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Do you agree? Electrophysiological characterization of online agreement checking during the comprehension of correct French passive sentences

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Abstract

With this research we investigated the real-time electrophysiological correlates of noun–verb agreement checking during the comprehension of correct passive sentences in French. Event-related potentials were acquired while participants read passive sentences that contained covert (singular, masculine) or overt (plural, feminine) noun–verb agreement. Results show that the processing of overtly or covertly agreeing verbs in passive sentences is associated with an asymmetrical electrophysiological response, reflecting former psycholinguistic evidence of markedness and unmarkedness of certain features. The reading of an overtly marked verb agreeing in number and gender with a feminine plural subject was associated with a left anterior negativity (LAN), whereas covertly marked verbs were associated with a negativity presenting a central-posterior distribution, an N400. These results, confirming the lexical status of features and their immediate but asymmetrical checking during sentence comprehension are discussed in the context of current linguistic and psycholinguistic models of agreement checking.

Keywords: Sentence comprehension; Event-related potentials (ERP); Noun–verb agreement; Electrophysiology; LAN; N400; French past participle

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1. Introduction

The present research investigates the cerebral bases of processing noun–verb agreement during sentence comprehension. We recorded event-related brain potentials (ERPs) while participants read passive French sentences that require overt or covert past-participle agreement. Using this particular case of agreement, we investigate the cerebral correlates of the functional asymmetry observed in the feature checking processes of agreement during sentence comprehension. Currently, many questions remain concerning this feature checking process. First, is it an automatic and obligatorily procedure that occurs in the same way for all types of feature or are only certain types of features checked in real-time? Second, is the process driven by forward-assigning or by backward-tracking mechanisms? Forward-assigning (or forward specifying) models state that features are stored in syntactic working-memory buffers, passed down the sentence syntactic tree and checked against incoming morphological marks. Backward-checking models conversely, assume that features are extracted from incoming words and checked against the existing syntactic structure constraints, only when necessary (Nicol, Forster, & Veres, 1997). In this second model, checking does not occur when features are morphologically unexpressed, as nothing is there to trigger the checking procedure. The paper is divided in three main sections. Section 2 reviews theoretical and experimental background concerning agreement. Section 3 describes our study and its methodology. Section 5 discusses the results, placing them within current linguistics and psycholinguistics debates on agreement and previously observed electrophysiological correlates.

2. Theoretical and experimental background

We first introduce the process of agreement and review linguistic approaches to the theory of features. In a follow-up subsection, we present psycholinguistic studies of agreement checking and introduce associated processing models. Then we review ERP experiments that identified electrophysiological markers associated with agreement checking and present the functional interpretations made of these cortical responses. Finally, we introduce the present study and show how French past-participle agreement can constitute an example of choice to address the issues of feature checking and the cortical responses associated to agreement processing during the comprehension of sentences.

2.1. Noun–verb agreement and the syntax of features

Noun–verb agreement is most commonly manifested as morphophonological modification of a verb conditioned by the grammatical properties of one of its nominal arguments, most usually the grammatical subject. Linguistic approaches propose slightly different formal models of the processes underlying the syntax of agreement. Two of the most well known linguistics models are the generative framework, with its most recent venue the Minimalist framework (e.g. Chomsky, 1995, 2000) and the head-driven phrase structure grammar (e.g. Chung, 1998, cited in Franck, Lassi, Frauendelder, & Rizzi, 2006). However, common to these distinct approaches is the idea that the morphological manifestations of agreement, sometimes called Φ-features (with Φ a set of different grammatical markers such as number, gender or person), are explicitly represented in the mental lexicon. Agreement is therefore understood as a feature-sharing process between two syntactic entities; say the noun and the verb for instance (see den Dikken, 2000 for a comprehensive review on the syntax of features). Understood in this way, the process of feature checking is one in which the features of the verb are compared to those of the noun as part of the building of syntactic representations. Syntactic agreement does not distinguish among types of features. It is morphology that later on, i.e. at the output of syntactic derivation, commands the realization of the checked features as a particular 'overt', i.e. phonologically realized or 'covert', i.e. phonologically silent morphemes.

2.2. *Parsing agreement*

The existence, in many languages, of reproducible noun–verb agreement error patterns during sentences production has been at the center of most experimental work exploring the psycholinguistic manifestations of agreement. Research in this domain focused mainly on the so-called 'attraction phenomenon', frequently observed in spontaneous speech (see amongst many others, Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock & Miller, 1991; Fayol & Got, 1991; Fayol, Largy, & Lemaire, 1994; Franck, Vigliocco, & Nicol, 2002; Franck et al., 2006; Hupet, Fayol, & Schelstraete, 1998; Vigliocco, Butterworth, & Garrett, 1996; Vigliocco, Butterworth, & Semenza, 1995; Vigliocco & Nicol, 1998). This phenomenon occurs whenever a noun embedded inside the subject noun phrase erroneously causes the verb to agree with it instead of with the subject head. In (1), for example, the verb erroneously agrees with the adjacent noun *president* instead of the head noun *missions*:

(1) *The different missions of that president ***is*** dangerous.

Studies of this phenomenon provide support for the syntactic grounding of agreement processing because they indirectly manifest structural, i.e. hierarchical constraints on agreement. But they also demonstrate the existence of a linear distance effect, the further embedded the head noun, the more probable the agreement error, suggesting the existence of a strong working memory component in the agreement process, not incompatible with its hierarchical aspect (see Franck et al., 2006 for recent developments). Although as of now, most psycholinguistics work has focused on sentence production, it is known that agreement also plays an important role in sentence comprehension. In sentences like (2) vs. (3) for example, auxiliary agreement determines the attachment of the following relative clause and hence its interpretation:

(2) The brothers of the actress who ***were*** playing quite well yesterday (…).
(3) The brothers of the actress who ***was*** playing quite well yesterday (…).

Correct identification of the feature-sharing elements is here the key to successful syntactic parsing and the mapping to different interpretations. Note in particular, that morphological marking and agreement must here be processed in real-time during sentence comprehension because agreement checking guides the correct attachment of the relative clause and hence the syntactic representation of the whole sentence as well as its interpretation. At present, much remain unknown concerning the cognitive processes at work in agreement checking during sentence comprehension and the cortical mechanisms underlying this process. The research reported in this paper addresses this issue. In Section 2.3 we summarize experimental background results in this area.

2.3. Psycholinguistic models of agreement checking in sentence comprehension

Two families of models are traditionally opposed in the context of agreement processing: the forward-specifying models and the backward-tracking models. Forward-assigning models are grounded in the observations of agreement errors in sentence production, where clear experimental effects of feature migration can be observed (e.g. Bock & Cutting, 1992). According to this view, features from the head-noun are stored in a working-memory buffer and passed down the syntactic tree of the sentence to the verb where the features from the head-noun and the verb are ultimately compared. In this context, it was observed that singular and plural feature manifest an asymmetry in production errors. Bock and Eberhard (1993) and Eberhard (1993), base their explanation of the asymmetry in production errors patterns between plural and singular features on the observation that only plural features are overtly marked. Singular, in contrast, corresponds to the absence of marking. They hypothesize that only overtly marked features are transferred, whereas unmarked are not. Although this model finds support in experiments looking at production errors, it seems less adapted to explain agreement processing in comprehension. Nicol et al. (1997) suggested that the nature of the computation of subject–verb agreement differed between production and comprehension and was forward-specifying in production and backward-checking in comprehension.

According to backward-checking models, features would be extracted from the marked or unmarked verb and then eventually compared to the features of the preceding head noun, after these features are backtracked along the syntactic structure. Certain authors claimed that this computational strategy should be more efficient in English, for a simple question of economy, with fewer than 25% of English verbs being overtly marked (Pearlmutter et al., 1999). To our knowledge, early experimental observations on agreement processing in sentence comprehension were interpreted as supporting the backward-tracking model as described in Nicol et al. (1997).

However, an asymmetrical effect of agreement processing during correct sentence comprehension was first reported by Nicol et al. (1997) who studied sentences in which the number feature of an embedded noun matched or conflicted with that of both the head subject and the verb as in (4)–(7). Results showed reading times (RTs) for non-matching sentences like (4) significantly longer (+124 ms) than for the corresponding singular matching ones (5). RTs for non-matching sentences (4) were also significantly longer than for the two other conditions (6 and 7) that showed equally shorter RTs.

