Cognitive Science 31 (2007) 343–354

ERP Evidence for the Rapid Assignment of an (Appropriate) Antecedent to PRO

Josep Demestre, José E. García-Albea

Departament de Psicologia, Universitat Rovira i Virgili, Tarragona, Spain

Received 10 February 2006; received in revised form 28 June 2006; accepted 6 July 2006

Abstract

Event-related brain potentials were recorded while subjects listened to sentences containing a controlled infinitival complement. Subject and object control items were used, both with 2 potential antecedents in the upper clause. Half of the sentences had a gender agreement violation between the null subject of the infinitival complement and an adjective predicated of it. The rapid detection of this anomaly would indicate that the parser had established the coreference relation between the null subject and an antecedent, and that the processor had rapidly consulted verb control information to select the proper antecedent of the null subject. The results showed that for both subject and object control items ungrammatical adjectives elicited a P600 effect. These data imply that the processor has coindexed the null subject with an antecedent, and that the antecedent has been selected on the basis of control information. These results are compatible with parsing models that emphasize the rapid influence of verb-specific information on sentence processing.

Keywords: Antecedent assignment; Null subject; Gender agreement; Sentence processing in Spanish; Auditory ERPs

1. Introduction

A central issue in the study of language processing is antecedent assignment to referentially-dependent elements; natural language is full of anaphors and other referring expressions, whose referents must be determined in order to arrive at a coherent interpretation of a discourse. One such referentially dependent element is the subject of nonfinite clauses.

Characteristically, and across languages, the subject of a nonfinite clause is implicitly understood, but not overtly specified. Chomsky (1986) posits in this position the empty

Correspondence should be addressed to Josep Demestre, Departament de Psicologia, Universitat Rovira i Virgili, 43007-Tarragona, Spain. E-mail: josep.demestre@urv.net

category PRO,[1] an abstract syntactic element with no phonetic content. PRO must inherit the minimal identifying features from another noun phrase (NP) with which it is coindexed. This coreference is determined by a relationship called *control* (Chomsky, 1981; Manzini, 1983). When PRO appears in an infinitival complement clause, one of the arguments of the matrix verb will be understood as its antecedent (its controller). Whether the controller is the subject or the object of the matrix clause depends on intrinsic lexical properties of that verb. In (1), the reflexive in the embedded clause takes as its antecedent the controlling NP. The ungrammatical reflexives show that *promise* is a subject control (SC) verb and *persuade*, an object control (OC) verb.

(1) a. Mary promised Bill to feed herself/*himself
b. Mary persuaded John to feed himself/*herself

In order to correctly coindex PRO with its antecedent, the parser must likewise use information specific to the main verb. In general, the availability of information in the stimulus, however, does not necessarily imply that that information is immediately used by the language processor. The question is not *if*, but *when*, control information is employed by the processor.

1.1. Experimental studies on antecedent assignment to PRO

The experimental literature to date yields far from conclusive results concerning the assignment of an antecedent to PRO. On the one hand, the cross-modal priming paradigm has provided evidence for the non-immediate assignment of an antecedent to controlled PRO (see Nicol & Swinney, 1989). Osterhout and Nicol (unpublished, reported in Nicol & Swinney, 1989) concluded that control information is used correctly but that the interpretation of the null subject is relatively slow. It is difficult to evaluate the Osterhout and Nicol claims in the absence of clear priming patterns for PRO. On the other hand, studies using other behavioral methodologies such as an on-line plausibility monitoring task (Boland, Tanenhaus, & Garnsey, 1990) and an end-of-sentence (i.e., off-line) comprehension task (Clifton & Frazier, 1986; Frazier, Clifton, & Randall, 1983) concluded that the parser assigns an antecedent to PRO very rapidly. The latter studies, however, disagreed with respect to the information the parser uses initially in selecting an antecedent. According to Frazier et al. (1983), the parser does not consult control information in making its initial assignment, but follows a decision procedure known as the *most recent filler strategy* (hereafter MRFS). This strategy claims that the less distant NP that occurs in a potential filler position in the phrase-marker will be selected as the antecedent of PRO.[2] Frazier et al. (1983) concluded that PRO is initially coindexed with the most recent NP, and, at a later stage, this assignment is checked when control information becomes available. On the contrary, Boland et al. (1990) found not only that verb control information was used to make the correct assignment, but that it was available early so that the implicit subject was interpreted immediately. They concluded that coindexing decisions are not made before control information becomes available, and that verb control information is available for use very early during sentence processing.

