ELSEVIER

Cognitive Brain Research 11 (2001) 47–58

COGNITIVE BRAIN RESEARCH

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Research report

Event-related brain responses to morphological violations in Catalan

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Accepted 19 September 2000

Abstract

The ERP (event-related potential) violation paradigm was used to investigate brain responses to morphologically correct and incorrect verb forms of Catalan. Violations of stem formation and inflectional processes were examined in separate experimental conditions. Our most interesting finding is that misapplications of stem formation rules elicit an early left preponderant negativity. This complements our previous ERP results on morphological violations in other languages in which misapplications of inflectional rules were shown to produce such effects. We make use of the linguistic distinction between lexically stored and rule-based word forms and suggest a unified interpretation of the experimental results, arguing that these negativities vary as a function of processes involved in morpho-syntactic structure building.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Event-related potential; Morphology; Catalan; Left anterior negativity; P600

1. Introduction

Many languages distinguish between inflected words that follow a regular pattern (e.g. English past tense: *play⇒played*, German past tense: *spielen⇒spielte*) and inflected words that are irregular (e.g. *catch⇒caught*, German: *fangen⇒fing*). The mental representation and processing of regular and irregular inflection and the corresponding brain processes have been the subject of a recent debate that involves complex theoretical arguments which are beyond the scope of the present study; for reviews see [2,22]. In broad terms, however, two competing classes of theories can be distinguished. The dual-mechanism perspective [35,2,21] adopts the linguistic view of a separation of the language faculty into a system responsible for grammatical computations and a lexicon. According to a dual-mechanism view of morphological processing, regular words are computed by applying a rule; in English past-tense formation, for example, by concatenating a stem *play* and a past-tense suffix *-ed*. Irregular forms, on the other hand, have to be retrieved from a lexicon that is associatively structured.

By contrast, associative single-mechanism models of inflection claim that all inflected word forms are listed and that associative mechanisms can simulate rule-like linguistic behavior. Connectionist models of the English past tense, for example, are based on the idea that regular and irregular past-tense forms are represented and processed like simple words, through associatively linked orthographic, phonological and semantic codes and in terms of activation patterns over units and weighted connections between them ([37] among others). Both models have different implications for understanding the knowledge and use of language in general and extend beyond the realm of inflectional morphology proper (see [8,19] for discussion). Recently, several studies using functional imaging [15,16],

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0926-6410/01/$ – see front matter
PII: S0926-6410(00)00063-X

data from patients with neurological disease [38], and event-related brain potentials [26] have tested predictions derived from the two competing models. Still, the debate is far from settled and there is no consensus as to what kind of data can be used to falsify one of the theories (see commentaries to [2]). Moreover, in terms of the brain processes involved, both classes of theory have to be further elaborated [28].

Despite the considerable number of studies, in particular on English and German, there are many reasons to conduct research on single versus dual-mechanism models of inflection over a wider range of languages. A major motivation here is that both English and German belong to the same language family–Germanic, so that any generalizations emerging from these languages may well be due to the specific characteristics of this family and not to truly universal properties of language. In the present investigation, our main aim is to add to previous findings by applying the ERP technique to Catalan, and in so doing to extend research on the neuroscience of morphology into the Romance languages. Apart from having a much richer verbal morphology than either English or German, Catalan presents a further interesting dimension, the presence of morphological classes or conjugations, and it is not immediately clear how current psycholinguistic models of inflection might account for such a system.

2. Previous ERP research on inflectional morphology

Over the past 20 years a wealth of ERP data on language tasks has been accumulated. Of particular relevance for the present investigation are findings obtained in studies of syntax and morphology. Here, two ERP components, a Left Anterior Negativity (LAN) with a latency of about 300 ms and a parietal positivity with a variable latency of around 600 ms (labeled Syntactic Positive Shift 'SPS' or P600) have emerged. The exact functional properties of both components are still controversial. For example, left anterior negativities have been found for perfectly grammatical stimuli taxing working memory [17] in addition to different kinds of morpho-syntactic [25,13] violations. Consequently, different theoretical accounts have been offered regarding the LAN; see [9] for review. Furthermore, it has to be pointed out, that in some experiments the distribution of the 'LAN' extended towards medial and posterior temporal sites (e.g. [25]) and it has been suggested that probably two (or more) components with a similar, albeit not identical, topography might account for the discrepancies in the literature; see [18] for further details. Likewise, while the SPS/P600 has been obtained for morpho-syntactic and several other types of syntactic violations as well as for so-called garden-path sentences, its specificity regarding syntactic processing [27] as well as language processing in general [6,7] has been questioned. In the remainder of the paper, we will call this effect P600, as this is more neutral with regard to the implicated underlying processes.

Replicable ERP effects have also been found in studies of inflectional morphology, in German, English and Italian. The results obtained, however, do not yet provide a coherent picture.

2.1. German

In previous ERP studies on German [34,40], a morphological violation paradigm has been used in which the brain responses to correctly formed complex words were compared to brain responses for words that were formed using an incorrect suffix. In German, the incorrect forms of irregular verbs (e.g. **gelauft* instead of the correct *gelaufen*-'run-past participle') and noun plurals (e.g. **Muskels* instead of the correct *Muskeln* 'muscles') gave rise to a left anterior negativity relative to correct forms. This effect was not present for violations of regular words, e.g. in **gekaufen* instead of the correct *gekauft*. These studies showed a clear dissociation of regular and irregular words in the violation paradigm and were therefore interpreted as favouring a dual-mechanism account of morphological processing.

2.2. English

The ERP violation paradigm has also been used to investigate past-tense formation in English [29]. A left anterior negativity was elicited for violations of regular inflection (*Yesterday I *slip on ice*), and a left posterior negativity for violations of irregular inflections (*Yesterday I sleep in bed*) which was interpreted as support for the dual-mechanism model of inflection. From a linguistic perspective, however, this interpretation is not entirely convincing. Note that in purely morphological terms there is nothing odd or wrong with the verb forms presented in this study (e.g. *slip, sleep*). Rather, the incorrectness results from a *syntactic* violation at the sentential level, caused by present-tense forms (*slip, sleep*) occurring in sentences with past-tense meanings (*Yesterday, I *slip on ice).* Hence, it is not clear to what extent the ERP effects elicited in this study are caused by purely morphological and/or syntactic violations.

2.3. Italian

In a recent study on Italian using the ERP violation paradigm [12], a negativity was found for overapplications of regular inflection to verbs that take irregular participle forms, e.g. **prend-a-to* instead of *preso* 'taken' (from *prendere* 'to take'). Even though this finding is similar to the negativities obtained for German plurals and participles, the scalp distribution of the negativities in the Italian study turned out to be different from those found in German. In the Italian ERP experiment, overapplications of regular inflection produced a negativity which was most pronounced at the midline and parasagittal electrode sets (Fz, Pz and Cz). In the German studies, effects were also found at these sites, but the most pronounced effects were found at the left anterior site (F7). It is not clear how these differences are to be explained.