(4) *The author of the speech**es** was subsequently well rewarded.*
(5) *The author of the speech was subsequently well rewarded.*
(6) *The authors of the speech**es** were subsequently well rewarded.*
(7) *The authors of the speech were subsequently well rewarded.*

These results clearly suggest that in English at least, singular and plural features are not equivalently processed or that the agreement checking procedure triggered by the morphologically unmarked singular feature differs from that associated with the morphologically marked plural feature. On the basis of these and other results from production error studies (e.g. Eberhard, 1997) and developmental studies (Franck et al., 2004), different authors proposed to view agreement processing as asymmetrical. Singular count nouns were hypothesized as being unmarked whereas plural count nouns were said to be marked. The observation of mismatching number features interfering with the processing of a subsequent verb were often interpreted as supporting backward-tracking processing models. However it was sometimes argued that it could be accounted for by both forward- and backward-specifying models, leaving this issue open (Pearlmutter, 2000). In a recent experiment for example, Solomon and Pearlmutter (2003), compared reading times for non-overtly marked singular-biased modal verbs (*could*, *may,* etc.), which occur with singular subjects approximately 70% of the time vs. number-equibiased modals (*can*, *must,* etc.), occurring equally with plural or singular arguments. Results from this experiment, showed reading time differences from the critical verb that were larger for singular-biased than for equibiased verbs suggesting that feature-checking would in fact occur according to a forward-assigning process. According to the same authors, the subject NP number feature would be computed as the subject NP is processed and then the verb number would be unified with the subject NP number by activating verb number features; most importantly, this would occur even for non-overtly-marked verbs.

Several questions arise from these various studies. Firstly, if agreement checking during sentence comprehension seems to be an established process, it remains unclear exactly what kind of features trigger checking procedures: do all features trigger checking equally or do only overtly marked ones do so, while the process is not invoked for unmarked ones? Secondly, how does this checking procedure operate during sentence comprehension, are features that should be checked, passed down the syntactic tree and compared to morphological marks of incoming words or are features extracted from the morphological marks of incoming words and backward-checked?

In this context, the recording of event related potentials (ERPs) might bring important information to this open debate. ERPs, thanks to their high temporal resolution (often around 500 samples per second) allow the real time measurement of cortical processes involved in the processing of words or sentences. Using ERPs, different works investigated the electrophysiological correlates of agreement processing during sentence comprehension.

We review these previous works in the following session.

2.4. Electrophysiological manifestations of agreement processing

A number of studies, using almost exclusively incongruity-detection paradigms, addressed the issue of characterizing electrophysiological correlates of agreement processing. Three main ERP markers have been associated with the detection of agreement violations: a frontal negativity showing a left anterior peak between 300 and 500 ms (LAN), a central-parietal negative wave peaking around 400 ms (N400) and a late posterior positive wave peaking around 600 ms (P600). We discuss each of these different electrophysiological markers before assessing their respective functional significance for agreement checking.

2.4.1. The N400 effect

The N400 is certainly the most well known and most extensively studied language-related ERP component. It is a central-parietal negative wave peaking around 400 ms after word onset. It was first correlated with the detection of semantic anomalies involved in contextual incongruence as in the sentence: **He shaved off his moustache and* ***city*** (Kutas & Hillyard, 1980). The N400 effect was later shown to be not just a marker of semantic violations but also a component of the normal cortical response to verbal stimuli or to pronounceable pseudo-words (Kutas, Neville, & Holcomb, 1987). The amplitude of the N400 effect is mainly modulated by the cloze-probability of a word and is therefore highly dependent on contextual effects in sentences. It is now assumed to be a general index of the ease or difficulty involved in retrieving stored conceptual knowledge associated with a word, which is dependent on both the stored representation itself, and the retrieval cues provided by the preceding context (see Kutas & Federmeier, 2000 for a review). The N400 is largely considered as an electrophysiological marker reflecting semantic processing.

2.4.2. The P600 effect

The P600 is a central-parietal positive wave peaking around 600 ms after word onset (Osterhout & Holcomb, 1992; Stemmer & Whitaker, 1998). Analogically to the N400, it was first identified as a marker for violations of subcategorization constraints as in the following sentence, where a noun not a verb is expected after the verb *persuade*: **The broker persuaded* ***to sell*** *the stock*, compared to the same sequence under *hope*, which is fine: *The broker hoped to sell the stock* (Osterhout & Holcomb, 1992). Here again, however, further inquiries revealed that the P600 component was also present when subjects read normal sentences with complex or unusual syntactic structure (Hagoort, Brown, & Groothusen, 1993). It was further argued to reflect syntactic repair or second-pass syntactic processing (Friederici, Hahne, & Mecklinger, 1996), showing sensitivity to the complexity of the syntactic structure of sentences (Münte, Szentkuti, Wieringa, Matzke, & Johannes, 1997). Different authors have suggested that there exist a family of P600 waves, individually characterized by their differentiable scalp topographies. A first P600 component, with a frontal-central topographic distribution was associated to the processing of syntactic ambiguities (re-analysis) or to the processing of complex syntactic structures (syntactic complexity). Another P600 effect, with a more posterior central-parietal distribution was associated to repair or revision of syntactic structure after the detection of an evident (e.g. word position) syntactic/structural violation (Friederici, Hahne, & Saddy, 2002; Kaan & Swaab, 2003).

2.4.3. Left anterior negativities (LANs)

LANs were originally associated with the detection of word-category constraints violations (Friederici et al., 1996, 2004; Münte et al., 1993). LAN effects were also associated with the misapplication of regular morphological rules (Gross et al., 1998; Penke, Weyerts, Gross, Zander, Munte, & Clahsen, 1997; Rodriguez-Fornells et al., 2001; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997). The LAN was therefore classically associated with the processing of incongruous morphosyntactic marks (see Friederici, 2002) and grammatical items indicating the building of syntactically complex phrase structures heavily taxing verbal working memory resources (Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998; Hoen & Dominey, 2000, 2004). In a recent paper, Krott, Hagoort and Baayen, (2006), directly addressed the issue of the functional significance of LAN markers. They ran a study looking at the electrophysiological correlates of processing existing or novel Dutch compounds. In their experiment, existing compounds contained correct or replaced interfixes (*dame+s+salons* > *damessalons* vs.

**dame+n+salons* > **damensalons* "women's hairdresser salons"), while novel Dutch compounds contained interfixes that were either supported or not supported by analogy to similar existing compounds (*kruidenkelken* vs. **kruidskelken* 'herb chalices'). Results from this study showed a LAN for the replacement of suffixes or interfixes in existing compounds. However, when manipulating the analogical support for interfixes in novel compounds, the authors did not observe a LAN. They therefore suggested that LANs would be caused by the mismatch between presented and stored lexical forms. LAN effects could therefore be considered as reflecting the processing of unexpected morphological forms.

2.4.4. Functional significance of ERP markers in agreement checking

Although the three above mentioned ERP components were observed in the context of agreement violation detection experiments, their presence or absence varied, according primarily to the complexity of the linguistic context in which agreement violations occurred. In particular, important distinctions appear between situations where agreement mismatches happened in minimal contexts (single words or word pairs) or in complex sentential contexts. Studying the effects on cortical responses of gender and number agreement violations in word pairs (Nouns–Adjectives) for example, Barber and Carreiras (2003), observed an N400 in response to both gender and number violations. In a series of experiments, Wicha and colleagues studied ERP responses to the presentation of drawings depicting a noun that was either congruent or incongruent with sentence meaning, and could agree or disagree in gender with the immediately preceding spoken article. In their experiments, semantically incongruent pictures were associated to an N400 effect. Gender agreement violations were associated to a P600 effect and an increased negativity with a later onset and distribution differing from the canonical N400 that was however not formally identified as a LAN (Wicha, Bates, Moreno, & Kutas, 2003; Wicha, Moreno, & Kutas, 2003, 2004). In minimal linguistic contexts, gender agreement violations between a determiner and the different constituents of German compound-words elicited a LAN but no P600 effect (Koester, Gunter, Wagner, & Friederici, 2004). This suggested that LAN effects would occur as soon as some structural relations exist between agreeing phrasal elements. Barber and Carreiras (2005), directly addressed this issue by manipulating the complexity of linguistic context in which agreement violations could occur. Detection of agreement violations in word pairs formed by a noun and an adjective produced an N400. When word pairs were made of an article and a noun, agreement mismatch detections were associated to a LAN. Finally, when these word pairs were presented in complete sentential contexts, agreement violations resulted in a LAN/P600 pattern. These studies therefore evidenced a strong influence of increasing complexity of sentential context on the cortical responses to agreement violations. It appears that in the absence of any structural link between simple lexical items in word pairs (Noun–Noun or Noun–Adjective), the detection of incongruent agreement is associated to an N400 component and would therefore be interpreted at a semantic level. As soon as word-pairs constitute at least minimal phrasal units as a noun-phrase made of a determiner and a noun, agreement violations are associated to a LAN effect. Finally, agreement violations occurring in complex sentential contexts trigger a LAN/P600 complex (see also Morris & Holcomb, 2005, for comparable observations). This latter pattern of responses was observed in different types of phrasal contexts and for different types of agreement violations. For example, a complement clause containing a predicate adjective marked for syntactic gender and mismatching in gender with the antecedent of the implicit subject, was associated to a LAN/P600 response