One of the problems of Frazier et al.'s (1983) and Boland et al.'s (1990) studies is that they did not isolate the phenomenon of control from that of movement, since they used sentences that contained both a PRO and a wh-trace.[3] This might result in a complex interaction between the

two kinds of empty elements, thus being difficult to isolate appropriately the processes involved in assigning an antecedent to PRO. Boland et al.'s (1990) study has yet another problem. In experiment 2 (in which they manipulated verb control) all materials were most recent filler sentences,[4] that is, sentences in which the antecedent selected by control information was also the most recent NP, thus making it impossible to contrast appropriately the predictions of a hypothesis based on a distance principle with the predictions of a hypothesis based on the rapid availability of control information.

In the light of the results of the studies mentioned above, there are two questions that deserve deeper examination: (1) how early does the parser assign an antecedent to PRO?, and (2) does the parser initially coindex PRO with the most recent NP or with the NP specified by control information?

1.2. Referentially dependent elements, agreement errors and ERPs

Event-related brain potentials (ERPs) have been successfully used to examine a great variety of parsing phenomena (see Brown & Hagoort, 2000; Hagoort, Brown, & Osterhout, 1999, for reviews). There are, however, few ERP studies on antecedent assignment to referentially dependent elements. Osterhout (1997) and Osterhout and Mobley (1995) examined the brain responses to violations of number and gender agreement between a reflexive and its antecedent (e.g., "*The salesman congratulated himself /*herself /*themselves*"). These anomalies have been reported to elicit a large-amplitude positive-going wave (labeled the *P600 effect* by Osterhout & Holcomb, 1992) widely distributed over central and posterior sites (Osterhout & Mobley, 1995), as well as a biphasic (i.e., a left anterior negativity [LAN] followed by a positivity) pattern (Osterhout, 1997). The immediate effects of violations of number and gender between reflexives and their antecedents imply that antecedent assignment to the reflexive has been made, and that one of the agreement features is not shared between them.

An agreement violation effect could be used similarly as evidence for antecedent assignment to PRO. If a sentence contains a word (e.g., an adjective) that must agree in gender with PRO but in fact does not agree with the antecedent assigned to PRO, then one would expect a similar effect of syntactic anomaly. Following this logic, Demestre, Meltzer, García-Albea, & Vigil (1999) conducted an auditory ERP experiment in Spanish that showed that the ERP methodology can be successfully used to examine the assignment of an antecedent to PRO. The authors examined the brain responses to NP-adjective gender agreement violations in controlled infinitival complements in two types of constructions: (1) SC-sentences with one potential antecedent (as in 2), and (2) OC-sentences with two potential antecedents (as in 3).

(2) a. María$_i$ (fem) quiere PRO$_i$ ser *rica* (fem)
    b. * Pedro$_i$ (masc) quiere PRO$_i$ ser *rica* (fem)
    [Mary (fem) [*Peter (masc)] wants to be rich (fem)]

(3) a. Pedro$_i$ (masc) ha aconsejado a María$_j$ (fem) PRO$_j$ ser *educada* (fem) con la gente
    b. * María$_i$ (fem) ha aconsejado a Pedro$_j$ (masc) PRO$_j$ ser *educada* (fem) con la gente
    [Peter/Mary has advised Mary/Peter to be polite with people]

The experiment showed that adjectives that did not agree in gender with the antecedent of PRO elicited a biphasic ERP response (an early negativity followed by a late positivity);

the brain's sensitivity to such anomalies indicates that PRO has been rapidly coindexed to its antecedent. The authors, however, did not address the question concerning the sources of information that are initially used to select an antecedent. As can be seen from the examples above, in both types of constructions the antecedent selected by control information is also the NP that is less distant from PRO; thus, the authors could not examine whether antecedent assignment is guided by control information or by a strategy such as the MRFS.