Moreover, recently presented behavioural data [30,31] have been claimed to provide evidence against the applicability of dual-mechanism models to Italian. This claim, however, is not borne out, since in these studies an important linguistic property of Italian word formation has not been taken into account, namely, the distinction between stem formation and inflectional affixation. In the priming experiment reported in [30], for example, the group of verbs classified as 'regular' included both 1st and 3rd conjugation verbs, classes which have independently been shown to exhibit divergent generalization properties [39]. Thus, one would have to tease apart 1st and 3rd conjugation stem forms, in order to see potential regular/irregular distinctions in priming more clearly. A reanalysis of the data from Italian child language presented in [31] in which stem formation and inflectional processes were properly distinguished [39] has shown that Italian children generalize regular patterns to irregular items, but that generalization of irregular patterns to regular verbs is rare or nonexistent. Moreover, similarity and frequency effects were found only for irregular, but not for regularly inflected, verb forms. These results are parallel to those from acquisition studies of the English past tense [20] and of German inflection [3,4].

3. The present study

In order to test the generalizability of previous ERP findings on regular and irregular inflection, we have investigated Catalan, a member of the Romance group of the Italic branch of the Indo-European language family, using an ERP violation paradigm. Catalan, with about eight million native speakers, is mainly spoken in the eastern and north-eastern part of Spain and the Balearic islands, as well as in the eastern Pyrenean region of France [5]. An important property of Catalan (as indeed of all Romance languages) is that inflection is stem-based, whereas in English it is largely word-based. In English, regular verbs (and nouns) have just one single uninflected base form, e.g. *walk, rat*, etc., which is not further decomposable, and constitutes a perfectly legal word to which inflectional affixes are directly attached, yielding forms such as *walked* or *rats*. In Catalan, however, inflected verb forms have a more complex internal structure. Regular inflectional affixes typically combine with stems, and stems are further decomposable into a root and a thematic vowel. The participle form *caminat*, for instance, of the verb *caminar* 'to walk' consists of three components, the root *camin*-(which carries semantic information and appears in the noun *camí* 'way-sing.', *camins* 'way-plur.' as well), the theme vowel -*a*-(which indicates conjugation class membership) and the inflectional ending -*t* (which marks the verb form as a participle). Thus, in examining Catalan verb forms, we need to study both stem formation and inflectional processes.

With respect to *stem formation*, Catalan has three morphological classes, or conjugations, identified by thematic vowels (TV) which appear between the verb root and the inflectional endings[1]. First conjugation verbs have the tv -*a*-, e.g. *cant*-***a***-*r* 'to sing', second conjugation verbs have the TV-*e*-[2], e.g. tém-**e**-r 'to fear', and third conjugation -*i*-, e.g. *dorm*-***i***-*r* 'to sleep'. The first conjugation represents the largest class of verbs. The third conjugation has by far fewer members, and is mostly regular. According to [10], the *Diccionari General de la Llengua Catalana* contains about 4500 current verbs, out of which 3500 belong to the 1st conjugation and 700 to the 3rd. The second conjugation has even fewer members than the third, which are for the most part irregular. Irregular stems are phonologically modified and do not have a TV, e.g. *après* from the verb *aprendre* 'to learn'.

In the linguistic literature on Catalan [23], it has been argued that the 1st and 3rd conjugations are productive, due to their frequency compared to the 2nd conjugation. However, the generalization properties of 1st and 3rd conjugation are quite different. While there is a restricted class of derived verbs in the 3rd conjugation (e.g. *enfortir, espessir*), the 1st conjugation exhibits unrestricted generalizability. Any kind of phonological shape can form a 1st conjugation stem, and neologisms and foreign loan words, for example, all fall into this class; the English word *'to print'*, for example, can come out as print*at* or print*ejat* as a Catalan participle. First conjugation verb roots are also phonologically heterogeneous[3]. These observations suggest that the first conjugation is the only default class. Thus, from a dual-mechanism perspective, one might hypothesize that 1st conjugation stem formation

[1]Traditionally, the second and third conjugations are divided into two groups each, IIa represented, for example, by *perdre* 'to loose', IIb by *témer* 'to fear', IIIa by *servir* 'to serve' and IIIb by *dormir* 'to sleep' [1,11]. In the past participle, though, both groups of verbs in the second and third conjugations follow one single pattern. Accordingly, we will not further distinguish between subgroups of 2nd and 3rd conjugation verbs.

[2]The character 'e' is meant here orthographically and not phonetically. It is pronounced in different ways, depending on the linguistic environment and the dialect area. In the present study, we are not considering pronunciation, but rather rely on visual stimuli.

[3]By contrast, several of the regular 2nd conjugation verbs end in -*tre* (e.g. *batre*), in -*ldre* (e.g. *caldre*) and -*rdre* (e.g. *perdre*), and many of the 2nd conjugation irregular verbs end in -*ndre* (e.g. *defendre*) or in -*tre* (e.g. compound forms with *metre*: *trametre permetre, ometre, cometre, sotmetre*). In the 2nd conjugation, there are also verbs ending in -V(owel)+*ure* (e.g. *caure*). Thus, an important subset of 2nd conjugation verbs is phonologically constrained, by exhibiting a relatively fixed phonological pattern (i.e. a vowel followed by a sonorant, either a liquid, a nasal or a glide, followed by the coronal/d/or/t/), preceding the infinitive ending -*re*. For the 1st conjugation, there are no such patterns.

is rule-based, whereas 2nd and 3rd conjugation stems are lexically stored, paralleling the differences between regular and irregular inflection. The 1st conjugation stem formation rule (*Add -a-*) would apply to any verbal root in Catalan to form a regular stem. Like any other default rule, it would apply unless blocked by some listed (2nd or 3rd conjugation) stem. The rule operates on any root belonging to the syntactic category [+V], and would not be constrained by phonological properties. In contrast to 1st conjugation stems, 2nd and 3rd conjugation stems might not be rule-based, but rather stored in the lexicon. This would account for the fact that 2nd and 3rd conjugation stems exhibit restricted generalizability and do not apply under default circumstances. In the experiment to be reported below, we will examine stem formation in Catalan with respect to these differences.