(Demestre, Meltzer, Garcia-Albea, & Vigil, 1999). The same pattern could also be observed for gender agreement violations between an article and a noun (Gunter, Friederici, & Schriefers, 2000) or subject–verb agreement (De Vincenzi et al., 2003; Gunter, Stowe, & Mulder, 1997; Kaan, 2002; Rossi, Gugler, Hahne, & Friederici, 2005). However, other studies have used agreement violations to study syntactic violations in general and focused on the P600 effect without reporting any LAN effects (Hagoort, 2003; Martin-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006; Münte, Szentkuti, Wieringa, Matzke, & Johannes, 1997; Wassenaar, Brown, & Hagoort, 2004). The functional significance of the P600 effect in this context can be derived from above mentioned classical interpretations of P600 waves. This marker would reflect the processes of repair necessarily engaged after the detection of a syntactic mismatch in a sentence and would therefore be specific to the detection of the syntactic incongruity caused by the agreement violation rather than to the processing of agreement *per se*. The case of the LAN effect is way more unclear. Although it could be accounted for by the hypothesis of Krott et al. (2006), that it is the mismatch between the presented incongruous verb-form and the awaited form that triggers the LAN effect. However, it is still unknown if this response is mainly related to the processing of incongruous agreement marking or if it also part of the normal cortical response to correct agreement processing, LANs being sometimes observed for the processing of syntactically correct constructions as well (e.g. Rösler et al., 1998). At this point it seems necessary to elaborate paradigms demonstrating immediate feature extraction in the context of (i) correct sentence processing in (ii) frequent sentence constructions, in order to better understand the cortical processes implicated in agreement checking.

3. The present study

In order to address the issues of (i) asymmetrical checking of features during sentence comprehension, (ii) processing models of agreement and (iii) the neural correlates of agreement checking during the parsing of correct sentences, we ran a visual ERP experiment on French passive sentences that feature past participle agreement, a well-known example of morphosyntactic marking of verbs in French (8a, 8b).

3.1. French past participle agreement

(8a) *Un discours a été prononc**é** par le président.*
"A discourse [+masc., +sing.] was [+sing.] pronounced [+masc., +sing.] by the President."

(8b) *Des idioties ont été prononc**ées** par le président.*
"Insanities [+fem., +plur.] were [+plur.] pronounced [+fém. (-***e***), +plur. (-***s***)] by the President."

In this particular example, the first noun is the underlying object of the main verb (*prononcer*) and agrees in gender and number with it. In French, a participle can agree in number and gender with objects that are fronted through syntactic movement be it in passive or other types of syntactic displacement. French indeed exhibits a strong correlation between agreement and syntactic movement (see Déprez (1998) for a linguistic description and discussion). Note that in this case, the suffixation of the main Verb in −***ées*** does not constitute a case of morphological irregularity. On the contrary, it is even extremely regular, letter −*e* being the prototypical mark for feminine gender and letter −*s* being the canonical mark for plural in French (see Meunier & Marslen-Wilson, 2004). What is non-canonical is the syntactic structure of the sentence, passive causing the main verb to agree with a moved object. In (8a) the object *discours* is masculine and singular [+masc., +sing.] and the verb agrees with it with a [+masc., +sing.] covertly marked ending ***-é***. In (8b) the subject *idioties* is feminine and plural [+fem., +plur.] and the verb agrees with it, by a modification of its surface form consisting in the addition of a feminine mark ***-e*** and a plural mark ***-s***, leading to the overtly marked ending [+fem., +plur.] ***-ées***.[1]

Contrary to English, French gender is frequently marked, as is number, and gender agreement plays an important role on lexical decision (see for example Jakubowicz & Faussart, 1998). In this experiment, we wanted to avoid the distinction between gender- and number-agreement, in order to focus on the specific process of feature-checking and its electrophysiological counterparts. Other authors having demonstrated that ERPs were not significantly modified by the type of agreement error involved (e.g. Barber & Carreiras, 2003, 2005), we decided to compare sentences differing in both features: gender [masc. vs. fem.] and number [sing. vs. plur.] as in the previously mentioned examples (8a vs. 8b). Note as well that in these particular sentences, the passive structure, implicating a non-canonical thematic role distribution (Patient–Verb–Agent) is indicated by the presence of the second auxiliary *été* (past participle of *to be*). This allowed us to separate thematic structure determination (assumed to be resolved by the presence of this second auxiliary) and agreement feature checking (manifest only on the main verb). The separation seemed important because both of these processes have been previously associated with the ERP signature LAN (see Friederici, 2002 for review). Finally, in order to potentially avoid general working memory effects and non-specific attentional modulations due to the nature of the task, known to modify ERP markers, we decided to engage participants in a classical violation detection paradigm mixing semantic and structural violations always occurring after the verbal group in our sentences. Moreover, our test-sentences comprised both active and passive voice sentences. The processing of syntactic structures and particularly agreement was thus performed outside the scope of the task. Therefore, any observable effects on normal sentence processing are assumed to be imputable to natural parsing processes, not to any specific task demand (see for example, Shtyrov, Pulvermuller, Näätänen, & Ilmoniemi, 2003; see also Picton et al., 2000, for methodological concerns).

3.2. Hypotheses

In this experiment, we mainly focus our analysis on words from the past participle verbal group, including the two auxiliaries and the main verb in passive sentences. We compare conditions of overt agreement, where the verb exhibits morphosyntactic marks of gender and number agreement (e.g. *prononc**ées*** [+fem., +plur.]) and conditions of covert agreement, where the agreement in gender and number does not implicate overt marking on the verb (e.g. *prononcé* [+masc., +sing.]). The following hypotheses were directly derived and extended from previously mentioned behavioral observations (Clifton,

[1]This also happens in the auditory modality, with verbs from other groups than the first one, like *prendre*, "to take", as in *Les photos que tu as **prises*** (pronounced /iz/—"The photos that you took" [+fem., +plur.]) vs. *Le billet que tu as **pris*** (pronounced /i/—"The ticket that you took [+masc.]").

Frazier, & Deevy, 1999; Deevy, 2000; Nicol et al., 1997; Pearlmutter, 2000; Pearlmutter et al., 1999).

1. *Immediate feature checking and the LAN effect:* a finite verb with agreement features is checked real-time as it is encountered. Agreement-checking should thus be associated with specific ERP responses. If the LAN effect already identified for the detection of incongruous agreement is reflecting agreement processing, we should observe a LAN for the processing of morphosyntactic marks indicating noun–verb agreement.
2. *Selective feature checking:* as previously observed in English, checking does not occur for every feature. Only features that overtly modify the form of the verb by the addition of specific morphosyntactic marks trigger feature checking. In particular, the singular feature is unmarked whereas the plural feature is marked. Thus, only overt agreement conditions should be associated with the appearance of a specific ERP marker. We would thus expect a LAN effect for the checking of overtly marked features only.

4. Materials and methods

4.1. Participants

Twenty-one participants (11 f, 10 m), aged 18–39 years, all right-handed and free of known neurological impairment or language deficits entered the study. After being informed of the physical details of the stimulation and recording techniques employed, participants gave their consent.

4.2. Stimuli

One hundred and sixty French sentences were visually presented word by word, each presentation lasting 400 ms with a 400 ms blank between two successive words (ISI = 800 ms). Amongst those sentences, half (80) were active voice 8–9 words filler sentences (9). The other half (80) were the corresponding 10–11 words passive-voice sentences following the general schema (Det1–Noun1–Aux1–Aux2–Verb–Prep1–(Det2)–Noun2–Prep2–Det3–Noun3) (10).

(9) *Le facteur a donné le courrier à Jean.*
"The postman gave the post to John."

(10) *Le courrier a été donné à Jean par le facteur.*
"The post was given to John by the postman."

Half of the target passive voice sentences ($n = 40$) contained covert number and gender agreement (11) and half ($n = 40$) overt number and gender agreement on the main verb (12).

(11) *Le courrier a été donn-é à Jean par le facteur.* (Covert)
"The post [+masc., +sing.] was given [+masc., +sing.] to John by the postman."

(12) *Les lettres ont été donn-ées à Jean par le facteur.* (Overt)
"The letters [+fem., +plur.] were given [+fem., +plur.] to John by the postman."

Amongst each set of 40 sentences per agreement type, one quarter contained a structural violation (word position exchange: *The post was given to* ***by*** *John the postman,* $n = 10$) and one quarter a semantic violation (semantically incongruent word insertion: *The post was given to John by the* ***squirrel****,* $n = 10$), the twenty remaining sentences were correct. The distribution of violations of each type was balanced across agreement conditions. All violations always occurred after the main verbal group in all sentences and therefore the presence of a violation never interfered with the reading and processing of agreement at the main verbal positions. We subsequently analyzed ERPs on all passive voice trials (40 trials per agreement conditions).

4.3. Procedure and task

Participants sat comfortably in a sound proof room. The 160 sentences were presented in pseudo-random order on a 14-inch video screen. The recording session was divided in 4 blocks of 80 sentences. The total duration of the recording was around 30 min. The paradigm consisted in a correctness judgment task. Each sentence was followed by a 2 s response screen during which participants were asked to give their response by pressing a "yes" (correct sentence) or "no" (incorrect sentence) button on a response pad using either the left or right index (side balanced across participants). Participants were informed that they participated in an acceptability decision task and asked to give accurate responses inside the response delay.

4.4. EEG recording

Scalp voltages were continuously acquired with a 65-electrode geodesic net referenced to Cz and amplified with an AC-coupled, 65-channel, high input impedance amplifier (200 MΩ, Net Amps, Electrical Geodesics Inc., (EGI) Eugene, OR, USA). Amplified analog voltages (0.1–200 Hz bandpass filtered) were sampled at 500 Hz. Individual electrodes were adjusted at an impedance of less than 40 kΩ. Trials were automatically rejected from analysis if they contained eye movements, as monitored by two EOG electrodes.

4.5. EEG analysis

4.5.1. Segmentation and artifacts rejection

Raw EEG recordings were segmented into 1 s recording windows, starting 100 ms before and ending 900 ms after target word onset, using the in-built tool from EGI (Netstation^{TM}). EEG segments were then scanned and an automatic rejection algorithm was applied, systematically excluding segments contaminated by: (i) electrodes showing voltage values superior or inferior to $\pm 200\,\mu V$; (ii) eye blinks, defined as deflections of $\pm 70\,\mu V$ on the EOG electrodes; (iii) movements, defined as deflections of $\pm 70\,\mu V$ on all electrodes; (iv) transitory amplitude variations of $\pm 100\,\mu V$ and (v) ten or more simultaneously artifacted electrodes. Surviving segments were then imported within the software BESA 2000 (MEGIS Software GmbH, Munich, Germany), for visual inspection of the efficacy of automatic rejection. Recordings were completely excluded from further analysis steps if they presented more than 10% of rejected trials by conditions or more than 10% of bad electrodes (6/64). In this experiment, 16 volunteers (8 m, 8 f) out of 21, provided recordings of sufficient quality to be included in further analyses.

4.5.2. Averaging and grand-averaging

Surviving segments were normalized taking the 100 ms preceding stimulus onset as voltage baseline. Before visualization, an average reference was applied to the resulting ERP waveforms. Ultimately, recordings were filtered using a low-pass filter at 30 Hz. Segments corresponding to correct trials, ensuring accurate parsing of the sentences were then averaged for each subject before statistical analysis and Grand-Average waveforms were obtained by averaging data from the 16 included recordings together. ERPs were visualized as single electrode recordings as well as 2 and 3D mappings of voltage amplitudes.

4.5.3. Target-words and statistical analyses

In this experiment, we decided to analyze the evoked potentials obtained for all three words in the verbal group of our passive sentences separating the two agreement conditions Covert [+masc., +sing.] vs. Overt [+fem., +plur.]. The major target word was the main verb properly: Covert (prononc-***é***) [+masc., +sing.] vs. Overt (*prononc-**ées***) [+fem. +plur.]. However, we also analyzed, as controls, the evoked potentials obtained for the two preceding words, the first auxiliary: Covert (*a*) [+sing.] vs. Overt (*ont*) [+plur] and the second auxiliary Covert (*été*) vs. Overt (*été*). After visual identification of the main target markers, the analysis was restricted to the time window defined from 400 to 600 ms. No later effects (P600 type) being clearly identifiable on the recording tracks, we restrained analyses to this earlier time-window.

Numerical data corresponding to the average value of scalp voltage amplitudes in this particular time-window were exported and comparisons were done by repeated-measures ANOVA (ANOVA-RM, $\alpha = 0.05$). In order to be able to clearly separate the LAN effect from other ERP markers, on the basis of a statistically valid topographical distinction, the ANOVA included a factor Spatial Domain (2 : Anterior Left/Central Parietal), respectively, grouping 7 electrodes. The Anterior Left domain contained the electrodes 8, 9, 11, 12, 13, 15 and 16 from the geodesic sensor net, respectively corresponding to the 10–20 electrodes: F1, Fc1, Fp1, AF3, F3, F7 and Fc5. The Central-Parietal domain contained the electrodes 18, 29, 30, 34, 42, 43 and 65 from the geodesic sensor net, respectively, corresponding to the 10–20 electrodes: Cp1, P1, CPz, Pz, P2, Cp2 and Cz. When an effect had more than one degree of freedom on its numerator, the correction of Greenhouse-Geisser/Huynh Feldt (Greenhouse & Geisser, 1959) was applied, in these cases, the reported values of degrees of freedom and p values are corrected values.

5. Results

In the results section, we first briefly report the behavioral results observed for the general violation detection task, as these assert that participants carefully read and judged the sentences, thereby also accurately parsing them. In a second section we review the electrophysiological results, starting with our main observation on the main verb and then successively reporting the two control-words, the second and the first auxiliary. Finally, we briefly report on ERP markers observed for words causing semantic or syntactic violations.

5.1. Behavioral results

All 16 participants retained for the following steps of the statistical analysis mastered the task and performed with an average correct response rate of 97.11% (SD = 3.93). We ran a repeated-measures ANOVA on the individual correct judgment rates that included factors: Syntax (2: Active voice/Passive voice) and Violation (3: Correct sentence/Semantic violation/Syntactic violation). This analysis revealed no main effect of the factor Syntax ($F(1, 15) = 1.22$, n.s.), suggesting that participants performed the judgment task equally well on active voice ($M = 97.50\%$; SD = 3.68) and passive voice ($M = 96.72\%$; SD = 4.16) sentences. The main effect for violation was not significant either ($F < 1$), showing that the different types of sentences: correct sentences ($M = 96.96\%$; SD = 3.22), sentences including a semantic violation ($M = 96.56\%$; SD = 4.99) or a structural violation (M = 97.81%; SD = 3.35), were processed with comparable ease. The second level interaction remained non significant ($F < 1$), suggesting that the syntactic structure of the sentence (active voice or passive voice) did not significantly modulate the complexity of the violation detection task.

5.2. ERP recordings and agreement checking on the main verb

In this first analysis, we report the results observed for the reading of the main verb in a passive voice sentence in French. The distinction is made between a condition of covert agreement (1), where the verb agrees in number and gender with its [+masc., +sing.] subject and shows the covertly marked ending ***–é*** and a condition of overt agreement (2), where the verb agrees in number and gender with its [+fem., +plur.] subject and shows the overtly marked ending ***-ées***.

(1) *Covert agreement: Le courrier a été **donn-é** à Jean par le facteur.*
"The post [+masc., +sing.] was given [+masc., +sing.] to John by the postman."
(2) *Overt agreement: Les lettres ont été **donn-ées** à Jean par le facteur.*
"The letters [+fem., +plur.] were given [+fem., +plur.] to John by the postman."

In time-window 400–600 ms, reading of the target verbs was associated to the appearance of two dissociable negative components. The reading of a main verb in the covert agreement condition enhanced a negative wave peaking around 400 ms at central parietal sites while the reading of a main verb in the overt agreement condition was associated to more negative average amplitude values around 500 ms over anterior left sites (Fig. 1).

A repeated measures ANOVA analysis was performed on scalp voltage values averaged over time-window 400–600 ms including as factors: Agreement (2: Covert / Overt), Spatial Domain (2: Anterior Left/Central Parietal) and Electrodes (7 electrodes in each spatial domain). This analysis revealed no main effect of factor Agreement ($F < 1$), the reading of both verbs being globally associated to average negative scalp potential values. The main effect of Spatial Domain remained non-significant ($F < 1$) reflecting the fact that the two negative waves were distributed over the two spatial domains. The second level interaction was significant ($F(1, 15) = 12.22$, $p < 0.05$) suggesting that the effect observed for factor Agreement depended on the spatial domain considered. Subsequent post hoc analysis using a *Scheffé* test ($\alpha = 0.05$) revealed

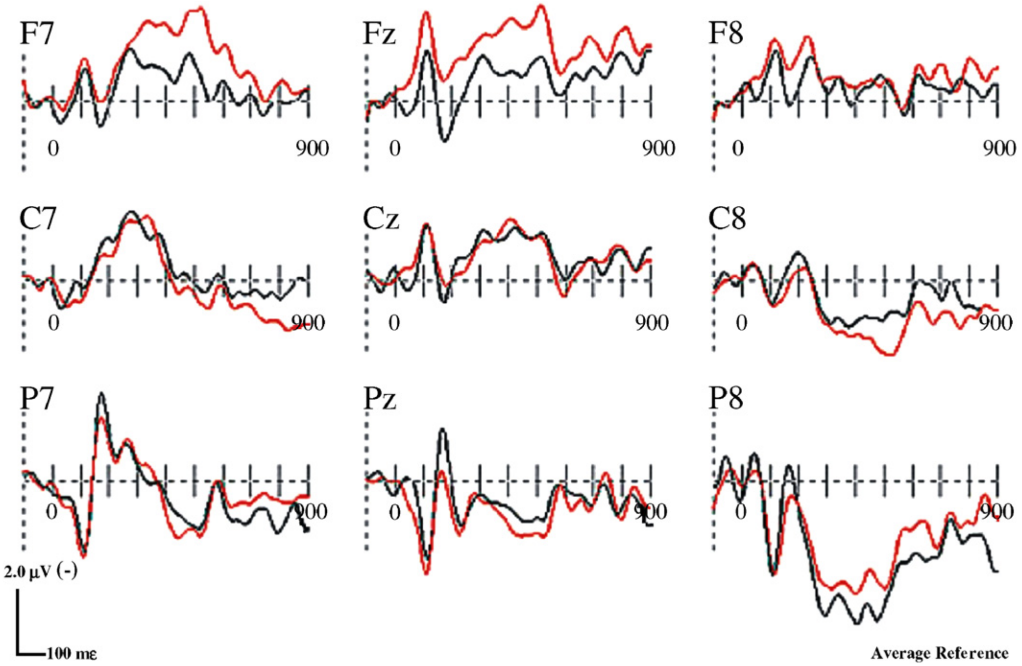


Fig. 1. Single electrodes plots of the event-related brain potentials evoked by the reading of the main verb in the covert agreement (black line) and overt agreement (red line) conditions.

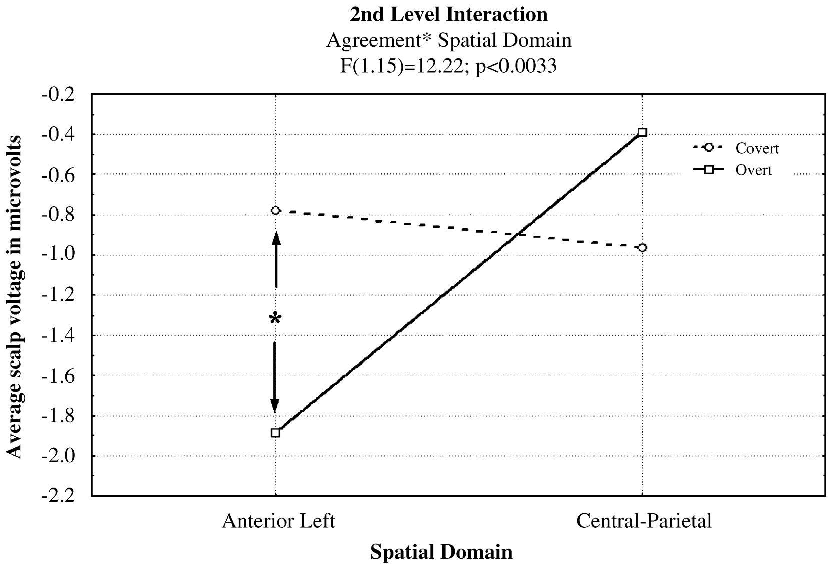
an effect of Agreement in the spatial domain Anterior Left ($p < 0.05$), the values observed for overt agreement being more negative than the values observed for covert agreement. This effect remained non-significant in spatial domain Central Parietal (see Graphic 1).

In time window 400–600 ms, the reading of a main verb in a passive voice sentence with covert agreement is associated to the appearance of a central-parietal negative wave peaking around 450 ms, an N400 effect. The reading of the same verb with overt agreement morphosyntactic marking is associated to a sustained negative activity peaking over anterior left electrodes around 500 ms, a LAN (Fig. 2).

5.3. ERP recordings obtained for the second auxiliary

As a first control, we performed a second ERP analysis on the second auxiliary in the verbal group, in French the target word *été*. The form of the second auxiliary is not modified by the agreement between the subject and the verb, it remains *été* whether in a covert (3) or overt (4) agreement condition.

(3) Passive covert agreement: *Le courrier a* ***été*** *donné à Jean par le facteur*.
"The post [+masc., +sing.] was given [+masc., +sing.] to John by the postman."
(4) Passive overt agreement: *Les lettres ont* ***été*** *données à Jean par le facteur*.
"The letters [+fem., +plur.] were given [+fem., +plur.] to John by the postman."



Graphic 1. Graphical representation of the second level interaction between factors Agreement (Covert *"donné"* vs. Overt *"données"*) and the spatial distribution (Anterior Left vs. Central Parietal) of the ERP marker observed for the reading of the main verb in the time window 400–600 ms.

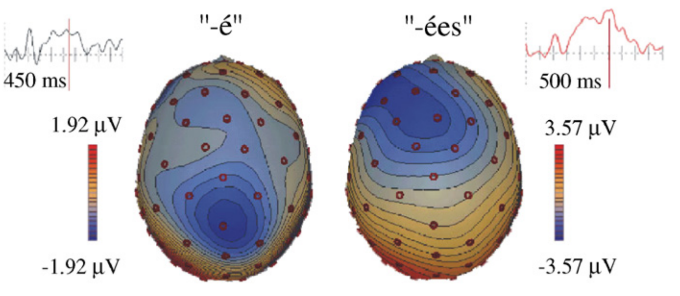


Fig. 2. 2D visualization of the 3D modeling of the spatial distribution of ERP markers to the reading of the main verb, for the overt agreement (right) and the covert agreement (left) conditions.

Visual inspection of evoked traces in time-window 400–600 ms revealed that the reading of both second auxiliaries was associated to the appearance of a left anterior negative component peaking around 450 ms (Fig. 3).

We performed an ANOVA on the same previously mentioned factors (Agreement, Spatial Domain and Electrodes). This analysis confirmed these observations as it revealed no main effect of factor Agreement ($F<1$), the reading of both second auxiliaries being globally associated to average negative scalp potential values. The main effect of Spatial Domain was significant ($F(1,15) = 14.51$, $p<0.05$), reflecting the strong asymmetry of the observed component in favor of spatial domain Anterior Left. The second level interaction between Agreement and Spatial domain remained however non-significant ($F<1$), suggesting that the effect of topographical asymmetry in favor of spatial domain anterior left was independent of the agreement condition considered (Graphic 2).

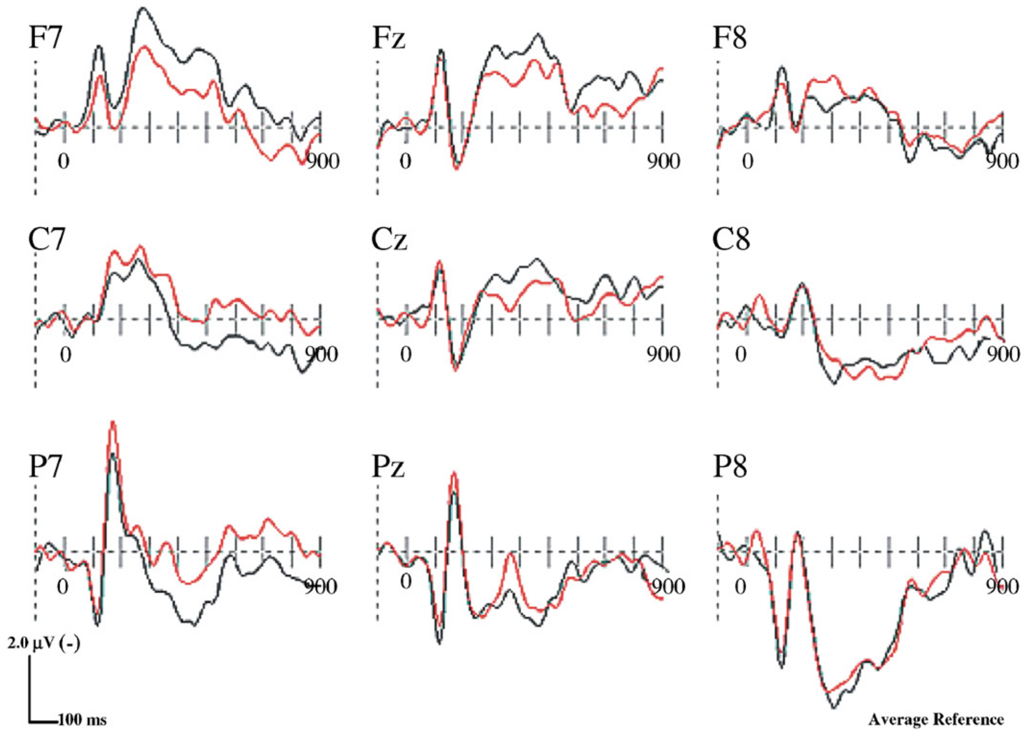


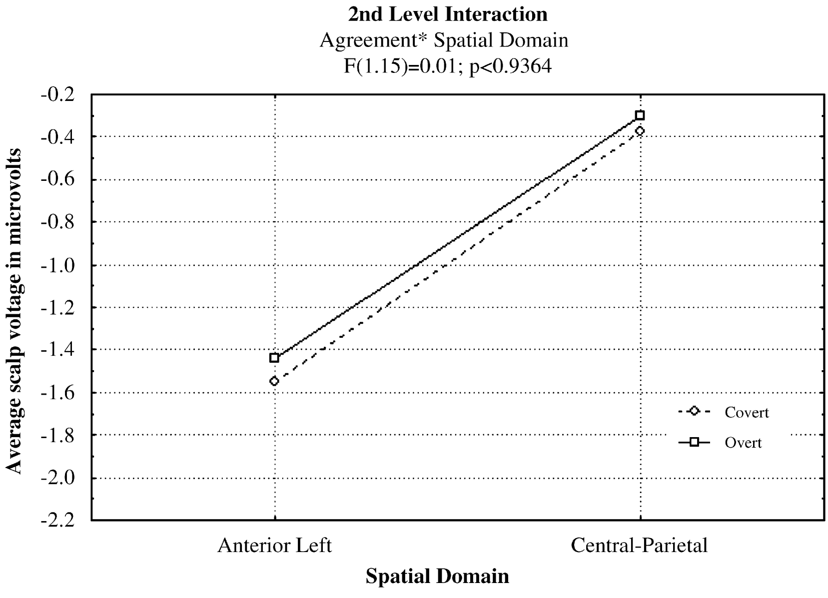
Fig. 3. Single electrodes plots of the event-related brain potentials evoked by the reading of the second auxiliary in the covert agreement (black line) and overt agreement (red line) conditions.

In time window 400–600 ms, the reading of a second auxiliary verb is associated to a LAN effect, whatever the agreement condition is (Fig. 4).

5.4. ERP recordings obtained for the first auxiliary

As a second control, we analyzed the ERP traces obtained for the reading of the first auxiliary in the verbal group, in French the target words *a* and *ont*. The form of the first auxiliary is modified by the agreement in number between the subject and the verb. Its form is *a* [+sing.] in the covert agreement condition (6) and *ont* [+plur.] in the overt agreement condition (7). This is also the case in active sentences where both forms exist depending on the number of the subject (8 and 9). The first auxiliary being present both in active voice and passive voice sentences, it is not giving, in our particular sentence set, any crucial parsing information as far as canonicity of the distribution of thematic roles is concerned.

(6) Passive covert agreement: *Le courrier* ***a*** *été donné à Jean par le facteur.*
"The post [+masc., +sing.] was given [+masc., +sing.] to John by the postman."
(7) Passive overt agreement: *Les lettres* ***ont*** *été données à Jean par le facteur.*
"The letters [+fem., +plur.] were given [+fem., +plur.] to John by the postman."



Graphic 2. Graphical representation of the second level interaction between factors Agreement (Covert "*été*" vs. Overt "*été*") and the spatial distribution (Anterior Left vs. Central Parietal) of the ERP marker observed for the reading of the second auxiliary in the time window 400–600 ms.

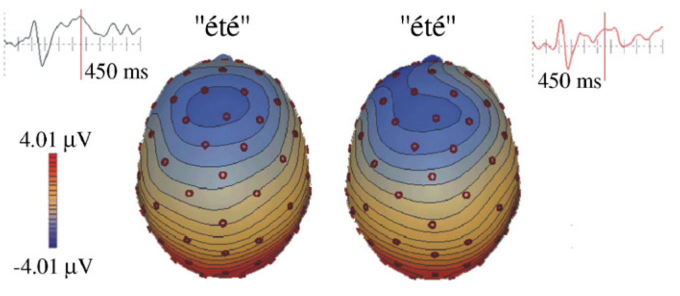


Fig. 4. 2D visualization of the 3D modeling of the spatial distribution of ERP markers to the reading of the second auxiliary, for the overt agreement (right) and the covert agreement (left) conditions.

(8) Active covert agreement: *Le facteur* ***a*** *donné les lettres à Jean.*
"The postman gave the letters to John."

(9) Active overt agreement: *Les postières* ***ont*** *donné les lettres aux gens.*
"The postwomen gave the letters to the people."

Visual inspection of evoked traces in time-window 400–600 ms observed for the reading of the first auxiliary verb in passive sentences shows a broad negative activity, peaking around 450 ms that seems distributed over the two spatial domains, without showing any clear distinction between the two agreement conditions (Fig. 5).

The same statistical analysis including the same factors as described above (Agreement, Spatial Domain and Electrodes) revealed no main effect of factor Agreement ($F<1$), the

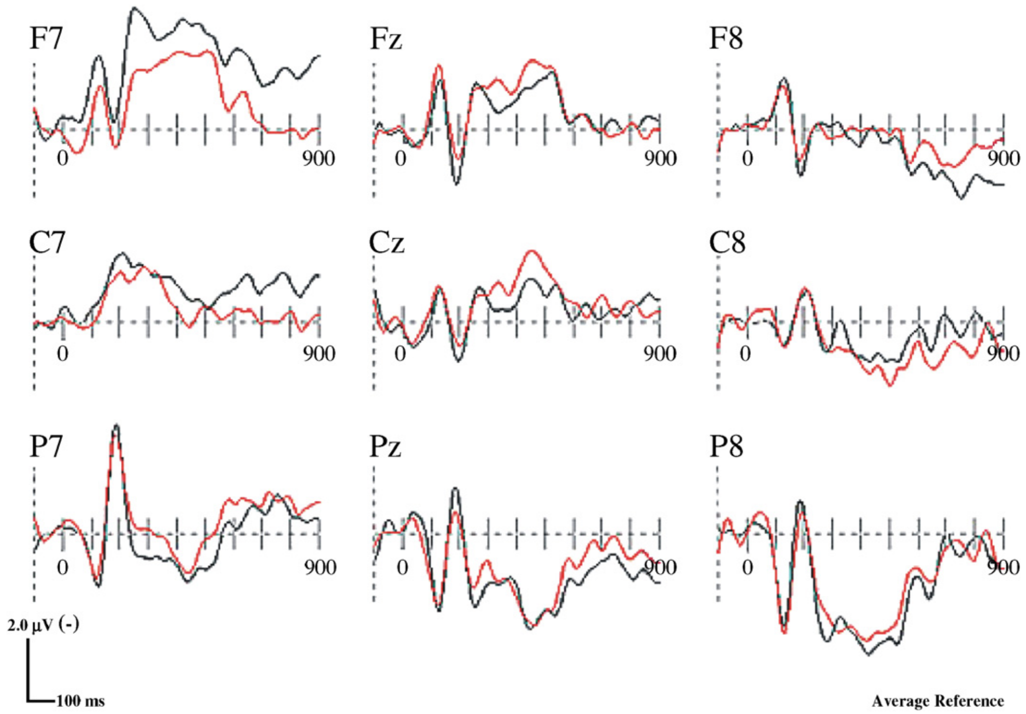


Fig. 5. Single electrodes plots of the event-related brain potentials evoked by the reading of the first auxiliary in the covert agreement (black line) and overt agreement (red line) conditions.

reading of both forms of the first auxiliary was globally associated to negative waves. The main effect of Spatial Domain show a clear tendency ($F(1, 15) = 3.71$, $p = 0.07$), confirming the visual impression that the observed negative wave was spatially distributed over both spatial domains. The second level interaction between Agreement and Spatial domain was non-significant ($F(1, 15) = 3.27$, *n.s.*), confirming that the broad distribution of the observed waveform was true in both agreement conditions.

In time window 400–600 ms, the reading of a first auxiliary verb was associated to a low intensity broadly distributed negative component, showing a tendency to be more negative over left-anterior sites. This effect did not show any significant modulation by agreement conditions (Fig. 6).

5.5. *ERP recordings for semantically and syntactically incongruent words*

Finally, we analyzed ERP traces obtained for the reading of mismatching words causing either structural- (word position exchange: *The post was given to* ***by*** *John the postman*) or semantic-violations (semantically incongruent word insertion: *The post was given to John by the* ***squirrel***). As these were not the main conditions of interest in this study we just report results concerning these words briefly. Data for words creating a structural or semantic violation were analyzed in two time windows, from 250 to 450 ms and from 450 to 900 ms containing, respectively, N400 and P600 markers. Repeated-measures ANOVA were performed on scalp voltage values averaged over each time-window and included as

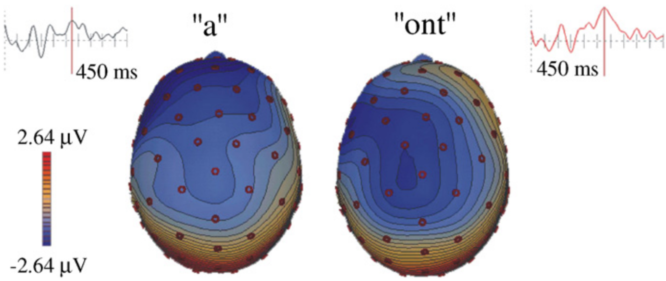


Fig. 6. 2D visualization of the 3D modeling of the spatial distribution of ERP markers to the reading of the first auxiliary, for the overt agreement (right) and the covert agreement (left) conditions.

factors: Violation (2: Congruent/Incongruent), Electrodes (20: Selection of 20 electrodes covering the whole scalp and corresponding to the 10–20 positions: F3, F7, F4, F8, Fz, FCz, C1, C3, C2, C4, Cp1, Cp2, T7, T8, P3, P7, P4, P8, Pz et POz).

5.5.1. Semantic violations

In the 250–450 ms time window, semantic violations were associated to a central parietal negative wave peaking over the whole time-window, with an onset around 250 ms and offset around 450 ms. Average peak latency as measured by an automatic peak detection tool was of 394 ms (SD = 42) at Cz. The spatial distribution of the wave was clearly central-parietal with a unique negative peak between Cz and CPz. The ANOVA revealed a significant main effect of Violation ($F(1,\ 15) = 22.56$, $p<0.05$), average scalp potential values being globally more negative in the semantically incongruent condition. The effect of Electrodes as well as the second level interaction were significant, respectively: ($F(19, 285) = 5.40$, $p<0.05$), and ($F(19,\ 285) = 3.38$, $p<0.05$), reflecting the specific spatial location of the negativity. An LSD post hoc test ($p<0.05$) revealed the presence of the negative marker over electrodes C2, C4, Cp1, Cp2, P3, P4, P8, Pz and POz. This classical spatial distribution and temporal characteristics are typical of the N400 effect, classically observed for semantic violations of the sort. In the later time window between 450 and 900 ms, semantically incongruent words were associated to a positive wave with rather small amplitude. The main effect of conditions was only marginally significant ($F(1, 15) = 4.12$, $p = 0.06$), whereas the main effect of electrodes and the second level interaction were significant, respectively ($F(19, 285) = 7.14$, $p<0.05$) and ($F(19, 285) = 2.55$, $p<0.05$). An LSD post hoc test ($p<0.05$) revealed the presence of a positive component, significant over only 5 electrodes Cp1, Cp2, P8, Pz and POz. Semantically incongruent words in our experiment were associated to an N400 marker in an early time-window followed by a P600 effect in the later time window, between 450 and 900 ms.

5.5.2. Structural violations

Conversely to semantic violations, structural violations did not give rise to any significant effect between 250 and 450 ms. The main effect of condition remained non significant ($F(1,\ 15) = 1.09$, *n.s.*). The effect of factor Electrodes was significant ($F(19, 285) = 11.33$, $p<0.05$) as well as the second level interaction ($F(19, 285) = 2.08$, $p<0.05$), but this did not correspond to any clearly defined event-related potential. In the later time window, structural violations caused a clear P600 effect, peaking at 578 ms (SD = 21) over electrode Cz. All main effects as well as the interaction were significant ($F(1, 15) = 34.58$, $p < 0.05$), ($F(19, 285) = 3.50$, $p < 0.05$) and ($F(19, 285) = 9.61$, $p < 0.05$). An LSD post hoc test ($p < 0.05$) revealed the significant presence of the P600 marker over electrodes: FCz, C1, C3, C2, C4, Cp1, Cp2, P3, P4, Pz, POz (or its frontal negative counterpart, the potential showing an inversion line crossing frontally at the height of frontal temporal electrodes). Words constituting a structural violation were associated to a clear P600 effect, but no identifiable evoked component in the earlier time-window.

6. Discussion

The current experiment was designed to determine the cerebral bases of real-time subject–verb agreement checking using ERP recordings. In particular, we addressed the issue of the functional asymmetry existing in feature-checking processes implicated during sentence comprehension. We also wanted to check if ERP-markers obtained for the processing of correct sentences could help determining if this process was driven by forward-assigning mechanisms or by backward-checking mechanisms. We therefore recorded ERPs while volunteers read passive voice sentences containing past participle subject–verb agreement that was covertly (masculine, singular) or overtly (feminine, plural) marked. In order to ensure that participants correctly read and parsed sentences and that they did not specifically focus on agreement, we inserted, however outside the agreement sensitive portions of test-sentences, semantic or syntactic violations. Analyses of behavioral results showed that participants managed to perform the violation-detection task on mixed semantic or syntactic violations with satisfying success rates demonstrating they had correctly read, parsed and understood the presented sentences. The syntactic structure difference between active voice and passive voice sentences did not interfere with the task confirming that both sentence types were easily processed and comprehended.

6.1. ERP manifestations of agreement checking on the main verb

The only clear effect of agreement in our experiment was observed for the reading of the main verb where a LAN, peaking around 500 ms over electrode F7 appeared in the case of overt agreement (*prononc-**ées***), and a central-parietal wave, peaking around 450 ms at CPz was observed in the case of covert agreement (*prononc-**é***). We proposed to label this second wave as an N400 effect, associated to semantic integration of lexical items (see Kutas & Federmeier, 2000 for a review). We thus observed that the processing of a verb with covert agreement was associated to an N400 effect, whereas the reading of a verb with an overt agreement mark was associated to a LAN. This demonstrates that agreement features can modify ERP waveforms in correct agreement cases, outside the context of syntactic violation detection. This is of first importance because only in this case it is possible to disentangle ERP effects related to the detection and processing of a violation from ERP markers related to the processing of both relevant and correct linguistic information. Moreover, this result shows that the LAN is implicated in correct agreement checking. This extends the different former observations from ERP experiments that demonstrated LAN effects associated to the processing of agreement violation detection (De Vincenzi et al., 2003; Gunter et al., 1997; Kaan, 2002; Morris & Holcomb, 2005; Münte et al., 1997; Rossi et al., 2005). To our knowledge, it is the first time that such kinds of effects are observed in syntactically correct sentential contexts. Thirdly, the asymmetrical observation of the LAN effect being present in the case of overt marking (***-ées***) and not for covert marking (***-é***), suggests that agreement checking is not an automatic and obligatory process, but occurs only for certain features as feminine and plural marking in French. This is in line with the studies that showed asymmetric effects of features in English where plural would be a marked feature whereas singular would remain unmarked (Clifton et al., 1999; Nicol et al., 1997; Pearlmutter, 2000; Pearlmutter et al., 1999). It therefore seems that the LAN effect observed in our experiment reflects agreement checking of overtly marked morphosyntactic features.

6.2. ERP components observed on auxiliaries

For the reading of both the first and second auxiliary, we found no major differences between covert and overt agreement cases, the reading of the second auxiliary being associated to a clear left anterior negative component, a LAN. Reading of the first auxiliary was associated to a low intensity negative wave showing a broad spatial distribution, spanning over central-parietal and anterior left sites with a tendency to show emphasize over anterior left sites. The result observed for the second auxiliary is consistent with former researches that have shown that the LAN effect was associated to the reading of function words indicating complex, non-canonical syntactic constructions (King & Kutas, 1995; Kluender & Kutas, 1993; Matzke, Mai, Nager, Russeler, & Munte, 2002; Rösler et al., 1998; Schlesewsky, Bornkessel, & Frisch, 2003). In French indeed, the form of the second auxiliary is not modified by the agreement between the moved object and the past participle. It remains *été* whether in a covert (1) or overt (2) agreement condition. However, the reading of this function word is highly relevant for the parsing of passive sentences as it indicates the voice of the sentence. This effect was reinforced in our experiment where the appearance of the second auxiliary was the first discriminating factor between active voice (3 and 4) and passive voice sentences (1 and 2). Therefore, we propose that the target word *été* should be read as a function word indicating a non-canonical sentence structure and is thus associated to a LAN marker, whatever the agreement condition is.

(1) Passive Covert agreement: *Le courrier* ***a été*** *donné à Jean par le facteur*.
"The post [+masc., +sing.] was given [+masc., +sing.] to John by the postman."
(2) Passive Overt agreement: *Les lettres* ***ont été*** *données à Jean par le facteur*.
"The letters [+fem., +plur.] were given [+fem., +plur.] to John by the postman."
(3) Active: *Le facteur* ***a*** *donné les lettres à Jean*.
"The postman gave the letters to John."
(4) Active: *Les facteurs* ***ont*** *donné les lettres à Jean*.
"The postmen gave the letters to John."

The case of the first auxiliary is less clear cut and further, specifically designed experiments could address this issue. One limit in our experiment is that the first auxiliaries have an ambiguous lexical-syntactic status. Indeed, they can be processed as auxiliaries only when the next word (the verb) is encountered, otherwise they could have a verbal status (verb *avoir* "to have"). Moreover, the form of *a* and *ont* is not morphologically regular in French, i.e. outside of the auxiliary verb itself there is no straight association of *a* with singular and *ont* with plural. So both are irregular forms and both in this respect mark overt agreement. These auxiliaries are so-called suppletive forms; each form overtly marks what it marks: *a* is overtly marking the singular and *ont* the plural. These forms are thus both specific lexical entities in the sense that speakers cannot deduce from the infinitive form of the verb *avoir* (to have) that singular will be *a* and plural will be *ont*, and therefore both forms must be stored as rote forms. But both forms are also functional in the sense that they mark 'past tense', not modifying the lexical meaning of a verb. In this case, it is noteworthy that neither the ERP marker that stands for lexical semantics (N400) nor the one standing for functional processing (LAN) seem to be clearly identifiable. We therefore propose that both the lexical status ambiguity of the items *a* and *ont* and their statistically weak relevance in our closed-set of sentences caused the appearance of this rather undetermined ERP response, with low intensity broad distributed peaks.

6.3. Functional significance of ERP markers and models of agreement processing

ERP recordings can provide us with crucial temporal information, shedding light on the temporal organization of real time agreement checking. The observed LAN effect for agreement checking peaks around 500 ms. The classical N400 effect, observed for the reading of a verb with covert agreement marking and peaking around 400–450 ms, was sometimes hypothesized to reflect post-lexical effects of semantic integration (e.g. Brown & Hagoort, 1993). In our case, agreement checking would occur approximately in the same time range or, a little later as already suggested in recent work by van den Brink and Hagoort (2004). This observation is in line with the conception that agreement checking is a post-lexical process realized after feature extraction from the mental lexicon and supports the idea that features are stored lexical properties (Chomsky, 1995, 2000; den Dikken, 2000).

Our observation of a LAN effect for the checking of marked features [+fem, +plur], compared to the N400 observed for unmarked features [+masc, +sing], could be of support for backward-tracking models of agreement processing. In particular, if we assume, as suggested by Krott et al. (2006), that the LAN reflects the detection of a mismatch between the presented form of the verb and an awaited form, our observation of a LAN for marked features supports a backward-tracking explanation. Indeed, forward-assigning models assume that features are extracted from the syntactic subject, stored in a working memory buffer and passed-down the syntactic tree till the verb is encountered (e.g. Solomon & Pearlmutter, 2003). According to this model, features of the object agreeing in our sentences with the past-participle, should be transferred down to it and no mismatch between this stored representation and the presented verb would be awaited. Moreover, in our passive sentences: *Les roses ont été données …(The roses were given…)*, there is no other word embedded in the agreement relation between the Head Noun and the Verb, therefore, our observation of a LAN is very unlikely attributable to errors of agreement processing caused for example by distance effects or attraction because agreement errors are observed when the Head Noun and the main Verb are further apart than in our case and when a Noun is inserted between the Head Noun and the main Verb (e.g. Bock & Cutting, 1992; Bock & Eberhard, 1993; Eberhard, 1993). Therefore, if we assume that features had to be transferred from the syntactic subject to the main verb and if we assume the parser to be accurate, there should not have been any mismatch when the main Verb was encountered and both overtly-marked and covertly-marked verbs should have been associated to an N400 effect reflecting there lexical integration. However, this was not the case in our data and overtly marked verbs were on the contrary associated to a LAN effect. Backward-checking models can account for this observation if one assumes that the *−ées* ending in French is not awaited in this situation and constitutes a mismatch between an awaited ending (here presumably the covert *−é* ending) and the presented verbal form *−ées*. This could be attributable to morphological irregularity, or to syntactic analogy with frequent past participle forms and could occur despite the fact that *−ées* is the only grammatically valid ending in this situation. As already mentioned in the introduction, the object past participle agreement in our case does not implicate any irregular morphological ending, the ending *−ées* being on the contrary rather prototypical of feminine and plural features in French (see Meunier & Marslen-Wilson, 2004). The only plausible explanation is therefore that, what is irregular here is the fact that the main verb agrees with the object that was moved to a higher position in the syntactic structure and shares features with the main verb as being now its syntactic subject. It is the case that the *−ées* ending after the auxiliary *avoir* (to have) is a very rare and unusual construction in French that occurs only when the object was fronted via syntactic movement. As a matter of fact, the rule describing object past-participle in French is rather difficult to master and numerous born French speakers do not master it properly. Therefore it is probable as well that the ending **−ées** was not awaited in our sentences as it constitutes an irregular case of agreement compared to the canonical case saying that after the auxiliary *avoir* (to have) a verb belonging to the first French group takes an infinitive ending *−é*. However, even if detected as unexpected, this ending would still be acknowledged as being valid after backward-tracking agreement checking and would therefore not be treated as a syntactic violation, which would have caused a supplementary P600 effect to arise after the LAN marker, which was not the case in our experiment.

Another alternative interpretation proposal can be offered if we consider the LAN effect to reflect general processing of functional marks. In the context of the Minimalist framework (e.g. Chomsky, 1995, 2000) agreement marks are considered as functional morphemes. In this context, there is no theoretical difference between free functional morphemes (independent lexical entities, as auxiliary verbs) or bound functional morphemes (as flectional morphological marks). The hypothesis in this case would be that overt agreement is realized by the addition of a bound functional morpheme to the verbal root whereas in the case of covert agreement there is no added functional morpheme. Therefore, the ending ***−ées*** would be considered as a bound functional morpheme and processed as such. Therefore, if one assumes that the LAN effect reflects the processing of bound functional morphemes as well as free function words, the observation of an N400 effect in the case of covert agreement and of a LAN in the case of overt agreement could be explained by the fact that a supplementary functional mark is detected and processed in the case of overt agreement only, this supplementary functional mark being absent in the case of covert agreement. However this interpretation does not completely rule out the possibility that the LAN effect reflects the processing of unexpected morphological forms, it specifies it by considering that the unexpected morphological forms that are associated to LAN effects are actually processed as bound function-words, considering that flectional morphology is a direct reflection of syntax. Another final explanation that could account for the unexpected nature of the **−ées** ending in French could be derived from the theoretical framework associated with grammatical constructions. The essential distinction within this context is that language is considered to consist of a structured inventory of mappings between the surface forms of utterances and meanings, referred to as grammatical constructions (see Goldberg, 1995). According to this approach, structure to meaning mappings would vary along a continuum of complexity. At one end are single words and fixed holophrases, such as '*Gimme that*' that are processed as unparsed/holistic items (Tomasello, 2003). At the other extreme are complex abstract argument constructions that allow the use of sentences like this one. In this context, the usage-based perspective holds that simple, frequent and prototypical phrasal constructions are parsed with limited computational resources. In this context, one might assume that the prototypical construction for past participles would contain a main verb ending with ***–é,*** and that past participle would be parsed as such, by default. However, when encountering the regular but infrequent ending ***–ées***, a LAN would be triggered by the deviation between the awaited form ***–é***, asked by the prototypical construction form and the presented form ***–ées*** constituting a rule-based modification of agreement (see also Dominey, Inui, & