

## Are the anterior negativities to grammatical violations indexing working memory?

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### Abstract

Anterior negativities obtained when a grammatical rule is violated may reflect highly automatic first-pass parsing processes, the detection of a morphosyntactic mismatch, and/or the inability to assign the incoming word to the current phrase structure. However, for some theorists these negativities rather reflect some aspect of working memory processes. Event-related brain potentials (ERPs) obtained for word category and morphosyntactic violations were directly compared with effects obtained when working memory is particularly demanded (embedding subject- or object-relative clauses), yielding a significant dissociation in terms of topography. Even though, the anterior negativities for grammatical violations vanished when relative clauses were embedded, suggesting that the processes reflected by anterior negativities related to grammatical violations and those related to working memory manipulations, even if different, are placing demands on a common pool of limited resources.

**Descriptors:** Syntax, Working memory, LAN, P600

Among the most relevant and, at the same time, controversial components of the event-related brain potentials (ERPs) related to language processing are the anterior negativities accompanying grammatical violations. An important number of studies have reported negativities between 150 and 600 ms after stimulus onset with an anterior scalp distribution, left lateralised in most of the cases (e.g., Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). These negativities have been typically called the left anterior negativity and the early left anterior negativity, depending on their onset or peak latencies.

Word category violations, which disrupt the building of the phrase structure, are the anomalies most frequently associated with early left anterior negativity (Ainsworth-Darnell, Shulman, & Boland, 1998; Friederici, Hahne, & Mecklinger, 1996; Gunter, Friederici, & Hahne, 1999; Hahne & Friederici, 1999; Neville et al., 1991), whereas anterior negativities usually appearing later have been shown to be evoked by other grammatical anomalies, including (typically) morphosyntactic violations such as number agreement, gender agreement, and verb inflection violations

(Gross, Say, Kleingers, Clahsen, & Münte, 1998; Gunter, Friederici, & Schriefers, 2000; Hahne & Jescheniak, 2001; Penke et al., 1997; Vos, Gunter, Kolk, & Mulder, 2001). Extensive revisions on anterior negativities and the grammatical violations eliciting them can be seen in Vos et al. (2001) or in Hinojosa, Martín-Loeches, Muñoz, Casado, and Rubia (2003).

It is true, nonetheless, that all of these types of violations have also failed to elicit anterior negativities in several studies (Gunter & Friederici, 1999; Hagoort & Brown, 2000; Osterhout, McKinnon, Bersick, & Corey, 1996; Rodríguez-Fornells, Clahsen, Lleó, Zaake, & Münte, 2001). Indeed, some authors (e.g., Vos et al., 2001) claim that because the anterior negativities are small, they may be prone to statistical power problems. Furthermore, neither the anterior distribution nor the left lateralization of these negativities are consistent findings (e.g., Coulson, King, & Kutas, 1998; Gunter & Friederici, 1999; Hagoort, Wassenaar, & Brown, 2003; Münte & Heinze, 1994).

The functional significance of these anterior negativities has generated an intense debate. A widely accepted view suggests that these negativities reflect highly automatic first-pass parsing processes, the detection of a morphosyntactic mismatch, and/or the inability to assign the incoming word to the current phrase structure (Friederici, 1995; Hagoort, 2003; Hahne & Friederici, 1999). For a group of authors, however, anterior negativities related to grammatical violations would be reflecting some aspect of working memory operations, namely, working memory load (Kluender & Kutas, 1993a, 1993b). In support of this view, anterior negativities have been reported in grammatically well-formed sentences in which a larger demand of working memory

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resources is supposed to occur (King & Kutas, 1995; Kluender & Kutas, 1993a; Weckerly & Kutas, 1999). Additional support for the idea that anterior negativities may be reflecting working memory operations comes from the findings that the amplitude of a left anterior negativity to morphosyntactic violations was affected by the working memory span of the subjects classified according to the Reading Span Test (Daneman & Carpenter, 1980) as much as by the presence of a concurrent working memory load task (e.g., Vos et al., 2001).

Several authors (e.g., Friederici, 2002) have in fact proposed the existence of two types of anterior negativities: One would be reflecting purely syntactic operations (such as identification of word category or morphosyntactic information) and would be more conspicuous in its time course, whereas the other would relate to syntax working memory operations (such as maintaining active a given syntactic structure) and would be of a longer duration. Friederici (2002) has also proposed that whereas syntax working memory involves the superior–anterior portion of left BA 44, syntactic processing would be related to the inferior portion of left BA 44. Although the duration criterion seems not unambiguously applicable, because some of the cited studies relating anterior negativities to working memory did find conspicuous effects, and long duration negativities associated to grammatical violations are certainly not rare (e.g., Hahne & Friederici, 2002; Van den Brink & Hagoort, 2004), the proposed existence of two type of anterior negativities appears plausible. However, and strikingly, a direct comparison between the negativities obtained to syntax violations and those obtained when working memory is taxed has not been explicitly investigated to date. It is the aim of the present study to fill this gap. Still, it is necessary to directly compare electrophysiological responses caused by purely working memory manipulations with those caused by grammatical manipulations. Even if the former affects the latter, this would only mean that they are not independent, but not that they are the same phenomenon.

In the present study we undertake to directly compare ERP responses obtained for violations of grammaticality with those obtained when working memory is particularly taxed. Regarding the former, we will use two of the most extensively used, that is, morphosyntactic violations consisting in subject–verb agreement violations, and syntactic violations consisting of word category violations (namely, a noun appears where a verb is expected). It is not clear from the literature that the negativities obtained to both types of grammatical violations reflect the same processes. In this regard, some authors (e.g., Friederici, 2002) strongly claim that word category identification precedes morphosyntactic processing, whereas other authors (e.g., Hagoort, 2003) propose that latency differences (and, then, the distinction between an early left anterior negativity and a left anterior negativity) are, in fact, an artifactual product of the moment at which the violation appears within a word. On the other hand, the existence of between-studies discrepancies relative to the concrete distribution or lateralization of the anterior negativities due to violations of grammaticality has been mentioned. These discrepancies might in fact be a consequence of the use of different types of violations between studies. In this regard, it is certainly difficult to find studies in which both syntactic and morphosyntactic violations are investigated simultaneously (what is more, within the same experiment).

On the other hand, there are several situations in sentence processing where working memory would be particularly taxed, at least according to several models of sentence processing

(Chomsky & Miller, 1963; for concise and recent reviews, see Hsiao & Gibson, 2003; Traxler, Morris, & Seely, 2002). One is the distance between related elements (such as subject and verb) within a sentence. Distance would tap working memory, as an element must be kept active in working memory until it is connected to the one to which it is related, the storage of incomplete head dependencies in phrase structure involving greater storage costs (Gibson, 1998; Wanner & Maratsos, 1978). Distance between elements (specifically, between subject and verb) will be manipulated here by using simple, short sentences in which the verb immediately follows the subject, as in (1), below, and longer sentences in which a relative clause is placed between the subject and the verb, as in (2) and (3), below. When using relative clauses embedded between the subject and the verb of a sentence, there is also a possibility to additionally increase working memory demands, at least according to several grammatical theories. We refer to using object-relative clauses as compared to subject-relatives. In the latter, the subject of the relative clause is the same as that of the main sentence, as in (2), whereas a different element acts as subject of the relative clause in the former, as in (3). It has been widely demonstrated that object-relative sentences are more difficult to process than subject-relatives, and this difference in difficulty has been specifically attributed to working memory limitations by several authors (Gibson, 1998; Gordon, Hendrick, & Johnson, 2001; Wanner & Maratsos, 1978). In the present experiment, we include sentences with both subject-relative and object-relative clauses:

1. The reporter admitted the error.
2. The reporter [that attacked the senator] admitted the error.
3. The reporter [that the senator attacked] admitted the error.

Within sentences containing relative clauses of either type, however, there are certain specific points at which working memory would be taxed to a higher extent than others and, then, where ERP effects related to working memory load should be looked at with more caution. One of these points would be, obviously, the relative clause region. Particularly, the word “*that*” in (2) and (3), instantiating the onset of a relative clause (and, then, that the head noun phrase is still unintegrated), would yield ERP effects presumably related to working memory demands when compared to the verb of short sentences in which no relative clause has been embedded (and, then, where the head dependency has been completed; Gibson, 1998). A similar situation would come from the comparison between the word *the* within the relative clause in (3) and the verb of the relative clause in (2), *attacked*. In object-relatives, as in (3), the word *the* within the relative clause would mark the presence of an additional head dependency, contrasting with the situation in subject-relatives (Gibson, 1998). Several studies using behavioral measures, such as error rates (King & Just, 1991; Wanner & Maratsos, 1978), reaction times (King & Just, 1991), or eye movements (Traxler et al., 2002), support the greater difficulty of these points, although limitations in working memory resources are assumed to be the causal factor by some but not all models. Indeed, several ERP studies have examined the relative clause region when investigating working memory (e.g., Fiebach, Schleewsky, & Friederici, 2002; King & Kutas, 1995; Kluender & Kutas, 1993a; Vos et al., 2001).<sup>1</sup>

<sup>1</sup>It should be noted that by performing these comparisons, differences due merely to other variables such as word class (i.e., open- vs. closed-class), not directly related with the variables of interest (working mem-

Another point at which working memory could be taxed to a higher extent in sentences containing relative clauses is at the main verb of the sentence. Indeed, several behavioral studies have shown that this point may convey the highest degree of difficulty within a sentence containing a relative clause and where the greatest behavioral differences between object-relative and subject-relative sentences can be found, which has been interpreted within the frame of working memory limitations (Ford, 1983; King & Just, 1991). Indeed, in several studies, ERP responses presumably related to working memory were measured both in the relative clause region and in the main verb of the sentence (King & Kutas, 1995; Müller, King, & Kutas, 1997; Weckerly & Kutas, 1999). Accordingly, in the present study, anterior negativities presumably related to working memory load will be measured, on the one hand, within the relative clause region and, on the other hand, at the main verb. It is in the latter position where we will have the two grammatical violations that should also induce frontal negativities.

## Methods

### Participants

Thirty-two native-Spanish subjects (25 women, mean age 21.9 years, range 18–38) participated in the experiment. All of the participants were right-handed, with average handedness scores of +76, ranging from +50 to +100, according to the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision and had no history of reading difficulties or neurological or psychiatric disorders.

### Materials

There was a pool of critical items consisting of a set of 180 Spanish transitive sentences. One-third of these sentences had a simple syntactical structure (short sentences), whereas the remaining 120 sentences had a relative clause always center embedded between the subject and the predicate of the main clause. Two types of relative clauses were included: Half (60) included subject-relative clauses, whereas the other half included object-relative clauses. Furthermore, next to the correct version of each group of sentences (short, subject-relative, and object-relative), two ungrammatical versions were created. One contained a word category violation, that is, the verb of the main clause was replaced by a noun. Specifically, this noun had to be semantically related to the verb used in the correct version, and this was actually made by nominalizing that verb. Nouns that could be interpreted as the past participle of the verb or as an adjective were explicitly excluded. In three different samples of participants, other than the experimental one, we measured the degree of expectancy to which a verb was indeed expected in the corresponding position in short ( $n = 17$ ), subject-relative ( $n = 15$ ), and object-relative ( $n = 15$ ) sentences by presenting the part of the sentence immediately preceding the verb and letting the participants complete the sentences freely. Eighty-two percent, 77%, and 78% of participants' responses, respectively, were verbs, and none of the responses was a noun or a noun phrase.<sup>2</sup> The other incorrect version contained a morphosyntactic violation, con-

or), could also be obtained in the ERP. Accordingly, the results concerning these comparisons should be viewed with some caution. Nevertheless, in the present study these comparisons did not display the ERP effects expected for an open- versus closed-class comparison (see Brown, Hagoort, & ter Keurs, 1999).

sisting of a fault in the verb inflection (first person singular past tense instead of the corresponding third person singular past tense), that is, a subject–verb disagreement. Verbs in the experimental materials were always conjugated in past tense. All short sentences contained five words, whereas all sentences with a relative clause contained nine words (each relative clause contained always four words). The word lengths varied between two and four syllables.

Examples of each type of sentence and a version of the violations are given below. Note that the examples of the sentences containing relative clauses do not include violations, since they were the same as in the short sentences.

#### a. Short sentence:

- Correct: El compositor *editó* [V, Sing., 3rd person] la ópera. (The composer *edited* [V, Sing., 3rd person] the opera.)
- Category violation: \*El compositor *edición* [Noun] la ópera. \*(The composer *edition* [Noun] the opera.)
- Morphosyntactic violation: \*El compositor *edité* [V, Sing., 1st person] la ópera. \*(The composer *edited* [V, Sing., 1st person] the opera.)

#### b. Sentence with a center-embedded subject-relative clause:

- Correct: El compositor [que odió al cantante] *editó* la ópera. (The composer [that hated the singer] *edited* the opera.)

#### c. Sentence with a center-embedded object-relative clause:

- Correct: El compositor [que el cantante odió] *editó* la ópera. (The composer [that the singer hated] *edited* the opera.)

We also included 120 fillers that were of syntactic structures other than those in the experimental sentences. One-third of them were ungrammatical, so that considering the number of ungrammatical sentences in the experimental materials viewed by each subject (see below) half of the sentences in a whole experimental session were grammatical and half ungrammatical. Ungrammaticality in filler sentences included both word category and morphosyntactic violations equally, but of different types than those used in the experimental materials (e.g., a determinant-noun number disagreement, a verb appears in the position of a noun, etc.). All sentences were presented word-by-word in the center of a computer screen, with 300 ms duration per word and with a 500-ms SOA, allowing 1500 ms between the end of the last word in a sentence and the appearance of the first word in the next sentence. Each sentence was presented in the same form: The first word began with a capital letter and the last word was presented together with a period at the end. All stimuli were matched in visual aspects. They were presented white-on-black on a computer monitor and controlled by SuperLab Software. Participants' eyes were 65 cm from the monitor. At that distance, all stimuli were between 0.7° and 1.3° high and between 1.1° and 6° wide.

<sup>2</sup>A reviewer pointed out the possibility that this is not a word category violation in a strict sense, as a noun phrase–noun phrase order is allowed for some types of sentences in Spanish. However, none of our sentences were of these types. Moreover, even in those cases in which a noun phrase can follow a noun phrase in Spanish, the second noun must be preceded by a determinant or be a noun with an adjectival functioning. The nouns eliciting the violation in our materials were never preceded by a determinant nor could they be interpreted as adjectives.

### Procedure

Each experimental session lasted for about half an hour. Participants were told that they would be presented with a series of sentences and had to perform a grammaticality judgment about the correctness of every sentence. They were instructed to press one of two buttons when the sentence was correct and the other button when the sentence was incorrect. Participants were told to give their response just after the end of the sentence.

For each participant, sentences were extracted from the pool of 180 sentences and their corresponding ungrammatical versions, and they were arranged in three blocks. Each block contained 60 short sentences, 60 sentences with a subject-relative clause, and 60 sentences with an object-relative clause embedded. Within each type of sentence, 20 were correct, 20 contained a category violation, and 20 a morphosyntactic violation. No sentence, either in the short, subject-relative, or object-relative version, as much as in the grammatical or ungrammatical versions, was repeated within an experimental session. The same 120 fillers were always presented to all the participants. All sentences were presented in a randomized order. The session started with a short practice block. This block did not include any of the experimental sentences.

### Electrophysiological Recordings

The electroencephalogram (EEG) was recorded by means of tin electrodes embedded in an electrode cap (ElectroCap International). Scalp locations were: Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FCz, FC4, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, PO7, PO8, O1, and O2, plus a left mastoid (M1) electrode. All the electrodes were originally referenced to the right mastoid (M2). These labels correspond to the revised version of the 10/20 International System (American Electroencephalographic Society, 1991). Bipolar horizontal and vertical electrooculograms (EOG) were recorded for artifact rejection purposes. Electrode impedances were kept under 3 k $\Omega$ . The signals were recorded continuously with a bandpass from 0.01 to 40 Hz and a sampling rate of 250 Hz.

### Data Analysis

First, to analyze anterior negativities within the relative clause region, multiword ERPs were performed starting at the onset of the first word in the sentence. Two types of epoch length were used for these multiword ERPs. In one type, performed for both the short and the relative clause sentences, the epoch lasted 3000 ms (covering 1000 ms after the onset of the last word in the short sentences). Only for the sentences containing relative clauses were additional epochs lasting 4500 ms performed (covering 500 ms after the onset of the last word in these sentences). In all these multiword epochs, the period covering from the onset of the first noun in the sentence to the onset of the subsequent word was used as the 500-ms "prestimulus" baseline. Subsequently, to analyze anterior negativities within the main verb region, average ERPs from 200 to 1500 ms after the presentation of that word were computed for each experimental sentence and aligned to a -200 ms prestimulus baseline.

Those epochs that exceeded  $\pm 160 \mu\text{V}$  in the multiword ERP and  $\pm 65 \mu\text{V}$  in single-word (main verb) ERP were eliminated. Off-line ocular correction was made using the method described by Gratton, Coles, and Donchin (1983). For the entire sample of electrodes, originally M2-referenced data were re-referenced off-line using the average of the mastoids (M1 and M2) as the new reference.

Overall repeated-measures analyses of variance (ANOVAs) were first performed with the purpose of comparing amplitudes between the ERP patterns elicited by the main factors. Amplitude was measured as the mean amplitude within a particular time interval. To decrease the number of comparisons performed in the ANOVAs, the original 29 scalp locations were reduced to 18 regions of interest (ROIs): FP (the mean of Fp1 and Fp2), F7, F8, FC1 (F3 and FC3), FCc (Fz and FCz), FCr (F4 and FC4), T7, C3, Cz, C4, T8, TP1 (TP3 and P7), CP1 (CP3 and P3), CPc (CPz and Pz), CPr (CP4 and P4), TP8 (TP8 and P8), PO1 (PO7 and O1), and PO8 (PO8 and O2). As can be appreciated, to construct these ROIs some electrodes were pooled whereas others entered the ROI factor as single electrodes.

The factors included in the ANOVAs depended on the region of analysis. For the relative clause region, the factors were Type of Sentence and ROI (eighteen levels). The type of sentence factor included three levels (short, subject-relative, and object-relative) when the analyses pertained to the activity immediately following the onset of the third word in the sentence (*that* in the relative clauses, the main verb in the short sentences), and two levels (subject-relative, object-relative) for the activity after the onset of the fourth word (the relative clause's verb in subject-relatives, the determinant in object-relatives). On the basis of a visual inspection, the following time windows were chosen for the statistical analyses of the mean amplitude: 200–400 ms and 400–600 ms after the onset of the third word in the sentence, and 150–350 ms and 350–550 ms after the onset of the fourth word. For the main verb region, the factors included in the ANOVAs were Type of Sentence (three levels: short, subject-relative, and object-relative), Grammaticality (three levels: correct, morphosyntactic violation, and word category violation), and ROI. Again, on the basis of a visual inspection, the time windows for the statistical analyses were 150–350 ms, 350–550 ms (left anterior negativity effects to grammatical violations), 550–700 ms, 700–900 ms (P600 effects), and 900–1300 ms. The Greenhouse–Geisser correction was always applied. Further, we performed planned second-order post hoc ANOVAs where overall ANOVAs and a visual inspection of the data indicated that this was pertinent.

Profile analyses (McCarthy & Wood, 1985) were performed to assess differences in scalp topographies independent of overall ERP amplitude (Rugg & Coles, 1995). To appropriately perform these analyses, the total set of 29 electrodes was used instead of the ROIs, so that subtle differences in topography that could be eliminated by the ROI procedure were included in the analyses.

## Results

### Performance Data

The percentage of both correct grammatical and ungrammatical judgments was measured. On average, subjects judged correctly 93.2% of the grammatical sentences and 97.3% of the ungrammatical sentences. In detail, grammaticality judgments in short sentences were 98.1%, 97.9%, and 95.4% for the correct sentences, those including a morphosyntactic violation, and for those including a word category violation, respectively. With respect to sentences with a subject-relative clause, grammaticality judgments were, respectively, 95.1%, 98.4%, and 96.5%. Finally, for sentences with an object-relative clause, the results were, respectively, 86.4%, 99.5%, and 96.4%. An ANOVA revealed significant effects of type of sentence,  $F(2,62) = 5.83$ ,  $p < .012$ ,  $\epsilon = .700$ , grammaticality,  $F(2,62) = 10.59$ ,  $p < .0001$ ,  $\epsilon = .801$ ,

and a Type of Sentence  $\times$  Grammaticality interaction,  $F(4,124) = 12.14$ ,  $p < .0001$ ,  $\epsilon = .386$ . As can be seen, the worst results were for correct sentences with an object-relative clause.

Reaction times (RTs) were computed for correct materials as a function of the type of sentence: short, with object-relative clause, and with subject-relative clause. They were 683 ms, 792 ms, and 618 ms, respectively. An ANOVA indicated a significant effect of the type of sentence,  $F(2,62) = 3.89$ ,  $p < .05$ ,  $\epsilon = .666$ . This means that it took our subjects about 100 ms more to respond when the sentence included an object-relative clause than to the rest of the materials. Incorrect materials, however, yielded similar reaction times across type of sentence (596 ms, 602 ms, and 590 ms, respectively)  $F(2,62) = 1.19$ ,  $p > .1$ ,  $\epsilon = .500$ .

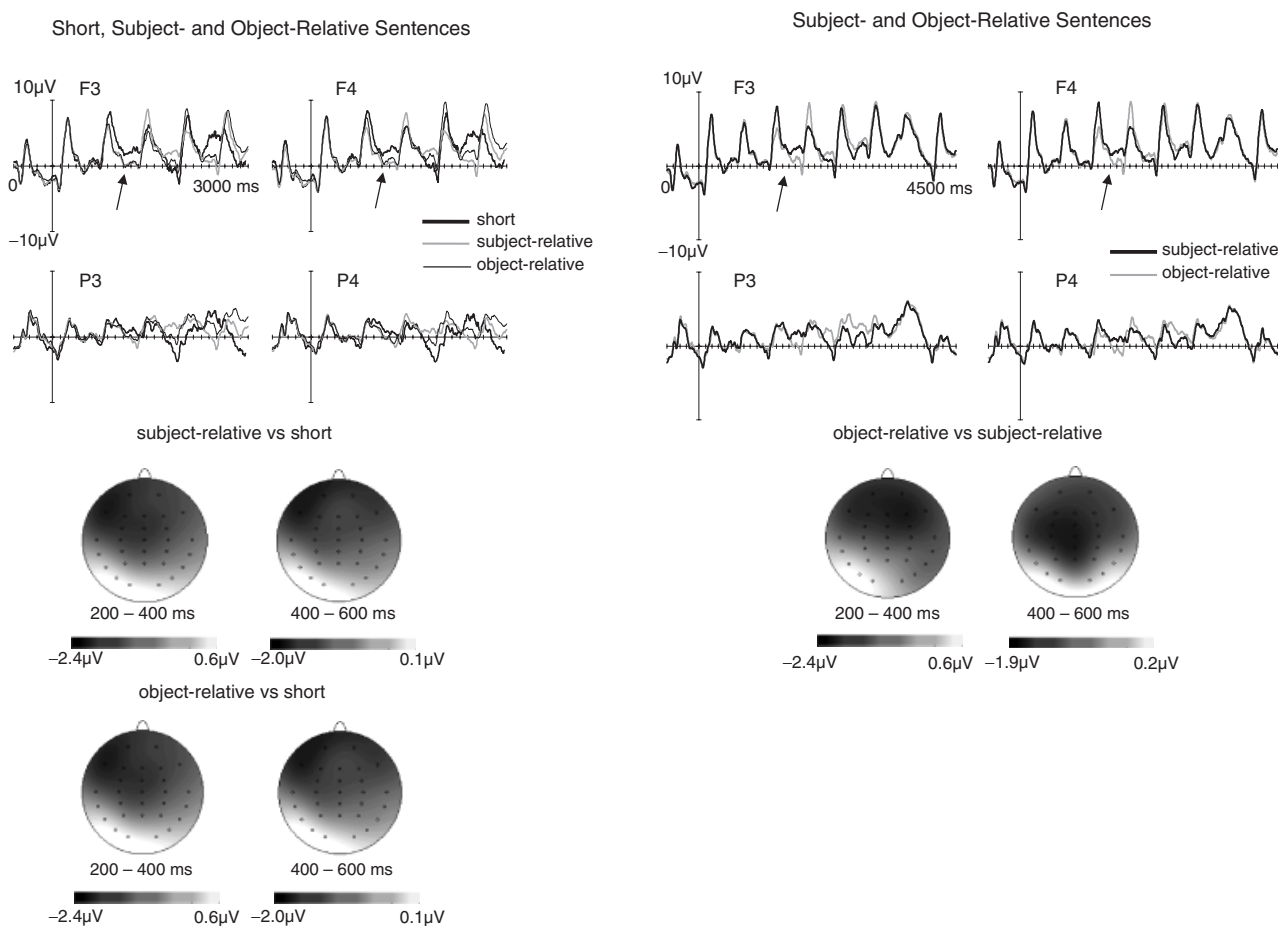
### Event-Related Potentials

#### Relative Clause Region

Comparing “that” in relative clauses with the verb in short sentences (third word in the sentence). Figure 1 (left side) summarizes the main results for this comparison. There, it can be seen

that a negativity develops in both types of relative clauses when compared to short sentences. This negativity started at about 200 ms and resolved at about 600 ms after the onset of the critical word. Its largest values appeared in the first half of this period and presented a wide frontal distribution, slightly left lateralized, along the whole time period. Main ANOVA results in the 200–400-ms time window yielded significant effects of a Type of Sentence  $\times$  ROI interaction,  $F(34,1054) = 6.5$ ,  $p < .0001$ ,  $\epsilon = .199$ . In the 400–600-ms time window, significant effects appeared again for an interaction of Type of Sentence  $\times$  ROI,  $F(34,1054) = 2.9$ ,  $p = .013$ ,  $\epsilon = .192$ .