2. The present study

The aim of the present study was twofold: (1) to examine whether the assignment of an antecedent to PRO is a rapid or delayed process, and (2) to examine whether such process is guided by verb control information or by a decision procedure such as the MRFS. In order to investigate these issues, we devised the following strategy: (a) to use ERPs due to their high temporal resolution, (b) to use sentences with only one empty element (that is, sentences with a PRO and with no traces), and (c) to contrast distant and recent filler constructions by using three-argument verbs in both SC- and OC-sentences. Decisions (b) and (c) were made in order to avoid some of the problems and limitations of previous studies (Boland et al., 1990; Demestre et al., 1999; Frazier et al., 1983).

Given that PRO has no phonetic content, it lacks inherent gender. It inherits its gender feature, via coindexing, from another structurally superior NP. Whereas in the complement clause of an SC-verb such as *prometer* ("to promise") in (4), PRO is understood as coreferent with the matrix subject, in the complement clause of an OC-verb such as *aconsejar* ("to advise") in (5), the implicit subject is understood as coreferent with the matrix object. The adjective (underlined) in the subordinate clause must agree in number and gender with the NP it modifies, namely PRO. Hence the ungrammaticality of (4b) and (5b), due to the clash in gender between PRO and the adjective:

(4) a. Pedro$_i$ (masc) ha prometido a María$_j$ (fem) PRO$_i$ ser *estricto* (masc) con los alumnos
b. *María$_i$ (fem) ha prometido a Pedro$_j$ (masc) PRO$_i$ ser *estricto* (masc) con los alumnos
[Peter/Mary has promised Mary/Peter to be strict with the students]

(5) a. Pedro$_i$ (masc) ha aconsejado a María$_j$ (fem) PRO$_j$ ser *educada* (fem) con la gente
b. *María$_i$ (fem) ha aconsejado a Pedro$_j$ (masc) PRO$_j$ ser *educada* (fem) con la gente
[Peter/Mary has advised Mary/Peter to be polite with people]

The detection of these violations would imply that the processor had established the coreference relation between the null subject of the lower clause and its antecedent in the higher clause. If the parser had detected the null subject and coindexed it with its proper antecedent (i.e., the one specified by control information), then we would expect that in both SC- and OC-items the NP-adjective gender agreement violations (examples 4b and 5b) would evoke a brain response (i.e., an anomaly effect) reliably different from that elicited by grammatical adjectives (examples 4a and 5a). If the parser had detected PRO and coindexed it with the most recent NP (as predicted by the MRFS), then one would expect an interaction between

grammaticality and *verb type*; in other words, one would expect an anomaly effect in response to adjectives (examples 4a and 5b) that do not agree in gender with the most recent NP (i.e., the object). Whereas in SC-items one would expect an anomaly effect in response to grammatical adjectives (example 4a), in OC-items one would expect an anomaly effect in response to ungrammatical adjectives (example 5b). Given that the gender clash (between the null subject and the adjective predicated of it) is syntactic and not semantic, and given that previous ERP studies of syntactic gender agreement violations in sentence contexts (Barber & Carreiras, 2005; Demestre et al., 1999; Hagoort & Brown, 1999; Gunter, Friederici, & Schriefers, 2000; Osterhout & Mobley, 1995) have shown that the most prominent ERP effect elicited by such syntactic violations is the P600 effect, we hypothesize that the anomaly effect elicited by adjectives perceived as ungrammatical would be an ERP component related to syntax similar to that found in previous studies.