The *inflection* of participles is linguistically independent of conjugation class. What matters here is the distinction between regular and irregular inflection. Regularly inflected past participles are formed by adding the participial suffix *-t* to the verb stem[4], irrespective of conjugation class. Irregular past participles are characterized by phonologically modified stems, absence of the TV, and one or other of the endings *-s* or -s*t*. Examples are given in Appendix A. In addition to truly irregular participle forms such as those listed in Appendix A, there is a group of 2nd conjugation verbs that have modified stems, but are still affixed with the regular *-t* participle ending; cf. for example, *tem-u-t* from *témer* 'to fear', *creg-u-t* from *creure* 'to believe', the latter illustrating the so-called velar increment (*-g-*) added to the root. These are similar to the semi-regular or mixed verbs of English and German (*feel-fel-t, keep-kep-t*). Some verbs in the 2nd conjugation have doublets with the prescriptively correct form in —*u-t* and a non-standard form with —g-u-t (*saber* 'know', *sab-u-t*/*sapig-u-t*). In some dialects, for instance in Balearic, this velar increment has been extended to further verb forms.

Clearly, the advantage of studying the verbal system of a Romance language such as Catalan is that we can examine the potential distinction between rule-based and associatively-based representations of language not only for inflection (as in English and German), but also for stem formation. In the light of previous results on morphological violations, separate predictions can be made for stem formation and for inflection:

1. For violations of inflectional rules, a LAN should be present for overapplications of *-t* participle affixation to verbs that have irregular participle forms, e.g. **admetat* instead of *admès*.
2. With respect to stem formation, a LAN is expected in cases in which the inflectional ending is correct, but the *-a*-stem formation rule of the 1st conjugation has been overapplied to a 2nd or a 3rd conjugation verb, e.g. **dorm-a-t* instead of *dorm-i-t* or **tem-a-t* instead of *tem-u-t*.
3. If 3rd conjugation stem formation were rule-based as well, a LAN would be expected in cases in which the inflectional ending is correct, but the *-i*-of the 3rd conjugation has been overapplied to a 1st conjugation verb, e.g. **cant-i-t* instead of *cant-a-t*.

In this way, the study of Catalan allows us to distinguish between a narrow model of the LAN and a linguistically less specific interpretation of the LAN. If prediction (1) holds, but (2) and/or (3) do not, this would provide support for a narrow interpretation of the LAN, indicating that it is sensitive only to violations of inflectional rules. If predictions (2) and/or (3) can be confirmed, this would indicate that the LAN is sensitive to violations of morphological structure-building in more general terms, i.e. to violations of inflectional rules as well as to violations of stem formation rules. We have also investigated overapplications of 3rd conjugation stems to 1st conjugation verbs, e.g. **cant-i-t* instead of *cant-a-t*, 'sung', in order to determine whether 3rd conjugation stem formation is rule-based. If this is the case, a LAN effect is expected to occur in cases in which *-i*-stems are overapplied. In this way, our results will shed light on the question as to whether 1st and 3rd conjugation stem formation involves rule-based mechanisms in Catalan.

With regard to the P600 we do not make any predictions. Previous investigations conducted on German surprisingly had not produced a P600 for morphological violations. However, the analysis epoch in these experiments was confined to 900 ms poststimulus. In order to allow for a more detailed analysis of morphological violations with respect to the P600, it was decided to analyze ERPs for a two-second epoch in the present study.

4. Method

4.1. Subjects

Eighteen native Catalan speakers participated in the present experiment (age range 20–29 years). Three subjects were rejected because of excessive blinking artifacts. All participants gave informed consent and were paid for participation. All the subjects were high proficiency bilingual speakers of Catalan and Spanish. Fourteen subjects had been exposed to Catalan from birth on and had used Catalan at home during childhood either exclusively or in conjunction with Spanish. The other four subjects had a

[4]The participial suffix alternates between *-t* in the masculine and *-d*-in the feminine. This alternation is an orthographic reflex of the general phonological process of final devoicing of obstruents, which also affects masculine participles. In order to avoid this problem, we presented all stimuli in the masculine form of the participle.

high proficiency in speaking and writing Catalan although they had been exposed to Spanish first.

4.2. Design

A violation paradigm was chosen similar to the one used in previous studies on German participles [34]. Correct and incorrect forms of the past participle were embedded within short stories. The stem violations of the first conjugation were created using the 3rd conjugation pattern (replacing the correct theme vowel *-a-* with *-i-*), while maintaining the correct inflectional suffix *-t*. For 2nd and 3rd conjugation verbs, stem violations were created by replacing the correct theme vowels with the 1st conjugation form *-a-*. Inflectional violations were created by using the root followed by the TV of the 1st conjugation plus the regular *-t* participle affix for 2nd conjugation verbs with irregular participle forms in Catalan. Thus, the following conditions were used:

	Infinitive	Correct participle	Incorrect participle
1st, regular	*cantar*	*cantat*	*cantit*
2nd, regular	*témer*	*temut*	*temat*
2nd, irregular	*admetre*	*admès*	*admetat*
3rd, regular	*dormir*	*dormit*	*dormat*

As is clear from this table, the incorrect participle forms in all conditions involved stem errors, but only the irregular condition involved an (additional) inflectional error. In this way, effects resulting from inflectional violations can be teased apart from effects of stem errors.

A list of 50 participles (masculine form) was created for each of the four conditions. Each of these critical words was presented twice within the stories, once in the correct form and once in the incorrect form. The order of presentation of correct and incorrect forms was counterbalanced between subjects. Thus, half of the subjects saw the correct form of the participle first, and the other half saw the incorrect form first. Stories were presented word-by-word (duration 300 ms, stimulus onset asynchrony 500 ms) in the middle of the screen of a video-monitor in yellow letters against a blue background (1.5 degrees of visual angle). An interval of three s separated two consecutive sentences. A fixation dot was present in the centre of the screen during the entire experiment. Critical verbs in the four conditions were matched for frequency [36] as best as possible, yielding the following mean frequencies (per million words) for past participles: 1st conj.=5.24 (mean length correct forms: 7.6, incorrect: 7.6), 3rd conj.=4.6 (length correct: 7.6, incorrect: 7.6), 2nd irreg.=5.2 (length correct: 6.2, incorrect: 8), and 2nd reg.=8.23 (length correct: 7.9, incorrect: 8). The 2nd regular condition could not be matched exactly due to the presence of high frequency verbs and the low overall number of regular verbs in this conjugation.

An experimental session lasted about an hour and a half. Subjects were told that the main purpose of the experiment was to test their memory and after each of the stories they received a questionnaire with simple questions pertaining to the contents of the story. In all cases the performance on this questionnaire was nearly perfect.