Second-order ANOVAs confirmed that the difference between short and subject-relative sentences at this point was significant, in both the 200–400-ms window (Type of Sentence  $\times$  ROI interaction,  $F[17,527] = 8.1$ ,  $p < .0001$ ,  $\epsilon = .272$ ) and the 400–600-ms window (Type of Sentence  $\times$  ROI interaction,  $F[17,527] = 2.8$ ,  $p = .026$ ,  $\epsilon = .230$ ). Similarly, there was a significant difference between short and object-relative sentences at this point in both the 200–400-ms window (Type of Sentence  $\times$



**Figure 1.** Grand average multiword ERP ( $n = 32$ ) time locked to the onset of the first noun in the sentence (500 ms from sentence’s onset). Left: Differences between sentences containing a relative clause and short sentences started after the appearance of the third word in the sentence and mainly consisted of a frontal negativity for the former. The timings indicated below the maps correspond to the milliseconds after the onset of the third word of the sentence (1000 ms from sentence’s onset). Right: Differences between object-relative and subject-relative sentences started after the appearance of the fourth word in the sentence, and mainly consisted of a frontal negativity for the former. The timings indicated below the maps correspond to the milliseconds after the onset of the fourth word of the sentence (1500 ms from sentence’s onset). For this and subsequent figures, the maps are computed from the mean amplitude in the corresponding time windows used for statistical analyses, and are interpolated with spherical splines, using the algorithm described in Perrin, Bertrand, and Echallier (1989). Also for this and subsequent figures, only a selection of electrodes is displayed and individual scales based on the particular maximum and minimum values are used in the maps.

ROI interaction,  $F[17,527] = 7.4$ ,  $p < .0001$ ,  $\epsilon = .223$ ) and the 400–600-ms window (Type of Sentence  $\times$  ROI interaction,  $F[17,527] = 3.4$ ,  $p = .013$ ,  $\epsilon = .215$ ). As expected, the comparison between subject-relative and object-relative sentences did not yield any significant result. Profile analyses yielded no significant result when comparing the frontal negativity both between types of sentences and between time windows,  $F(28,868)$  between 0.3 and 1.1,  $p$  always  $> .1$ ,  $\epsilon$  between .112 and .136.

*Comparing “the” in object-relative clauses with the verb in subject-relative clauses (fourth word in the sentence).* Figure 1 (right side) summarizes the main results for this comparison. A negativity develops in object-relative sentences when they are compared to subject-relative sentences. This negativity started at about 150 ms and resolved at about 600 ms after the onset of the critical word. Again, the largest values for this negativity appeared in the first half of this period and also presented a wide frontal distribution, now rather bilateral, along the whole time period, although in the 350–550-ms window it displayed a trend to be more centrally distributed. Thereafter, a positive response appears in the object-relative sentences, replicating previous findings (King & Kutas, 1995), but this effect will not be analyzed as this is out of the scope of the present study. Main ANOVA results in the 150–350-ms time window yielded significant effects of a Type of Sentence  $\times$  ROI interaction,  $F(17,527) = 21.5$ ,  $p < .0001$ ,  $\epsilon = .214$ . In the 350–550-ms time window significant effects appeared again for a Type of Sentence  $\times$  ROI interaction,  $F(17,527) = 7.5$ ,  $p < .0001$ ,  $\epsilon = .205$ . Profile analyses yielded no significant result when comparing this negativity between time windows,  $F(28,868) = 1.4$ ,  $p > .1$ ,  $\epsilon = .176$ .

#### Main Verb Region

*Morphosyntactic and word category violations in short sentences.* In Figure 2 (left) it can be seen that both types of violations elicited anterior negativities peaking at about 450 ms, as much as a clear P600 peaking at about 800 ms. This was first supported by an overall effect of the grammaticality factor in the main ANOVA (see Table 1) throughout all the measured time windows, which is probably due to the fact that, although main effects of grammaticality collapse around the 350–550-ms and 700–900-ms time periods, at least part of these effects appear also to extend before and after the limits of these windows. When second-order ANOVAs were performed in the 350–550-ms window, these demonstrated that anterior negativities due to morphosyntactic violations were marginally significant (pairwise ANOVA comparing correct and morphosyntactic violation in short sentences with ROI as a second factor yielded a trend for a Grammaticality  $\times$  ROI interaction effect,  $F[17,527] = 2.4$ ,  $p = .057$ ,  $\epsilon = .201$ ), with those for word category violations yielding significant results,  $F(17,527) = 2.4$ ,  $p = .049$ ,  $\epsilon = .239$ .

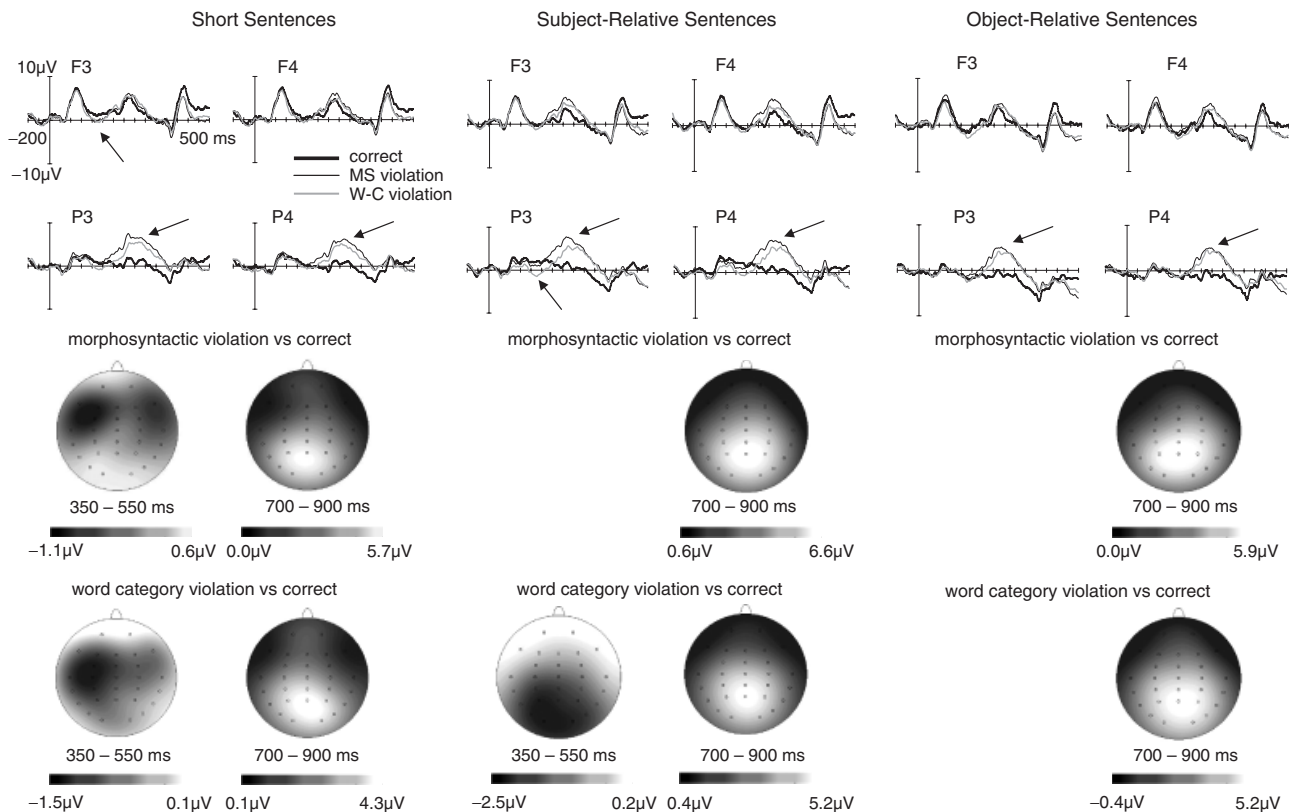
Apparently, the negativities caused by word category violations in short sentences were larger than those caused by the morphosyntactic violations, and their topographies were also nonidentical (see the maps in the left side of Figure 2). This might be supported by a trend for significance in the interaction between grammaticality and ROI,  $F(17,527) = 2.3$ ,  $p = .079$ ,  $\epsilon = .184$ , in a second-order pairwise ANOVA comparing morphosyntactic and word category violations in short sentences. Further, profile analyses comparing both types of violations yielded a trend for significance,  $F(28,868) = 2.1$ ,  $p = .09$ ,  $\epsilon = .115$ ). By looking at the maps in Figure 2 (left) for these anterior negativities, it appears

that whereas word category violations elicited a clearly left anterior negativity, morphosyntactic violations elicited a negativity with some degree of bilaterality, although it is true that left electrodes were clearly more affected. Regarding the P600, it appeared in Figure 2 (left) that the P600 was larger in the morphosyntactic than in the word category violations. Although the main ANOVA in Table 1 yielded no significant or marginal effects in the Type of Sentence  $\times$  Grammaticality interactions in the 700–900-ms window, when we performed a pairwise ANOVA comparing morphosyntactic and word category violations in short sentences in that window a significant interaction between grammaticality and ROI,  $F(17,527) = 2.9$ ,  $p = .035$ ,  $\epsilon = .185$ , was obtained. Their topography (maximum over parietal regions) is, however, highly similar.

*Morphosyntactic and word category violations in long sentences with a subject-relative clause embedded.* In Figure 2 (center) it can be observed that subject–verb distance seems to notably affect the negativities observed for short sentences. Significant interactions between type of sentence, grammaticality, and ROI in the main ANOVA in Table 1 for both the 150–350-ms and the 350–550-ms windows would be on the base of this observation. First, morphosyntactic violations did not yield any noticeable result in the waveforms, supported by an absence of significant results in a second-order pairwise ANOVA comparing correct version and morphosyntactic violation in these sentences in the 350–550-ms window (grammaticality,  $F[1,31] = 0.51$ ,  $p > .1$ ; Grammaticality  $\times$  ROI interaction:  $F[17,527] = 1.77$ ,  $p > .1$ ,  $\epsilon = .153$ ). Second, a word category violation effect was clearly obtained, confirmed by a second-order pairwise ANOVA comparing correct version and word category violation in these sentences in the 350–550-ms window (Grammaticality  $\times$  ROI interaction,  $F[17,527] = 11.03$ ,  $p < .0001$ ,  $\epsilon = .210$ ). The difference between both types of grammatical violations in these sentences is further confirmed when we perform a pairwise ANOVA comparing them in the 350–550-ms window (Grammaticality  $\times$  ROI interaction,  $F[17,527] = 4.96$ ,  $p = .001$ ,  $\epsilon = .230$ ).

However, the negativity caused by word category violation in long sentences with a subject-relative clause embedded does not have a frontal distribution, but rather a very posterior one, as can be seen in the corresponding map within Figure 2 (center). Regarding the P600, it appeared in Figure 2 (center) that the P600 was again larger in the morphosyntactic than in the word category violations. Again, despite an absence of significant or even marginal effects in the Type of Sentence  $\times$  Grammaticality interactions in the 700–900-ms window of main ANOVA in Table 1, a pairwise ANOVA comparing morphosyntactic and word category violations in sentences with subject-relative clauses was performed, yielding a marginally significant grammaticality effect,  $F(1,31) = 3.57$ ,  $p = .068$ , and no effect of a Grammaticality  $\times$  ROI interaction,  $F(17,527) = 2.03$ ,  $p > .1$ ,  $\epsilon = .185$ . Their topography (maximum over parietal regions) is, again, highly similar between them, and it is also the same as when short sentences are considered.

*Morphosyntactic and word category violations in long sentences with an object-relative clause embedded.* Figure 2 (right) shows that distance in the more syntactically complex sentences (by the use of object-relative clauses) is further affecting the negativities observed for short sentences. The already mentioned significant interactions between type of sentence, grammaticality, and ROI in the main ANOVA of Table 1 for both the 150–350-ms and the



**Figure 2.** Grand average ERP time locked to the onset of the main verb's position, displaying the effects of morphosyntactic and word category violations in simple, short sentences (left), long sentences with a subject-relative clause (center), and long sentences with an object-relative clause (right). The maps display the distribution of significant effects. In short sentences both types of violations elicited anterior negativities, mainly left and peaking at about 450 ms, as much as a clear P600 peaking at about 800 ms. In long sentences with a subject-relative clause, only word category violations elicited significant negativities, peaking at about 450 ms, with a posterior distribution. Both types of violations elicited a clear P600 peaking at about 800 ms. In long sentences with an object-relative clause, only word category violations seemed to elicit negativities, peaking at about 450 ms with an anterior left distribution, though statistical analyses did not yield significant results. Both types of violations elicited, again, a clear P600 peaking at about 800 ms.

350–550-ms windows would also be on the base of this observation. As for sentences with subject-relative clauses, morphosyntactic violations in sentences with object-relative clauses did not yield any noticeable result in the waveforms, supported by an absence of significant results in a pairwise ANOVA comparing correct version and morphosyntactic violation in these sentences in the 350–550-ms window (grammaticality,  $F[1,31] = 0.65$ ,  $p > .1$ ; Grammaticality  $\times$  ROI interaction,  $F[17,527] = 0.81$ ,  $p > .1$ ,  $\epsilon = .215$ ).

On the other hand, whereas some degree of word category violation effect was apparently obtained, with a left frontal distribution, a pairwise ANOVA comparing correct version and

word category violation in these sentences in the 350–550-ms window did not yield significant values (grammaticality,  $F[1,31] = 1.81$ ,  $p > .1$ ; Grammaticality  $\times$  ROI interaction,  $F[17,527] = 1.92$ ,  $p > .1$ ,  $\epsilon = .179$ ). Regarding the P600, it appeared in Figure 2 (right) that the P600 was slightly larger in the morphosyntactic than in the word category violations. However, a second-order pairwise ANOVA in the 700–900-ms window comparing morphosyntactic and word category violations in sentences with object-relative clauses yielded no significant effects either of grammaticality,  $F(1,31) = 1.10$ ,  $p > .1$ , or a Grammaticality  $\times$  ROI interaction,  $F(17,527) = 0.69$ ,  $p > .1$ ,  $\epsilon = .187$ . Their topography is, again, highly similar between

**Table 1.** Main ANOVA Results: Main Verb Region

|  | Window (ms)    |                |                |                |                |
|--|----------------|----------------|----------------|----------------|----------------|
|  | 150–350        | 350–550        | 550–700        | 700–900        | 900–1300       |
| Type of sentence, $F(2,62)$ ( $p$ )                            | 12.52 (<.0001) | 23.17 (<.0001) | 18.43 (<.0001) | 10.75 (<.0001) | 25.85 (<.0001) |
| Grammaticality, $F(2,46)$ ( $p$ )                              | 7.46 (.001)    | 7.22 (.002)    | 12.61 (<.0001) | 49.39 (<.0001) | 7.19 (.002)    |
| Type of Sentence $\times$ ROI, $F(34,1054)$ ( $p$ )            | 6.53 (<.0001)  | 7.96 (<.0001)  | 13.21 (<.0001) | 9.97 (<.0001)  | 10.98 (<.0001) |
| Grammaticality $\times$ ROI, $F(34,1054)$ ( $p$ )              | —              | —              | 6.01 (<.0001)  | 25.04 (<.0001) | 17.76 (<.0001) |
| T. Sentence $\times$ Gramm. $\times$ ROI, $F(68,2108)$ ( $p$ ) | 3.36 (.001)    | 4.82 (<.0001)  | —              | —              | —              |

Only significant results, or with a trend for significance, are displayed.

them (maximum over parietal regions), and it is also the same as when either short sentences or sentences with a subject-relative clause are considered.

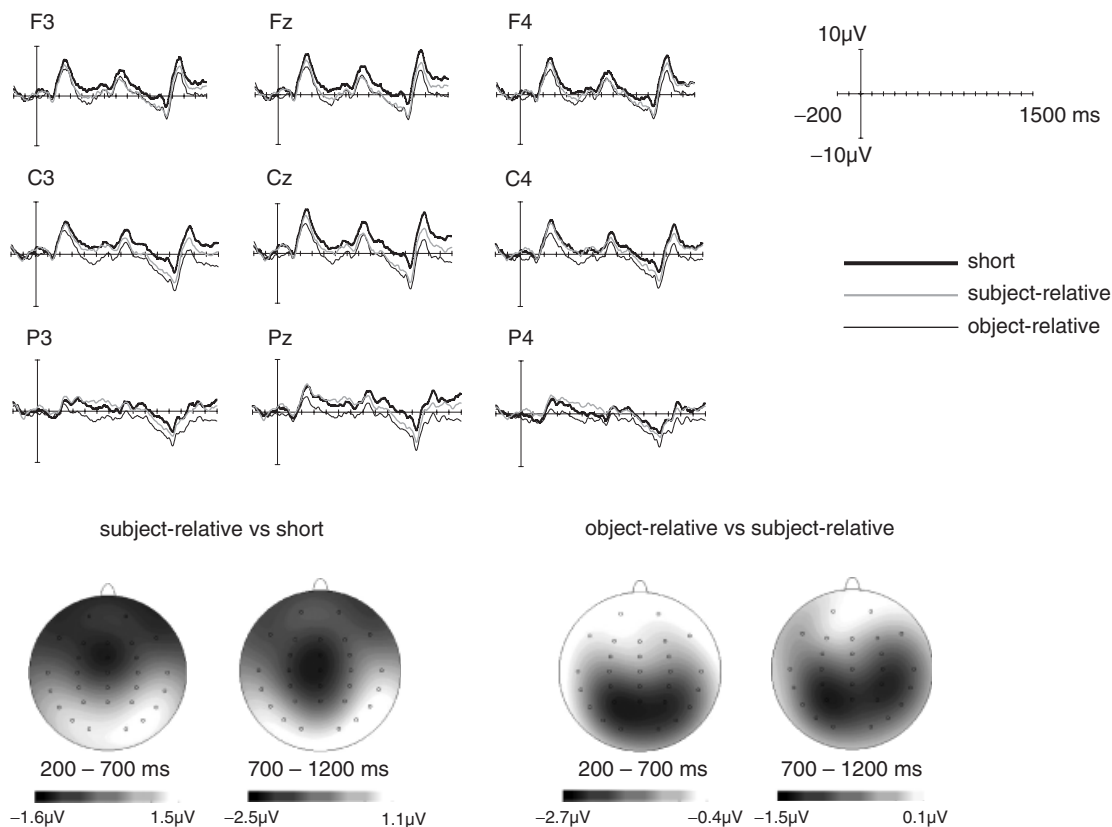
*Effects on main verb of embedding subject- and object-relative clauses in correct sentences.* Figure 3 shows that when the effects of distance alone are observed, that is, when we compare the waveforms in the sentences with subject-relative clauses and those in the short sentences, a long duration effect appears, starting roughly at about 200 ms and lasting throughout all the epoch. The significant effects of type of sentence and of the Type of Sentence  $\times$  ROI interaction in the main ANOVA of Table 1 across all the measured time windows support these effects. Furthermore, second-order pairwise ANOVAs comparing correct sentences with subject-relative clauses and correct short sentences yielded a significant Type of Sentence  $\times$  ROI interaction effect across all the measured windows,  $F(17,527)$  between 9.62 and 17.84,  $p$  always  $< .0001$ ,  $\epsilon$  between .166 and .243. The distribution of this effect appeared wide and frontal or fronto-central during the first part of the epoch (until about 700 ms), thereafter displaying a rather central maximum. Even though, profile analyses yielded no significant result when comparing the 350–550-ms with the 900–1300-ms time windows, two main representative windows for each part of the epoch,  $F(28,868) = 1.7$ ,  $p > .1$ ,  $\epsilon = .188$ .

When we compare the waveforms in the sentences with object-relative clauses and those in the sentences with subject-relative clauses, a long duration effect appears again, starting roughly at about 200 ms and lasting throughout all the epoch.

The distribution of this effect now appears rather homogeneous across time, with a mainly parietal distribution, although it appeared to display larger values during the first half of the period. The significant effects of type of sentence and of the Type of Sentence  $\times$  ROI interaction in the main ANOVAs of Table 1 across all the measured time windows would also support these effects. Additionally, second-order pairwise ANOVA comparing correct sentences with object-relative clauses and correct sentences with subject-relative clauses yielded a significant type of sentence effect across all the measured windows,  $F(1,31)$  between 4.87 and 27.60,  $p$  between .035 and .0001. A significant Type of Sentence  $\times$  ROI interaction effect was also obtained for the first three windows,  $F(17,527)$  between 4.22 and 6.77,  $p$  between .006 and .0001,  $\epsilon$  between .178 and .196, together with a trend for significance in the 700–900-ms window,  $F(17,527) = 2.36$ ,  $p = .066$ ,  $\epsilon = .203$ .

#### *Comparing Anterior Negativities Related to Working Memory and to Grammatical Violations*

From our results, we have clearly obtained four frontal negativities that, at least according to several models, are presumably related to working memory load during sentence processing. We have also obtained two frontal negativities related to grammatical violations. Overall, it appears that frontal negativities to grammatical violations (Figure 2, left) present a narrower distribution, it even being possible to observe a small polarity inversion in the more frontal portions of the scalp, contrasting with a wider distribution over frontal regions of the negativities presumably related to working memory, involving also the most anterior parts of



**Figure 3.** Grand average ERP time locked to the onset of the main verb's position, displaying the effects of distance and syntactic complexity on correct sentences. Distance and syntactic complexity seemed to elicit long duration negativities, the former with a fronto-central distribution and the latter involving more posterior regions.



the scalp (Figures 1 and 3). For the main purposes of this study, all these negativities deserve to be compared by means of profile analyses. To make comparisons equivalent, 200-ms-wide windows were selected from those negativities with longer durations, namely, those presumably related to working memory.

As demonstrated before, the distribution of these long-lasting negativities was rather homogeneous across time, at least in statistical terms, and the windows selected for these profile analyses were those in which the negativity either presented a clearer frontal distribution (therefore being indeed needed to disentangle it from frontal negativities caused by grammatical violations) or displayed its highest values. These windows were 200–400 ms when comparing relative clauses with short sentences in the third word of the sentence, 150–350 ms when comparing object-relative with subject-relative sentences in the fourth word of the sentence, and 350–550 ms when comparing subject-relative with short sentences in the main verb. The window used to analyze the frontal negativities to grammatical violations was 350–550 ms.

Results of these comparisons can be seen in Table 2. They confirmed what was apparent to the eye. In this regard, the ERP effects caused by working memory manipulations (negativities 1–4 in Table 2) differed significantly in topography from the responses caused by grammatical violations (negativities 5 and 6). In turn, the effects caused by working memory manipulations did not differ significantly in topography between them. The responses caused by grammatical violations also did not differ significantly in topography between them, although they yielded a trend for significance.

## Discussion

The main aim of the present study was to investigate whether the negativities obtained in the ERP when a grammatical violation has taken place during the processing of a sentence can be identified with the negativities obtained in situations in which working memory load is presumably taxed during language processing. Our main result is that the frontal negativities related to grammatical violations appear qualitatively different from those related to working memory manipulations. Overall, the left lateralization appeared clearer and more reliable for the negativities related to grammatical violations than for the negativities related to working memory, the latter also displaying a wider distribution than the former and involving the most anterior parts of the scalp. The difference between these topographies was supported statistically. Our results also indicate that the duration

of the effects may be another valid criterion to dissociate these two types of negativity. Overall, frontal negativities presumably related to working memory displayed longer durations than those related to grammatical violations.

The qualitative dissociation between both types of frontal negativities would hold even if previous studies have reported negativities related to working memory load with a more noticeable left lateralization (e.g., King & Kutas, 1995) or negativities to grammatical violations with wider and more bilateral distributions (e.g., Hagoort et al., 2003). The same could be said relative to the duration of the effects. Indeed, subtle differences in the design, the materials employed, the task requirements, and even across-language differences could account for noticeable differences in topography or duration across studies. However, when the comparisons are made within the same experiment, overriding all possible differences but those depending on the experimental manipulations, finding different topographies and durations between two ERP components is enough evidence for an unambiguous dissociation. Indeed, the topography alone is a robust and valuable criterion to dissociate ERP components, representing a strong argument for assuming underlying different brain areas (Rugg & Coles, 1995) and, therefore, for dissociating cognitive elements (e.g., Johnson, 1993). Accordingly, grammatical violations and working memory load during sentence processing probably relate to at least partially different loci at the cognitive level.

Direct evidence favoring the hypothesis that the negativities related to grammatical violations are not expressly reflecting working memory load has been scarce. Indeed, to our knowledge, the only published work is the one by Schlesewsky, Bornkessel, and Frisch (2003), who used German sentences in which dislocated arguments were instantiated either by nonpronominal or by pronominal noun phrases. These authors found a phasic negativity (i.e., left anterior negativity) at the position of the determiner of a dislocated noun phrase, but only in sentences with nonpronominal arguments, both types of arguments presumably taxing working memory equally. Accordingly, these findings were interpreted as reflecting that the left anterior negativity would be a reflection of a local syntactic mismatch, rather than of an increase in working memory load. However, some theoretical accounts such as the *integration cost account* (Gibson, 1998) claim that indexical pronouns impose less of a load on working memory than other, nonpronominal, referring expressions, accounting for Bever's (1974) intuition that unbounded dependency constructions containing indexical pronouns are easier to process.

**Table 2.** Comparisons between Frontal Negativities by Means of Profile Analyses (*F* Values)

| Frontal negativities  | Presumably involved process | Comparisons |     |     |        |                   |
|---|-----------------------------|-------------|-----|-----|--------|-------------------|
|   |                             | (2)         | (3) | (4) | (5)    | (6)               |
| Contrast yielding the negativity  |                             |             |     |     |        |                   |
| (1) Subject relative vs. Short in 3rd word in sentence (relative clause region)           | Working memory              | —           | —   | —   | 3.05*  | 3.30*             |
| (2) Object-relative vs. Short in 3rd word in sentence (relative clause region)            | Working memory              |             | —   | —   | 3.23*  | 3.38*             |
| (3) Object-relative vs. Subject-relative in 4th word in sentence (relative clause region) | Working memory              |             |     | —   | 4.92** | 3.23*             |
| (4) Subject-relative vs. Short (main verb region)   | Working memory              |             |     |     | 3.67** | 3.12*             |
| (5) Word category violation vs. Correct in short sentences (main verb region)             | Gramm. violation            |             |     |     | —      | 2.19 <sup>+</sup> |
| (6) Morphosyntactic violation vs. Correct in short sentences (main verb region)           | Gramm. violation            |             |     |     |        | —                 |

*F*(28,868).

<sup>+</sup>  $p < .1$ ; \* $p < .05$ ; \*\* $p < .01$ . Only significant results, or with a trend for significance, are displayed.

Our results would, therefore, constitute the only direct evidence for dissociating frontal negativities related to grammatical violations from frontal negativities presumably related to working memory load. However, even if different, the syntactic operations involved in grammatical violations and working memory load are not completely independent. When working memory is tapped by embedding a relative clause, the processes reflected by the anterior negativities to grammatical violations seem to be compromised, as indicated in the disappearance of the anterior negativities for grammatical violations under these circumstances. Similar effects have been reported by other authors (e.g., Vos et al., 2001), which has been taken as supporting the working memory nature of the anterior negativities to grammatical violations. However, in our view, this interaction can be interpreted alternatively in the light of very recent accounts of linguistic working memory from the connectionist framework (MacDonald & Christiansen, 2002), an attempt to overcome some of the caveats of the two traditional and opposing views of linguistic working memory (Just & Carpenter, 1992; Waters & Caplan, 1996).

According to connectionist proposals, the processing of input is achieved through the passing of activation through a multi-layer network, disregarding the existence of a separated computational workspace. Accordingly, the working memory would be located at the network itself, and the long-term knowledge of language would not be functionally separated from the locus of processing. Interestingly, similar proposals for working memory have already come from the neurosciences (e.g., Basar, 2004; Fuster, 1995). The finding that anterior negativities to grammatical violations are reduced or eliminated when working memory resources are presumably more in demand, together with the finding that anterior negativities to grammatical violations can be dissociated from anterior negativities presumably reflecting working memory, could indicate that the two negativities are, in fact, reflecting the activations of qualitatively dissociable portions of one and the same network. The reduction or even the disappearance of the anterior negativities to grammatical violations in the difficult sentences could be interpreted as a reduction of the resources employable to detect grammatical errors under circumstances in which part of the overall resources of the language processor, of limited capacity, are already occupied by other, different processes.

What these different processes might be is a different question. As mentioned in the introduction section, these have been interpreted by several authors as working memory processes in the traditional view, that is, as synonymous with maintaining active a given syntactic structure or performing operations in a separated computational workspace (e.g., Friederici, 2002). But, following MacDonald and Christiansen (2002), this maybe a narrow or inaccurate conception of working memory. In view of our results, it might be that maintaining active a syntactic structure (or performing the additional operations required when a sentence contains a relative clause) and performing the operations requested by the appearance of a grammatical violation pertain equally to the same unitary system, even if they pertain to at least partially qualitatively different subsystems. The system as a whole could be called linguistic working memory or, more properly (in connectionist framework terms), language *processing capacity* (MacDonald & Christiansen, 2002).

Morphosyntactic and word category violations in the short sentences yielded fairly nonidentical frontal negativities, in line with previous studies (Friederici et al., 1993; Hinojosa et al., 2003). Even though, the processes reflected by both negativities

would be common for the most part, because the differences were not significant in statistical terms. We also did not observe a latency difference between both types of frontal negativities, at variance with Friederici et al. (1993), but again in line with other studies (Hinojosa et al., 2003). This would support that the proposal that negativities to word category violations precede those to other types of grammatical violations may be based on an artifactual product of the moment at which the violation occurs within a word (Hagoort, 2003).

A striking finding was a parieto-occipital (mainly left) negativity accompanying word category violations in sentences with subject-relative clauses, whereas the same grammatical manipulations yielded a classical left frontal negativity (i.e., left anterior negativity) in short sentences. Although we can only speculate in this regard, it is our opinion that some local structural differences between our subject-relatives and the short sentences could account for this irregular topography. In the subject-relative sentences, the word category violation might be referred to either the immediately appearing noun (then an adjective could have been a correct category modifying that noun) or the noun constituting the main subject of the sentence (then a verb would be the correct word). But it would remain unexplained why a posterior negativity could reflect this plausible situation of ambiguity, and it is also true (as mentioned in the Methods section) that the degree of expectancy of a verb in that position was high and comparable to the other types of sentences.

Even though, this is not the first report in which a very posterior negativity was obtained for grammatical violations. Coulson et al. (1998) reported a certainly similar distribution for verb agreement (i.e., morphosyntactic) violations in short sentences in which the incorrectly inflected verb was immediately preceded by the subject, which was always a pronoun. These authors interpreted this result by suggesting that subjects perceived these violations as subtle changes in the sentence meaning rather than as grammatical violations, assuming that the distribution of this effect could be equated to some extent with that of an N400 component. This explanation would be unsatisfactory in our view, however, mainly because the distribution of such left parieto-occipital negativity in both the Coulson et al. (1998) and the present study is indeed far from resembling the slightly right centro-parietal distribution typical of the N400 (Kutas, Federmeier, Coulson, King, & Münte, 2000).

It would also remain to be explained why we found a bilateral parietal long-duration negativity resulting from the comparison between sentences with object-relative and subject-relative clauses in the main verb of the sentence where we expected to find another frontal negativity presumably related to working memory. To our knowledge, in the literature, the experimental arrangement most similar to ours is that of King and Kutas (1995), who reported instead a left frontal negativity for main verbs in object-relative sentences as compared to subject-relatives. A good candidate for the processes reflected by our bilateral parietal negativity could be grammatical and thematic roles assignment. Indeed, Weckerly and Kutas (1999) have suggested that there would be an extension of the role assignments in object-relative clauses into the processing of the main verb.

In this regard, Martín-Loeches et al. (2005) reported a negativity presumably originating in both prefrontal (BA 10 and 44) and temporal (BA 22, BA 21, and BA 37) areas according to source localization algorithms, and presumably related to thematic role assignment. If both frontal and posterior generators contribute to these effects, it might be that subtle differences

between the study of King and Kutas (1995) and ours might be involving these neural circuits differentially. It must be noted, nevertheless, that when Müller et al. (1997) replicated the experiment by King and Kutas (1995) but with an auditory natural-speech presentation, interestingly, the negativity associated to the main verb in object-relative sentences displayed a rather central and anterior-temporal distribution, being also more bilateral than in the previous study.

Although it was not the main aim of the present article, a few words should be devoted to the P600 component. The P600 appeared different when comparing word category and morpho-syntactic violations, the latter displaying larger amplitudes across all types of sentences. This difference between syntactic and morphosyntactic violations parallels previous findings (e.g., Hinojosa et al., 2003) and could be related to the fact that morphosyntactic violations induce both reanalysis and repair operations whereas word category violations only produce re-

analysis operations (Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001). The other variables here manipulated (namely, embedding subject- and object-relative clauses) did not seem to influence the P600, in consonance with previous reports (e.g., Kaan, 2002). Also in line with this finding, Phillips, Kazanina, and Abada (2005) have recently proposed that the P600 amplitude reflects the syntactic and semantic operations involved in confirming the compatibility of syntactic dependencies for thematic role assignment, being therefore insensitive to the length of the dependency.

In conclusion, anterior negativities related to grammatical violations and those related to working memory manipulations are not equivalent. This is true both in terms of topography and duration. Accordingly, they appear to reflect at least two different cognitive processes. However, even if different, these cognitive processes would be placing demands on a common pool of limited resources.

## REFERENCES

- Ainsworth-Darnell, K., Shulman, H. G., & Boland, J. E. (1998). Dissociating brain responses to syntactic and semantic anomalies: Evidence from event-related potentials. *Journal of Memory and Language*, 38, 112–130.
- American Electroencephalographic Society. (1991). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, 3, 38–42.
- Basar, E. (2004). *Memory and brain dynamics: Oscillations integrating attention, perception, learning, and memory*. Boca Raton, FL: CRC Press.
- Bever, T. B. (1974). The ascent of the specious, or there's a lot we don't know about mirrors. In D. Cohen (Ed.), *Explaining linguistic phenomena* (pp. 173–200). Washington, DC: Hemisphere.
- Brown, C. M., Hagoort, P., & ter Keurs, M. (1999). Electrophysiological signatures of visual lexical processing: Open- and closed-class words. *Journal of Cognitive Neuroscience*, 11, 261–281.
- Chomsky, N., & Miller, G. A. (1963). Introduction to the formal analysis of natural languages. In R. D. Luce, R. R. Bush, & E. Galanter (Eds.), *Handbook of mathematical psychology* (pp. 269–321). New York: Wiley.
- Coulson, S., King, J., & Kutas, M. (1998). Expect the unexpected: Event-related brain potentials to morphosyntactic violations. *Language and Cognitive Processes*, 13, 21–58.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19, 450–466.
- Fiebach, C. J., Schlesewsky, M., & Friederici, A. D. (2002). Separating syntactic memory costs and syntactic integration costs during parsing: The processing of German WH-questions. *Journal of Memory and Language*, 47, 250–272.
- Ford, M. (1983). A method of obtaining measures of local parsing complexity throughout sentences. *Journal of Verbal Learning and Verbal Behavior*, 22, 203–218.
- Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language*, 49, 259–281.
- Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, 6, 78–84.
- Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). The temporal structure of syntactic parsing: Early and late ERP effects elicited by syntactic anomalies. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 5, 1219–1248.
- Friederici, A. D., Mecklinger, A., Spencer, K. M., Steinhauer, K., & Donchin, E. (2001). Syntactic parsing preferences and their on-line revisions: A spatio-temporal analysis of event-related potentials. *Cognitive Brain Research*, 11, 305–323.
- Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, 1, 183–192.
- Fuster, J. M. (1995). *Memory in the Cerebral Cortex: An Empirical Approach to Neural Networks in the Human and Nonhuman Primate*. Cambridge, MA: MIT Press.
- Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, 69, 1–76.
- Gordon, P. C., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 27, 1411–1423.
- Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, 55, 468–484.
- Gross, M., Say, T., Kleingers, M., Clahsen, H., & Münte, T. F. (1998). Human brain potentials to violations in morphologically complex Italian words. *Neuroscience Letters*, 241, 83–86.
- Gunter, T. C., & Friederici, A. D. (1999). Concerning the automaticity of syntactic processing. *Psychophysiology*, 36, 126–137.
- Gunter, T. C., Friederici, A. D., & Hahne, A. (1999). Brain responses during sentence reading: Visual input affects central processes. *NeuroReport*, 10, 3175–3178.
- Gunter, T. C., Friederici, A. D., & Schriefers, H. (2000). Syntactic gender and semantic expectancy: ERPs reveal early autonomy and late interaction. *Journal of Cognitive Neuroscience*, 12, 556–568.
- Hagoort, P. (2003). How the brain solves the binding problem for language: A neurocomputational model of syntactic processing. *NeuroImage*, 20, S18–S29.
- Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading: The P600/SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia*, 38, 1531–1549.
- Hagoort, P., Wassenaar, M., & Brown, C. M. (2003). Syntax-related ERP-effects in Dutch. *Cognitive Brain Research*, 16, 38–50.
- Hahne, A., & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience*, 11, 194–205.
- Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research*, 13, 339–356.
- Hahne, A., & Jescheniak, J. D. (2001). What's left if the Jabberwock gets the semantics? An ERP investigation into semantic and syntactic processes during auditory sentence comprehension. *Cognitive Brain Research*, 11, 199–212.
- Hinojosa, J. A., Martín-Loeches, M., Muñoz, F., Casado, P., & Rubia, F. J. (2003). Similarities and differences between phrase structure and morphosyntactic violations in Spanish: An event-related potentials study. *Language and Cognitive Processes*, 18, 113–142.
- Hsiao, F., & Gibson, E. (2003). Processing relative clauses in Chinese. *Cognition*, 90, 3–27.
- Johnson, R. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, 30, 90–97.

- Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*, 122–149.
- Kaan, E. (2002). Investigating the effects of distance and number interference in processing subject-verb dependencies: an ERP study. *Journal of Psycholinguistic Research*, *31*, 165–193.
- King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, *30*, 580–602.
- King, J. W., & Kutas, M. (1995). Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience*, *7*, 376–395.
- Kluender, R., & Kutas, M. (1993a). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience*, *5*, 196–214.
- Kluender, R., & Kutas, M. (1993b). Subjacency as a processing phenomenon. *Language and Cognitive Processes*, *8*, 573–633.
- Kutas, M., Federmeier, K. D., Coulson, S., King, J. W., & Münte, T. F. (2000). Language. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 576–601). Cambridge, UK: Cambridge University Press.
- MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). *Psychological Review*, *109*, 35–54.
- Martin-Loeches, M., Casado, P., Hinojosa, J. A., Carretié, L., Muñoz, F., & Pozo, M. A. (2005). Higher-order activity beyond the word level: Cortical dynamics of simple transitive sentence comprehension. *Brain and Language*, *92*, 332–348.
- McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, *62*, 203–208.
- Müller, H. M., King, J. W., & Kutas, M. (1997). Event-related potentials elicited by spoken relative clauses. *Cognitive Brain Research*, *5*, 193–203.
- Münte, T. F., & Heinze, H. J. (1994). ERP negativities during syntactic processing of written words. In H. J. Heinze, T. F. Münte, & G. R. Mangun (Eds.), *Cognitive electrophysiology* (pp. 211–238). Boston: Birkhauser.
- Neville, H., Nicol, J. L., Barss, A., Forster, K. I., & Garrett, M. F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *3*, 151–165.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113.
- Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family? *Journal of Cognitive Neuroscience*, *8*, 507–526.
- Penke, M., Weyerts, H., Gross, M., Zander, E., Münte, T. F., & Clahsen, A. (1997). How the brain processes complex words: An ERP study of German verb inflections. *Cognitive Brain Research*, *6*, 37–52.
- Perrin, F., Bertrand, O., & Echallier, J. F. (1989). Spherical splines for scalp potential and current density mapping. *Electroencephalography and Clinical Neurophysiology*, *72*, 184–187.
- Phillips, C., Kazanina, N., & Abada, S. H. (2005). ERP effects of the processing of syntactic long-distance dependencies. *Cognitive Brain Research*, *22*, 407–428.
- Rodriguez-Fornells, A., Clahsen, H., Lleó, C., Zaake, W., & Münte, T. F. (2001). Event-related brain responses to morphological violations in Catalan. *Cognitive Brain Research*, *11*, 47–58.
- Rugg, M. D., & Coles, M. G. H. (1995). The ERP and cognitive psychology: Conceptual issues. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 27–39). Oxford, UK: Oxford University Press.
- Schlesewsky, M., Bornkessel, I., & Frisch, S. (2003). The neurophysiological basis of word order variations in German. *Brain and Language*, *86*, 116–128.
- Traxler, M. J., Morris, R. K., & Seeley, R. E. (2002). Processing subject and object relative clauses: Evidence from eye movements. *Journal of Memory and Language*, *47*, 69–90.
- Van den Brink, D., & Hagoort, P. (2004). The influence of semantic and syntactic context constrains on lexical selection and integration in spoken-word comprehension as revealed by ERPs. *Journal of Cognitive Neuroscience*, *16*, 1068–1084.
- Vos, S. H., Gunter, T. C., Kolk, H. H. J., & Mulder, G. (2001). Working memory constraints on syntactic processing: An electrophysiological investigation. *Psychophysiology*, *38*, 41–63.
- Wanner, E., & Maratsos, M. (1978). An ATN approach in comprehension. In M. Halle, J. Bresnan, & G. Miller (Eds.), *Linguistic theory and psychological reality* (pp. 119–161). Cambridge, MA: MIT Press.
- Waters, G. S., & Caplan, D. (1996). The capacity theory of sentence comprehension: Critique of Just and Carpenter (1992). *Psychological Review*, *4*, 761–772.
- Weckerly, J., & Kutas, M. (1999). An electrophysiological analysis of animacy effects in the processing of object-relative sentences. *Psychophysiology*, *36*, 559–570.

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