2.1. Method

2.1.1. Participants

Sixteen students (12 women and 4 men) from the Universitat Rovira i Virgili participated in the experiment for course credits. All were native speakers of Spanish, right-handed, and with no known hearing deficit. Their ages ranged from 19 to 28 (M = 22) years.

2.1.2. Materials

Ninety-six sentence pairs were constructed: 48 SC-pairs (as in 4) and 48 OC-pairs (as in 5). One version of each pair was grammatically well formed. In the second version, the adjective disagreed in gender with the antecedent of PRO. In half of the pairs the adjective was marked for feminine and in half for masculine. All the adjectives were carefully selected in order to avoid semantic/pragmatic biases (that is, adjectives were equally plausible for both masculine and feminine nouns). The infinitival complement remained constant for both sentences in all pairs; all gender manipulations appeared in the matrix clause.

In the experimental items, the infinitival clause was a complement of a matrix clause consisting of a proper noun in subject position, a finite subject or object control verb, and a proper noun in object position. In the matrix clause, there was one feminine and one masculine noun. The clash in gender was created by inverting the syntactic position of the two names.

These materials were then used to create two stimulus lists. Each list contained 48 exemplars (24 ungrammatical) of each verb type. Items were counterbalanced such that only one version of each pair was presented on a given list. Additionally, a set of 54 filler sentences (half were ungrammatical) was constructed with different syntactic structures. Thus, each subject heard a total of 150 sentences. The three types of sentences (SC, OC, and fillers) were randomly intermixed.

Each sentence was spoken by a male speaker at a normal speaking rate and with normal pitch and intonation. The speaker was naive to the purposes of the experiment. The sentences were digitized and the onset of the critical word was determined by careful visual and auditory inspection of the speech wave to allow for a precise time-locking of the ERP in each sentence.

All speech waves were carefully examined to avoid acoustic, phonetic, or prosodic differences between the experimental conditions.

2.1.3. Procedure

Participants were tested one at a time, in an acoustically shielded room with low to normal illumination, seated in a comfortable reclining chair. When the participant was ready, the experimenter pressed a key that initiated the first trial of the session. Five seconds after the key pressing, the first sentence was presented binaurally over headphones. A neutral sound (a beep) indicated the end of the sentence, and that the participant was to perform a sentence acceptability judgment. Participants responded by pressing one of two buttons, and were instructed to give their response as fast and as accurately as possible. Participants were asked to avoid eye movements and to only blink their eyes between their response to the acceptability task and the presentation of the next sentence. Between the beep and the beginning of the next trial there was a silent pause of 2000 ms. The whole session lasted approximately 90 min.

2.1.4. Electrophysiological recording

The electroencephalogram (EEG) was recorded monopolarly from 9 Ag/AgCl electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4) mounted in an elastic cap (Electro Cap International) according to a standard extended 10–20 International Location System configuration. In addition, electrodes were placed beneath the right eye to monitor blinking and vertical eye movements and at the outer canthus of the left eye to monitor horizontal eye movements. All EEG channels were referenced to the left earlobe, and the right earlobe was employed as an active recording channel. Subsequently ERPs were algebraically re-referenced to the mean of the two earlobes. Electrode impedances were always <5 kΩ. All EEG and EOG channels were amplified using a NeuroScan Amplifier and recorded continuously with a bandpass from 0.01 to 30 Hz and digitized with 2 ms resolution.

2.1.5. Data analysis

ERPs were computed for each subject and each electrode within a 1300 ms time window (starting 100 ms before the onset of the critical word). ERP waveforms were averaged separately for each cell in the design. Each mean was calculated from approximately 21 trials (ranging 19–24). All ERP averages were aligned to a 100 ms prestimulus baseline. Artifacts were automatically rejected by eliminating those epochs that exceeded +/–50 μV and those with amplifier saturation artifacts. Approximately 10% of the trials (evenly distributed across conditions) were excluded for these reasons.

