that must be evaluated in order to conclude that the incoming word is incompatible with the existing structure. In the standard context that elicits a category violation, i.e., *Max's of...* the possessor indicates that the next word must be either the head of the NP or a pre-nominal phrase, such as an adjective or adverb. Therefore, when the parser looks for an attachment site for the word *of*, it need only consider the current 'workspace', consisting of the predicted noun position and potential positions immediately to its left, in order to determine that the sentence is ungrammatical. On the other hand, in the +ellipsis context, the possessor may be understood to be followed by a phonetically null noun, allowing the parser to close off the NP, with the consequence that the effective workspace for the attachment of the word *of* becomes the entire sentence structure. The parser cannot diagnose ungrammaticality until it has searched the entire right edge of the sentence structure in order to determine that there is no appropriate position for *of* to attach. This more open-ended search may take too long to elicit an ELAN response, and hence may attenuate early responses to syntactic violations, as observed in our study.

5. Conclusion

There is long-standing evidence that at least some aspects of syntactic processing in language comprehension are rather fast, occurring within around 300 ms of word presentation (Marslen-Wilson, 1973, 1975). This has been reinforced by findings in the ERP literature of an early left anterior negativity (ELAN) elicited by syntactic category violations (e.g., Friederici et al., 1993; Neville et al., 1991). Although it has long been clear that at least some syntactic analysis is very fast, it is less clear how this speed is achieved. Once time is factored in for basic sensory processing and lexical access, little time is left for syntactic pro-

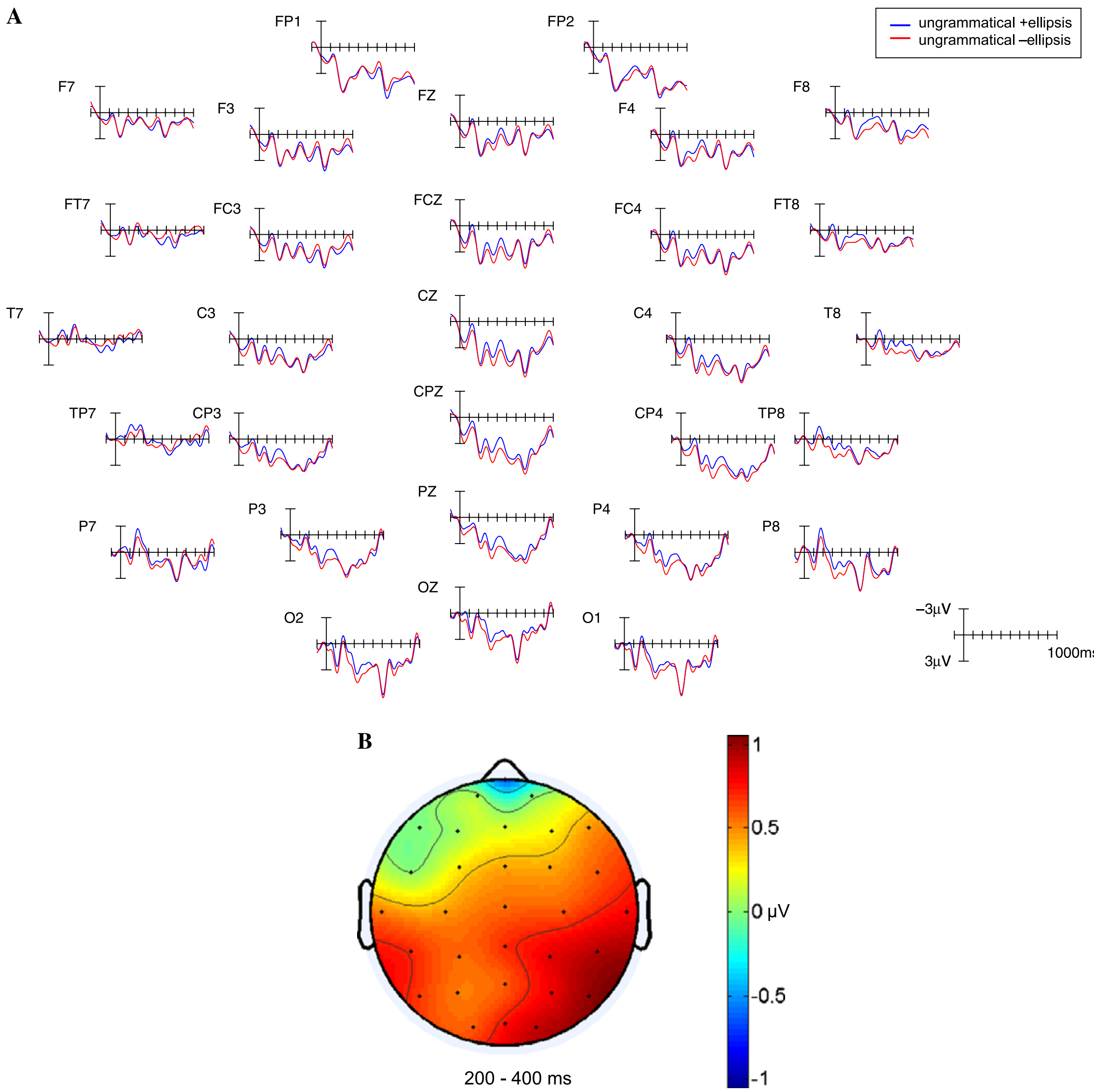

Fig. 4. Grand average responses in the ungrammatical +ellipsis (blue) and ungrammatical −ellipsis (red) conditions, mastoid reference, showing (A) all electrodes and (B) topographic plot of the difference in average potential from 200 to 400 ms latency for the two ungrammatical conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

cessing itself. Focusing on early ERP responses to syntactic violations, this study presented evidence on the role of predictive mechanisms in explaining rapid syntactic processing. Syntactic category predictions can narrow the syntactic 'workspace' and make the task of syntactic analysis more constrained, and hence faster. This account was motivated by the demonstration that an identical ungrammatical word sequence yielded differences in the early negativity, as a function of a contextual manipulation that varied the availability of ellipsis in the comprehension of a critical noun phrase. In situations where the contextual manipulation made the task of detecting a syntactic violation a more open-ended problem, there was a reduction in the early ERP response to the violation. This account should be compatible with any parsing model that both allows for predictive structure building and incorporates an explicit account of how violations are diagnosed, and thus it is largely orthogonal to recent debates about the 'modularity' of information flow in parsing and the role of probabilistic information in parsing. Although various questions remain about the details of the latency and scalp distribution of the early ERP response to syntactic anomalies, this study represents a contribution to the project of mapping the fine-grained timing information provided by ERPs onto detailed models of syntactic analysis.

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Appendix A

Fig. 4 shows grand average ERPs in the two ungrammatical category violation conditions, based upon a linked mastoid reference, together with a topographic plot showing the mean voltage differences between the two conditions at 200–400 ms after presentation of the critical word *of*.

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