4.3. Paper-and-pencil test

A paper and pencil test was designed to further test the materials used in the ERP experiment. A set of 50 sentences, each approximately 10 words in length was created for each morphological class. Each sentence had the following structure: Subject+Auxiliary+Verb (=incorrect past participle form)+Verb complements (=direct or indirect object, or prepositional). Subjects were required to read the sentences and to write down the infinitive form of the (incorrect) participle as quickly as possible in a space provided on the sheet. All sets had the same number of words (518 words) and the same number of characters (1883). Mean time spent for processing each set of sentences and number of errors were computed for each conjugation. Order of administration of the set of sentences of each conjugation was counterbalanced using a Latin square design. Eight subjects participated in this test. After completion of the sentence test, subjects assessed the extent to which each incorrect form used in the experiment ‘sounded familiar’ to them on a 7 point Likert-type scale.

4.4. Psychophysiological recording

The electroencephalogram (EEG) was recorded from the scalp using tin electrodes mounted in an elastic cap (Electro-Cap International) and located at 29 standard scalp locations (Fz, Cz, Pz, Fp1/2, F3/4, Fc1/2, C3/4, Cp1/2, P3/4, O1/2, F7/8, FC5/6, T3/4, T5/6, Cp5/6, PO1/2). All scalp-electrodes were rereferenced off-line to the average of both mastoids. Vertical eye movements were monitored with an electrode below the right eye (vertical EOG). All electrode impedances (EEG and EOG) were kept below 5 kOhm. The electrophysiological signals were filtered with a bandpass of 0.01–70 Hz (half-amplitude cutoffs) and digitized at a rate of 250 Hz. Trials in which either base-to-peak electrooculogram (EOG) amplitude exceeded 75 μV, or amplifier saturation occurred, or the baseline shift exceeded 200 μV/s, were automatically rejected off-line (mean percentage of rejection was 27.2%). The EEG signal was averaged separately for each condition for epochs of 2048 ms including a 100 ms pre-stimulus baseline. The resulting waveforms were quantified by mean-amplitude measures in three time windows, 300–550 ms, 750–1000 ms and 1000–1250 ms, to the main effects seen upon visual inspection and corresponding to what has been reported in previous studies

[25,33]. These windows were designed to encompass the Left Anterior Negativity (LAN, early time window) and the P600 (two late windows). Data were subjected to repeated measures analyses of variance applied to different scalp locations: midline (ML; Fz, Cz, Pz), parasagittal (PS; Fp1/2, F3/4, C3/4, P3/4, O1/2) and temporal (TE; F7/8, T3/4, T5/6), including electrode Site as a factor (anterior to posterior, ML and TE: 3 levels, PS: 5 levels) and Hemisphere (left vs. right, PS and TE only). First, an overall ANOVA was conducted with Morphological Condition (levels: 1st reg. 2nd irreg. 3rd reg. and 2nd reg.), Correctness (levels: correct, incorrect), Hemisphere and Site as factors. As significant Condition×Correctness interactions emerged in the overall ANOVA, it was followed up by separate analyses for each morphological condition in order to clarify the complex pattern of results.

All ERP waveforms displayed in the corresponding figures were digitally filtered using a low-pass filter with a 6 Hz half-power cutoff. However, mean amplitudes used in all the statistical analyses reported were computed with unfiltered waveforms. For all statistical effects involving two or more degrees of freedom in the numerator, the Huynh–Feldt epsilon was used and the exact P-value after correction is shown below. All tests involving Electrode× Condition interactions were corrected prior to analysis using the vector normalization procedure [24].

5. Results

5.1. Paper-and-pencil test

The incorrect forms of the 1st and 3rd conjugations were processed faster than both regular and irregular 2nd conjugation forms. The required mean times (with SDs) for extracting the infinitive forms from the incorrect participle in each condition were: 1st reg.=2.9±0.2 min.; 3rd reg.= 3.2±0.5 min.; 2nd irreg.=4.1±1.2 min. and 2nd reg.= 4.2±0.7 min. A main effect of morphological condition was found ($F(3,21)=10.9$, $P<0.003$). Pairwise comparisons indicated no significant difference between 1st and 3rd conjugation verbs ($t(7)=-2.35$), and again no significant difference between the regular and irregular 2nd conjugation forms ($t(7)=-0.39$). All other planned pairwise comparisons were significant ($t(7)>2.48$, $P<0.042$). There was a non-significant trend for the sound familiarity to be better for 1st and 3rd conjugation forms: 1st reg.= 4.5±1.3; 3rd reg.=4.2±1.7; 2nd irreg.=3.9±1.2 and 2nd reg.=3.8±1.5 ($F(3,21)=3.3$, $P<0.074$ after epsilon correction).

5.2. ERP data

For a general impression of the ERPs obtained in the current task, consider Fig. 1 which presents the grand-average ERPs for the correct and incorrect participle forms collapsed for all conjugations. The corresponding averages of all conditions are shown in Fig. 2 for selected electrode sites. Waveforms are characterized by an initial negativity resolving in a large anterior P200 component[5]. The main statistical results from a set of omnibus ANOVAs with all 4 conjugation conditions as levels of one factor can be found in Table 1. In the following, however, effects of correctness will be discussed for each conjugation separately and respective statistical analyses will be supplied (see Table 2).

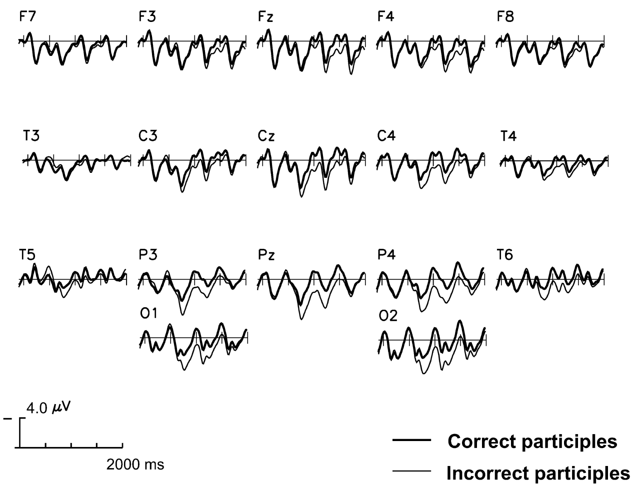

Fig. 1. Grand average ($N=15$) of an extended epoch (2100 ms) including three words after the critical word (SOA 500 ms). Correct and incorrect participles waves collapsed for all conjugations. A significant effect was obtained for the increased negativity observed around 300–550 ms in incorrect participles (LAN). At the range of 750–1000 ms, incorrect forms manifested an increased positivity (P600).

The first differences between correct and incorrect participles emerged at about 300 ms. An additional negativity for the incorrect words was observed for the 2nd regular (TE: $F(1,14)=5.5$, $P<0.034$, PS: $F(1,14)=4.7$, $P<0.05$) and for the 3rd regular condition (TE: $F(1,14)=5.9$, $P<0.028$). As illustrated by the isovoltage maps (Fig. 3) using spherical spline interpolation of the difference waves (incorrect-correct participles), this negativity shows a left-sided distribution with a maximum over medial temporal sites[6]. There was no such correctness effect for the two other conditions, i.e. 1st regular and 2nd irregular ($F<1$). A second effect differentiating incorrect and

[5]The differences in the early exogenous components were related mainly to differences in the physical characteristics of the stimuli presented. In the correct forms of the irregular 2nd conjugation, for example, the latency peak of the P200 component appears earlier than in the incorrect forms, and this is likely to be due to the fact that the correct irregular form (e.g. *admès*) is physically shorter than the incorrect one (e.g. *admetat*).

[6]There was also a very focal (F8) extended negativity in the second regular condition. Post-hoc tests (correct vs. incorrect, tested on F8 only) revealed that it was significant ($P<0.05$). At present, we do not have an explanation for this unexpected effect and therefore will not discuss it further.

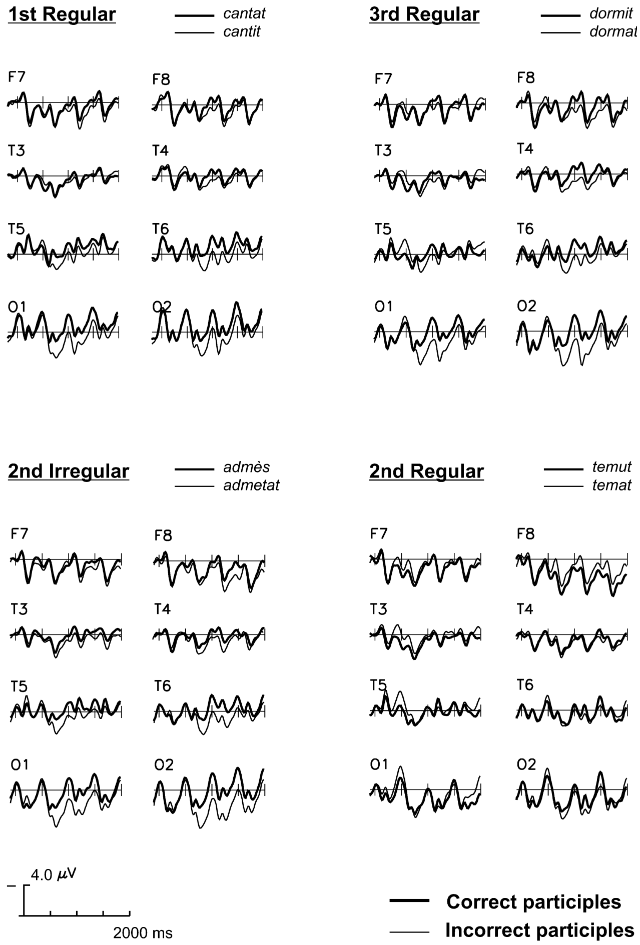

Fig. 2. Grand averages for correct and incorrect participle forms in four experimental conditions.

correct participles is an increased positivity for the incorrect words starting around 600 ms and continuing throughout the following two words (Fig. 2). The morphology and the distribution of this component resembles that of the previously reported P600 [14,33]. Significant effects were obtained for 1st regular, 3rd regular and 2nd irregular for this positivity (either for both time-windows or for the 1000–1250 ms time—window only—see Table 2). Even though inspection of the data suggested the presence of a small late positivity in the 2nd regular condition, this was not confirmed upon statistical analysis (again, see Table 2).

6. Discussion

The purpose of the present study was to investigate brain responses to morphologically correct and incorrect verb forms of Catalan in the light of the theoretical controversy between associative single-mechanism models and dual-mechanism models of morphological processing. The particular advantage of studying Catalan is that the distinction between rule-based and storage-based representations of morphologically complex words that is posited in the dual-mechanism model can not only be examined for inflection (as in English and German), but also for stem formation. The main results can be summarized in three points. First, we found that violations of stem formation rules elicited an early left preponderant negativity. Second, in contrast to stem formation processes, misapplications of the participle inflection rule did not produce a negativity in Catalan. Third, for both kinds of violations we obtained a P600 component. In the following, the experimental results for stem violations and for violations of inflectional processes will be discussed separately

6.1. ERPs to stem violations

The most interesting finding of the present investigation was a left sided negativity for stem violations. LAN effects were seen for overapplications of the default 1st conjugation theme vowel *-a-*to a verb form that requires a 2nd or

Table 1
Summary of overall ANOVAs[a]

	Correctness	MC×C	C×Hem	C×Ant	C×H×A	MC×C×H	MC×C×A	MC×C×H×A
	F=, *P*<	*F*=, *P*<	*F*=, *P*<	*F*=, *P*<	*F*=, *P*<	*F*=, *P*<	*F*=, *P*<	*F*=, *P*<
LAN								
Midline		3.1[c] *0.04*	n.a.		n.a.	n.a.	2.3[e] *0.05*	n.a.
Parasag.		3.0[c] *0.04*			3.6[d] *0.02*	3.2[c] *0.03*		
Temporal	5.9[a] *0.03*							
P600								
Midline	12.0[a] *0.01*		n.a.	22.7[b] *0.001*	n.a.	n.a.		n.a.
Parasag.	10.2[a] *0.01*	2.9[c] *0.05*	8.5[a] *0.02*	17.9[d] *0.001*				2.0[f] *0.03*
Temporal	5.6[a] *0.05*			15.8[d] *0.001*				

[a] Notes: 'MC'=Morphological Condition (1st regular, 2nd irregular, 3rd regular, 2nd regular), 'C'=Correctness (Correct vs. Incorrect forms), 'H'=Hemisphere, 'A'=Anterior-Posterior line of electrode locations. In columns containing the symbol 'x', interactions between factors are tested. Huynh–Feldt epsilon applied when it was pertinent and all the interactions that comprise the factors 'H' or 'A' have been normalized. LAN=Left Anterior Negativity (time window 300–550 ms) and P600=Syntactic Positive Shift (750–1000 ms). Blank cells in the Table were not significant ($P>.05$); Main 'H' or 'A' effects were omitted; n.a.=non applicable in the corresponding ANOVA. d.f. of the F values: [a] 1,14; [b] 2,28; [c] 3,42; [d] 4,56; [e] 6,84; [f] 12,168.

Table 2
ANOVA for the LAN (300–550 ms) and P600 components (H–F corrected; all interactions that comprise electrode sides were previously normalized)

		1st Regular						2nd Irregular						3rd Regular						2nd Regular					
	d.f.	LAN		P600[a]		P600[b]		LAN		P600[a]		P600[b]		LAN		P600[a]		P600[b]		LAN		P600[a]		P600[b]	
		F=	*P*<	*F*=	*P*<	*F*=,	*P*<	*F*=,	*P*<	*F*=	*P*<	*F*=,	*P*<	*F*=,	*P*<	*F*=	*P*<	*F*=,	*P*<	*F*=,	*P*<	*F*=	*P*<	*F*=,	*P*<
Temporal (TE)																									
Correctness (C)	1,14	0.3		3.8		7.5	*0.02*	0.1		9.7	*0.01*	10.5	*0.01*	5.9	*0.03*	4.0		7.0	*0.02*	5.5	*0.04*	0.3		0.0	
Hemisphere (H)	1,14	0.4		0.0		1.0		0.9		0.0		0.2		0.0		0.0		0.0		1.1		2.1		3.4	
Antpost (A)	2,28	8.5	*0.01*	0.2		4.1		3.2		4.5	*0.05*	11.1	*0.04*	6.8	*0.02*	0.7		3.1		13.3	*0.01*	4.5	*0.05*	3.1	
C×H	1,14	0.1		3.7		2.2		0.4		0.5		0.8		1.8		1.8		2.5		2.3		0.6		0.0	
C×A	2,28	0.9		3.8	*0.04*	2.0		0.4		14.6	*0.001*	3.8	*0.04*	0.8		3.4	*0.05*	0.1		0.1		0.4		0.1	
H×A	2,28	1.3		3.5	*0.05*	1.2		0.6		0.2		0.2		1.3		0.0		0.6		0.2		0.6		0.1	
C×H×A	2,28	2.0		0.6		1.2		1.0		0.6		0.5		1.6		0.5		0.1		1.2		2.4		1.5	
Parasagittal (PS)																									
C	1,14	0.6		6.3	*0.03*	13.1	*0.01*	2.2		15.1	*0.01*	17.6	*0.001*	3.0		4.5		12.3	*0.01*	4.8	*0.05*	0.0		0.0	
H	1,14	0.4		0.0		1.5		1.2		0.2		1.6		0.4		0.8		1.3		0.5		0.1		0.5	
A	4,56	4.4	*0.05*	0.6		2.9		2.2		1.2		4.9	*0.02*	5.1	*0.02*	0.9		4.5	*0.02*	7.2	*0.02*	0.5		1.3	
C×H	1,14	0.3		7.4	*0.02*	3.8		1.1		0.1		0.5		0.0		0.7		0.9		3.2		0.4		0.1	
C×A	4,56	0.8		3.8	*0.04*	1.3		0.6		8.8	*0.001*	3.9	*0.03*	1.0		4.8	*0.01*	1.1		0.6		1.0		0.7	
H×A	4,56	0.6		0.4		0.5		1.0		0.8		0.6		3.4	*0.03*	0.5		0.2		1.9		1.1		0.1	
C×H×A	4,56	0.9		2.9	*0.05*	1.1		1.2		0.6		0.3		2.3		1.8		0.5		0.9		1.3		2.3	
Midline (ML)																									
C	1,14	0.9		5.7	*0.04*	9.7	*0.01*	1.2		11.9	*0.01*	10.7	*0.01*	2.4		5.0	*0.05*	15.7	*0.01*	4.1		0.0		0.1	
A	2,28	3.1		2.9		1.3		0.2		2.8		2.2		1.0		1.0		1.2		5.3	*0.04*	0.0		0.8	
C×A	2,28	3.4		7.1	*0.01*	5.4	*0.02*	1.7		9.8	*0.01*	4.8	*0.05*	0.0		5.9	*0.01*	1.1		0.8		1.9		0.2	

[a] P600 (750–1000 ms).
[b] P600 (1000–1250 ms).

3rd conjugation form, e.g. **dorm-a-t* instead of the correct *dorm-i-t* or *tem-a-t* instead of *tem-u-t*. On the other hand, incorrect 1st conjugation forms in which the correct theme vowel (*-a-*) was replaced with the 3rd conjugation form (*-i-*), e.g. **cant-i-t* instead of *cant-a-t*, did not yield a LAN effect.

Our results provide evidence against a narrow interpretation of left sided negativities: these effects are not only sensitive to violations of inflectional rules (as shown by our previous studies on participles and plurals), but also to violations of stem formation rules as shown by the results of the present study. In line with the interpretation of the effects found in our previous studies, we suggest that the left negativity seen for stem violations in the present study reflects violations of morphological structure-building, as follows. Suppose that 1st conjugation stem formation is rule-based, whereas 2nd and 3rd conjugation stems are lexically stored. If this is correct, the morphological anomalies in incorrect 2nd and 3rd conjugation forms (**dormat, *temat*) result from a violation of morphological parsing, i.e. from a misapplication of the *-a*-stem formation rule to a verb that would normally block the rule, producing an illegal root+TV combination. The anomaly in incorrect 1st conjugation forms (**cant-i-t* instead of the correct *cant-a-t*), however, is of a different kind. If there is no *-i*-stem formation rule and 3rd conjugation stems are lexically stored, then incorrect stem forms such as **canti-* do not involve a violation of morphological structure building, and hence do not elicit a negativity[7]. This finding is parallel to our previous studies on participles and noun plurals: misapplications of inflectional rules (e.g. the participle *-t* and the plural *-s* in German) yielded LAN effects, whereas overapplications of stored irregular forms did not produce such effects. Taken together, these findings show that the left sided negativity is not restricted to inflectional rule violations, but that it can better be interpreted as reflecting processes involved in (morphological) structure building. At this point, we like to point out that the distribution of the negativity found in the present study extended to more posterior regions than the effects seen for morphological violations in German. At present it is unclear, what caused the difference between the two languages.

[7]Note that 1st conj. forms with the TV *-i*-are grammatically well formed as present tense subjunctive forms and as imperatives (e.g. *canti-i-s* 'speak-2nd sg. subj'), even though the combination of *-i*-and the ending *-t* is clearly ungrammatical for a 1st conjugation verb. We cannot completely rule out the possibility that subjects attempted to interpret forms such as **cantit* as subjunctives and/or imperatives, but given the syntactic contexts in which these items were presented in our experiment, we would consider this to be rather unlikely. In our study, the critical stimuli were presented within sentences in which the presence of an auxiliary made it clear that the critical items were participles with the correct participal ending (*-t*) and the wrong TV. In fact, treating the critical items as subjunctives or imperatives would be syntactically illicit given the sentential context, as the auxiliary requires a participle, rather than another finite verb form.

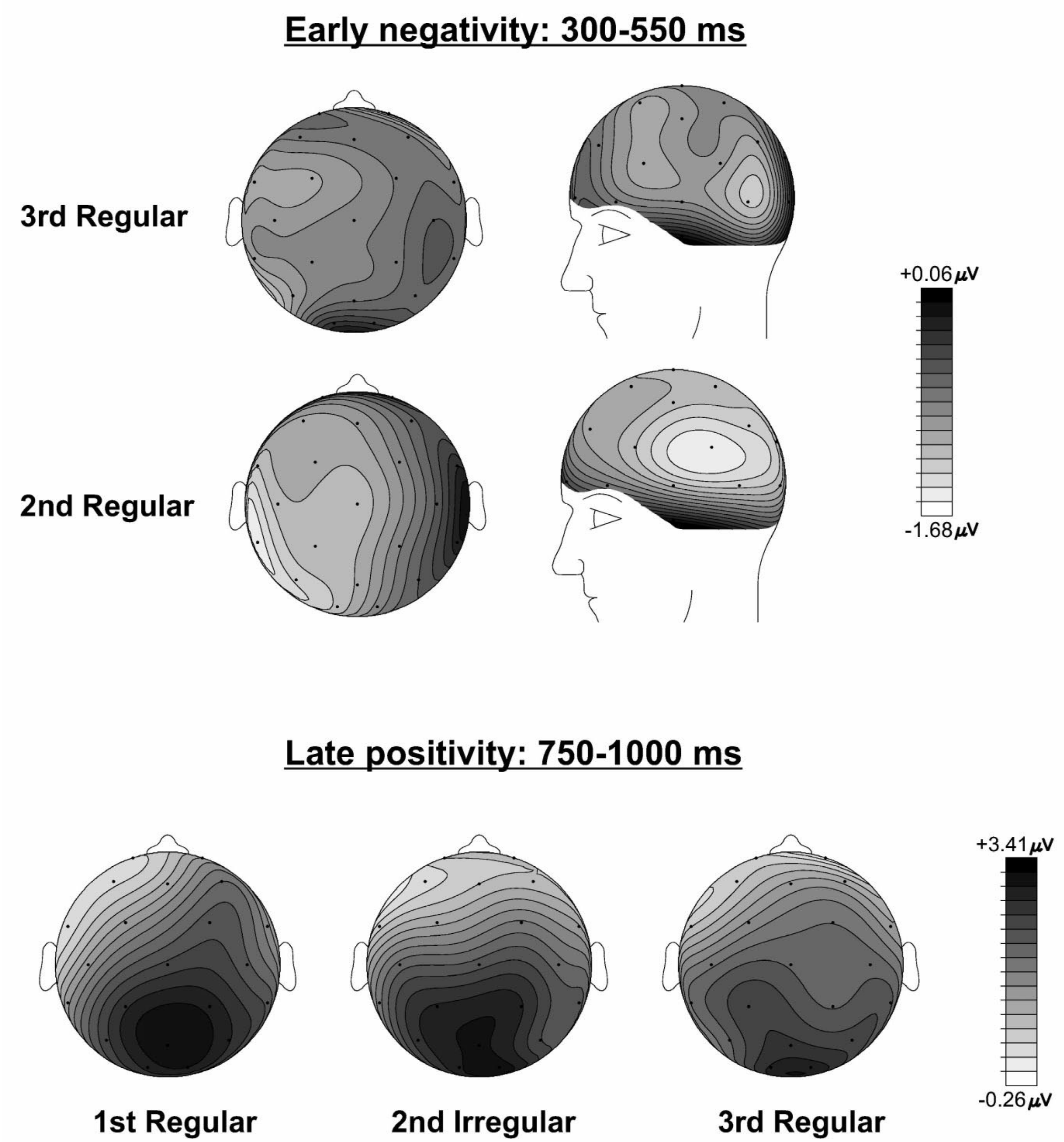

Fig. 3. Spherical spline-interpolated isovoltage maps derived from the difference waves (incorrect–correct participles). The top panel shows the topographical distribution (top and left view) of the Early Negativity (mean amplitude over 300–550 ms time-window) for the two conditions that showed this effect. Bottom panel depicts the distribution (top view) of the Late Positivity (750–1000 ms time-window) for the three conditions where the effect was significant.

Given the suggested interpretation of the left negativity found in the present study, one wonders, however, why stem violations in the previous study of Italian [12] did not produce a similar effect. Recall that the linguistic properties of Italian stem formation are largely parallel to those of Catalan and that the experimental conditions of the Italian ERP study were identical to those of the present study. But despite these similarities, stem violations such as **dorma-to* instead of *dorm-i-to* did not produce any significant ERP effect in the Italian study. The reason for this discrepancy might have to do with the fact that the design of the Italian ERP study differed, in important ways, from the design of the present study. The task assigned to subjects in the Italian study was to identify nouns from the stimulus list and press a response button accordingly. The word structure of nouns, however, is different from that of verbs in Italian: whereas inflected verbs generally consist of a root, a theme vowel and an inflectional ending (*parl-a-to* ‘spoken’), noun inflections are attached directly to the root, e.g. *tavol-o* ‘table-masc.sg., *tavol-i* ‘table-masc.pl.’. In order to identify nouns from the stimulus list, it is therefore sufficient to monitor the items only with respect to inflectional endings and corresponding roots. The form of the theme vowel, however, is likely to receive much less attention, as it does not provide any cue for solving the experimental task, i.e. detecting an Italian noun; hence the lack of a significant effect for stem violations. In the present study, all stimuli had to be read for comprehension and questions had to be answered on the content of the materials, a task encouraging subjects to process the form of the verb stimuli at the same level of detail as other stimuli and to analyze (and to correct) incorrect forms.

6.2. ERPs to violations of inflection

Recall that regular participles in Catalan are inflected with the ending *-t* which is suffixed to 1st, 2nd and 3rd conjugation stems yielding forms such as *canta-t* ‘sung’, *temu-t* ‘feared’ or *dormi-t* ‘slept’. By contrast, irregular participles have marked stems and are not suffixed with the regular *-t* ending. Thus, in the light of our previous studies on inflectional violations, we predicted that overapplications of *-t* affixation to verbs with irregular participle forms should produce a LAN-type effect. This prediction, however, was not confirmed. We found that in contrast to our previous study on German participles and noun plurals, where a LAN-type effect was seen for the irregular words, misapplications of *-t* affixation in Catalan did not produce a negativity.

We attribute the lack of a LAN-type effect for inflectional violations in Catalan to formal properties of incorrect irregulars in Catalan. To see this, compare the incorrect irregulars that were used in the German ERP studies [34,40] with the Catalan ones used in the present study.

	Base form (infinitive, singular)	Correctly infected form	Incorrect form as presented in the experiment
German participles	*auflad-en* ‘to load on’	*aufgelad-en*	*aufgelad-et*
German plurals	*Muskel (muscle)*	*Muskel-n*	*Muskel-s*
Catalan participles	*admetre*	*admès*	*admeta-t*

As illustrated here, the German examples do not involve any kind of stem changes. Even if the wrong ending is used, as in **Muskel-s* and **aufgelad-et*, the stem is unaffected and identical to the correct form. This means that in German the incorrect participle and noun plural forms are easily decomposable into stem and affix and consequently, items such as **Muskel-s* and **aufgelad-et* are recognizable as incorrectly inflected forms. In Catalan, however, all irregular participles involve stem changes, as for example in *admetre-admès*. Consequently, the incorrect participles used in the experiment had both an incorrect *-t* ending and an incorrect stem and therefore differed more radically from their corresponding correct forms. These two properties may make it difficult for subjects to process the morphological anomaly in forms such as **admetat*. The results of the paper-and-pencil test and the sound familiarity judgements reported in Section 5.1 provide support for this interpretation. Recall, in particular, that the incorrect forms of 2nd irregular verbs came out much worse on both measures than those of 1st and 3rd conjugation verbs. Thus, while it is always difficult to interpret missing effects, the lack of a LAN effect for incorrect irregular participles in Catalan might be due to the fact that these forms are less transparently related to their corresponding correct forms than the morphological anomalies in the German participles and plurals previously tested.

6.2.1. P600 effects

In the light of the wide range of conditions that give rise to this component, ranging from garden-path sentences to (in certain circumstances) semantic and orthographical violations [6,7,9,14,25,27,32] it is not surprising that a P600 was obtained in the present experiment. The effect occurred in all experimental conditions, even though in one condition (2nd regular) it was not statistically significant.

We suggest that in the German experiments three factors might have precluded the identification of a P600 component. First, an analysis epoch of only 900 ms post-stimulus was used, so that a late positivity might simply have gone undetected. Second, in two of the four German experiments, the morphological violations occurred within the sentence final word. Thus, a potential P600 might have been masked by the usual sentence-final closure positivity. Third, in one of the German experiments as well as in the Italian ERP study [34,12], a word list containing incorrect participles was used. As the P600 has been interpreted as reflecting reanalysis or repair processes on a sentential level, it is absent in word-list studies or under circumstances, in which a reanalysis is not possible as in pseudo-word sentences [25]. By contrast, active reanalysis was encouraged in the present paradigm as the subjects were required to understand the stories to be able to answer corresponding content questions.

7. Conclusion

Focussing on morphological violations, the present study demonstrates the relevance of left negativities in the study of morphologically complex words across typologically different languages. Whereas our previous studies have shown such effects in response to misapplications of inflectional rules, the study of Catalan has yielded a left sided negativity to misapplications of stem formation rules. This finding indicates that this class of negativities is not only sensitive to inflectional violations and that a narrow interpretation of the LAN does not seem to be correct. On the other hand, they cannot be taken as an unspecific response to morphological anomalies, as in all our studies left negativities have been selectively elicited by particular kinds of morphological violations.

Given the results currently available, we suggest that the left negativity varies as a function of processes involved in morpho-syntactic structure building. As shown in many previous studies, the effect occurs in cases of syntactic parsing violations, e.g. when phrase-structure rules are incorrectly applied. It also occurs when inflectional rules are misapplied, as shown by our studies on German inflection, and it occurs when stem formation rules are overapplied, as shown in the present study. Morphological anomalies, however, that do not result from morpho-syntactic rule violations, do not produce a negativity, hence the lack of effects for irregularizations in German participles and noun plurals, and for overapplications of 3rd conjugation stem forms in Catalan. Taken together, these results show the selectivity of the left negativity with regard to processes involved in morpho-syntactic structure building and the replicability of the effect across different languages. From a linguistic perspective, our findings indicate that the division of labour between rule-based and memory-based processes (as posited by dual-mechanism models of morphological processing) applies not only to inflection, but to stem-formation processes such as those found in the Romance languages.

Acknowledgements

Supported by a NATO Collaborative Research grant (project ≠ 970636), jointly awarded to ARF, HC and TFM and DFG-grant MU1311/7-1 to TFM. ARF was supported by a Post-doctoral Fellowship from the Spanish Government. We thank Joaquim Rafel and Pere Compañó from the Institut d'Estudis Catalans for making the electronic version of the Diccionari de Freqüències available to CL before its publication, Nuria Rodo for correcting Catalan stories, and Tessa Say for detailed comments on an earlier version of this article. We also thank Wido Nager and Urbano Lorenzo for their help during this project, and especially our subjects who kindly agreed to participate in this experiment.

Appendix A. Participles used in the present study: correct forms

1st regular: accelerat, acostat, acusat, agafat, anomenat, aturat, augmentat, comprat, comptat, convidat, creuat, defensat, destinat, detallat, disfressat, disparat, encaminat, endinsat, enfilat, entrevistat, esclatat, escoltat, esfumat, esmentat, esperat, estafat, imaginat, importat, inaugurat, informat, insinuat, interposat, inventat, llevat, manifestat, ocultat, queixat, realitzat, reclamat, recordat, regalat, remenat, retirat, retrobat, semblat, situat, sospirat, tirat, titulat, valorat;

3rd regular: abaltit, abolit, accedit, acollit, acudit, adquirit, advertit, ascendit, assumit, atrevit, avergonyit, coincidit, collit, compartit, conduit, construit, deduit, distribuit, dividit, endurit, engolit, enllestit, envestit, escollit, esmorteit, exhaurit, exhibit, expandit, garantit, insistit, introduit, intuit, invertit, persuadit, precedit, presidit, procedit, recollit, reduit, referit, repetit, resistit, resumit, retribuit, sortit, sucumbit, suggerit, tossit, vestit;

2nd regular: abatut, acrescut, aparegut, apercebut, assegut, atingut, batut, combatut, comparegut, complagut, concebut, conegut, contrabatut, convençut, corromput, crescut, cregut, debatut, decebut, decrescut, desaparegut, desconegut, desmerescut, detingut, discorregut, embegut, entretingut, espremut, interromput, irromput, malvenut, merescut, mogut, obtingut, percebut, perdut, pertanyut, planyut, plogut, prorromput, reaparegut, rebegut, rebut, reconegut, renascut, retingut, revenut, romput, temut, vençut, venut;

2nd irregular: admès, après, atès, clos, comès, commòs, compost, comprès, compromès, confós, corprès, correspost, depès, descompost, desprès, difós, emès, emprès, encès, enclòs, entès, entrevist, escomès, estès, exclòs, fos, imprès, inclòs, infós, malmès, malprès, ofès, omès, permès, pretès, promès, reclòs, recompost, refós, reimprès, remès, reprès, respost, romàs, sobreentès, sorprès, sotmès, suspès, tramès, transmès.

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