Statistical analyses were performed on the mean amplitude within two time windows: (1) 250 to 400 ms, and (2) 500 to 900 ms from the onset of the adjective. These time windows were chosen based on typically observed latency ranges of the LAN and P600 ERP components. All analyses were quantified using the multivariate approach to repeated measures (O'Brien & Kaiser, 1985; Vasey & Thayer, 1987). MANOVAs were conducted in the following way: data from midline and lateral sites were treated separately in order to examine hemispheric differences. The analyses for midline sites were conducted with the following within-subject factors: verb type (SC vs. OC), grammaticality (grammatical vs. ungrammatical), and electrode (Fz vs. Cz vs. Pz). At lateral sites the analyses were conducted

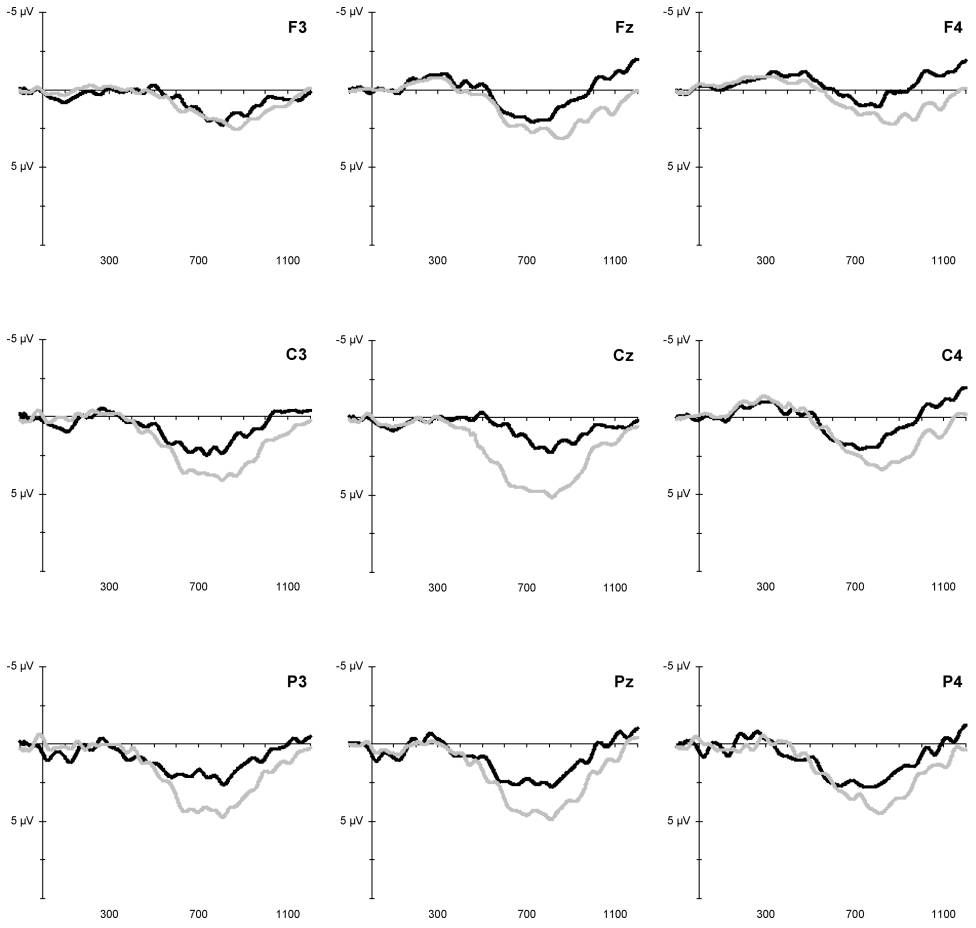

Fig. 1. Grand average ERPs (N = 16) to adjectives (onset at 0 ms) that agreed (black line) or disagreed (gray line) with the null subject in subject control items. Negative voltage is plotted up.

with verb type (SC vs. OC), grammaticality (grammatical vs. ungrammatical), hemisphere (left vs. right), and region (anterior vs. central vs. posterior) as factors. The six electrodes chosen for the two levels of the factor hemisphere were: F3/C3/P3 vs. F4/C4/P4. The three levels of the factor region were: anterior (F3/F4), central (C3/C4), and posterior (P3/P4).

2.2. Results

Figs. 1 and 2 display the grand average ERP elicited by the critical adjective in SC- and OC-items, respectively. As can be seen from the figures, ERPs in the ungrammatical conditions are more positive-going between 500 and 900 ms compared to their grammatical counterparts. Both in SC- and OC-items, adjectives disagreeing in gender with the antecedent of PRO elicited a monophasic response with a positivity widely distributed over central and posterior regions of both hemispheres.

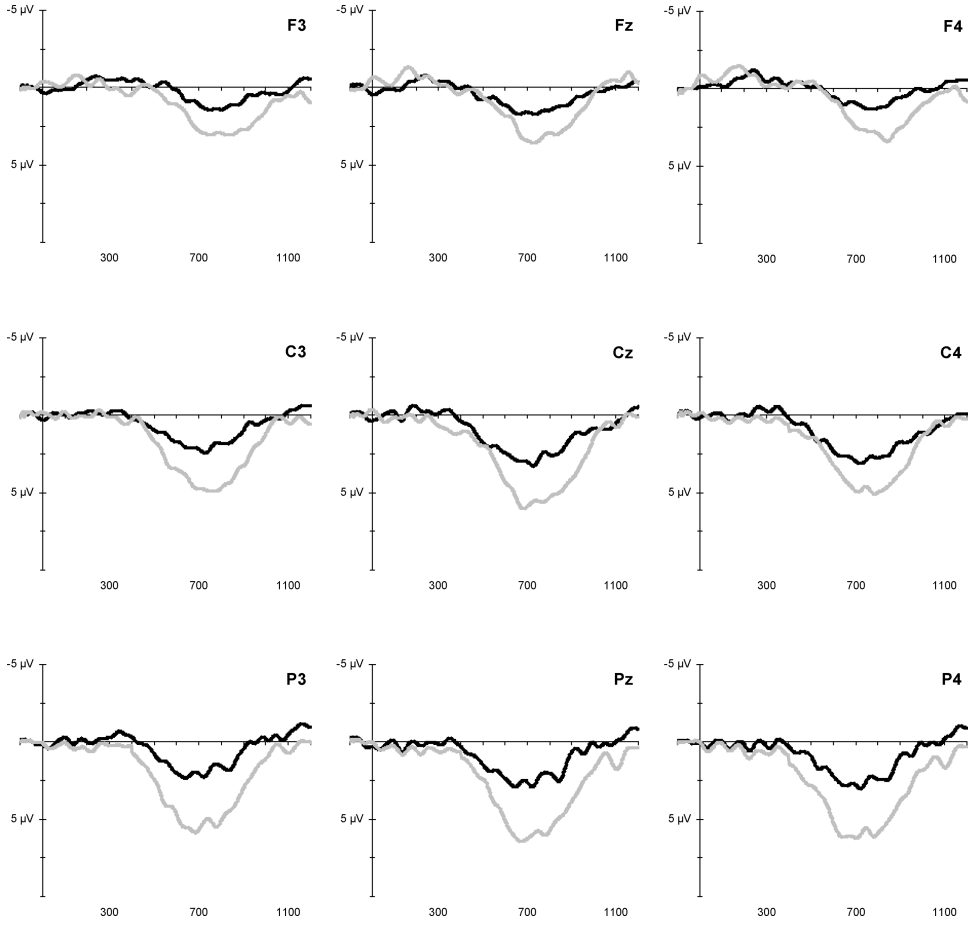

Fig. 2. Grand average ERPs (N = 16) to adjectives (onset at 0 ms) that agreed (black line) or disagreed (gray line) with the null subject in object control items. Negative voltage is plotted up.

2.2.1. Statistical analyses

250–400 ms: The MANOVA performed on the midline electrodes revealed a marginal main effect of electrode ($F(2, 30) = 3.07$, $p = .061$) reflecting the fact that at the anterior electrode the ERP was more negative-going than at the other two midline electrodes. No other main effects or interactions approached significance. The MANOVA performed on the lateral electrodes revealed a main effect of region ($F(2, 30) = 4.83$, $p < .05$), indicating that the ERP was more negative in the frontal electrodes as compared to central and posterior sites. No other main effects or interactions approached significance.

500–900 ms: Over midline electrode sites, the MANOVA revealed main effects of grammaticality ($F(1, 15) = 9.57$, $p < .01$) and of electrode ($F(2, 30) = 20.21$, $p < .001$). Ungrammatical sentences elicited a more positive-going ERP as compared to that elicited by their grammatical counterparts. The main effect of electrode indicated that at the anterior electrode the ERP was less positive-going than at the other two midline electrodes. No other

main effects or interactions approached significance. To further analyze the main effect of grammaticality we performed a separate analysis for each midline electrode. At Fz, the main effect of grammaticality was marginally significant ($F(1,15) = 3.68$, $p = .07$). At Cz, ERPs elicited by ungrammatical adjectives were reliably more positive-going than those elicited by the same words in grammatical sentences ($F(1, 15) = 6.03$, $p < .05$). At Pz, the analysis revealed a highly significant main effect of grammaticality ($F(1, 15) = 15.96$, $p < .005$). The analyses performed at these three midline electrodes showed that the main effect of verb type as well as the interaction between verb type and grammaticality were not reliable.

The MANOVA performed on the lateral electrode sites revealed a marginal main effect of grammaticality ($F(1,15) = 3.9$, $p = .06$). There was also a main effect of region ($F(2, 30) = 35.6$, $p < .001$), indicating that at central and posterior sites the ERP was more positive-going than at anterior sites. We found an interaction between grammaticality and region ($F(2, 30) = 4.95$, $p < .01$). No other main effects or interactions approached significance.

To further analyze the effect of grammaticality we conducted two other analyses. We first conducted a separate analysis at the anterior region; the MANOVA revealed neither main effects (of grammaticality, hemisphere and verb type), nor interactions. The second analyses aimed to examine the differences between central and posterior regions. The MANOVA showed main effects of grammaticality ($F(1,15) = 5.92$, $p < .05$) and of region ($F(1,15) = 4.8$, $p < .05$), as well as an interaction between these two factors ($F(2, 30) = 7.52$, $p < .05$). This interaction reflects that the differences between the ERPs elicited by ungrammatical adjectives and the ERPs elicited by their grammatical counterparts were bigger at posterior sites than at central electrodes. No other main effects or interactions approached significance.

3. Discussion

The most salient and consistent result of this experiment is that ungrammatical sentences were associated with a positive-going wave similar to the one reported in previous studies on ERPs and gender agreement violations; this positive wave clearly differs from the brain response elicited by semantic anomalies. Both in SC- and OC-items, adjectives that did not agree in gender with the controller of PRO elicited a P600 effect. No sign of the MRFS, that is, no interaction between *grammaticality* and *type of verb*, was observed at the word (i.e., the one that immediately follows the infinitive) we have examined.

The present study investigated the brain responses to NP-adjective gender agreement violations in controlled infinitival complements in spoken sentences in Spanish. It has been shown that antecedent assignment to a null subject can be studied by manipulating the gender features of words with which the null subject must agree. For a gender agreement violation to be detected, the language comprehension system has to identify the empty position and associate the null subject with a lexically specified phrase in argument position in the higher clause. Given that the implicit subject of an infinitive verb inherits its gender from its controller, then if the brain detects a failure of gender agreement, we may infer that PRO has been assigned its proper antecedent by the time the adjective is processed. The brain's sensitivity to such violations indicates that the comprehension system has detected the null subject of the infinitive and that it has been rapidly and correctly associated with a lexically specified phrase in the higher clause. Moreover, the electrophysiological differences between

grammatical and ungrammatical sentences in SC- and OC-items imply the rapid use of verb control information.

The results presented here seem to indicate that the parser rapidly uses information (other than syntactic category) stored at a verb's lexical entry. In order to detect the anomalies we have examined, the processor must access the information that specifies the control properties of the matrix verb. If the system were not using such information until a later stage, but following a heuristic such as the MRFS, then one would expect a syntactic anomaly effect (P600) in response to adjectives that do not agree in gender with the most recent NP (i.e., the object); that is, ungrammatical adjectives in OC-items, and, most importantly, grammatical adjectives in SC-items should elicit a P600. Given that the only reliable effect was that of grammaticality, we may conclude that the parser has already accessed verb control information when it processes the word immediately following the infinitive. This seems to suggest that the initial coindexing decision is guided by such verb-specific information. An alternative explanation would be that the initial coindexing decision is made following the MRFS (that is, ignoring verb control information), and that at the critical word (i.e., the adjective) the parser has already accessed verb control information and checked (and corrected, if necessary) the initial assignment. A convenient way to contrast these two explanations (immediate or delayed use of control information) would be to envisage an experimental design with sentences in which the critical region would be the infinitive, and not the word immediately following it. In other words, it would be convenient (if possible) to construct ungrammatical sentences by creating a (e.g., gender, number, or person) clash at the infinitive region. In Spanish, this could be done by attaching to the infinitive a clitic pronoun that has to obligatorily agree (or disagree) with PRO and with the antecedent assigned to it.

In summary, we have provided new ERP data that show that subjects rapidly interpret the referential dependency between a phonologically null element and a lexically specified phrase, and, most remarkably, that control information has a very rapid influence on the process of selecting an antecedent for such a null subject. The data we have reported are congruent with theories of sentence processing (e.g., lexicalist parsing models; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994) that assume the rapid influence of verb-specific information on the early stages of parsing. Furthermore, we have contributed to the demonstration, begun by Friederici, Pfeifer, and Hahne (1993) and Holcomb and Neville (1991), of the feasibility of doing ERP studies using continuous, natural speech as the stimulus materials.

Notes

1. We use the term PRO without commitment to any particular theory of grammar, but rather as an expository label for the implicit subject of an infinitival verb. Our aim is not to study the status of PRO as a grammatical construct nor to examine its psychological reality, but to address the question of when the language processor assigns an antecedent to the implicit subject of an infinitival complement.
2. Frazier et al. (1983) would then predict that—both in 1a and 1b—the parser initially selects the object (i.e., the less distant NP) of the main verb as the antecedent of PRO. At

a later stage of processing, verb control information becomes available and, if necessary, the parser corrects its initial assignment.

3. Whereas Frazier et al. (1983) used sentences with a relative clause ("This is the girl the teacher decided to talk to"), Boland et al. (1990) used wh-questions ("Which grandson did the grandma attempt to guide toward the pony?").
4. They used two-argument SC- and three-argument OC-verbs in sentences such as "Which grandson$_i$ did the grandma$_j$ attempt PRO$_j$ to guide t_i toward the pony?" and "Which grandson$_i$ did the grandma encourage t_i PRO$_i$ to guide the pony away?, respectively. As can be seen, both in SC- and OC-sentences PRO had to be interpreted as coreferent with the most recent NP (the subject of *attempt* in the SC-example, and the object of *encourage*, which happens to be a trace, in the OC-example).

Acknowledgements

The present research was partially supported by project grants (BSO2000-1252 and BSO2003-04854) from the Spanish Ministry of Science and Technology. We want to thank Andreu Vigil for his support in data acquisition.

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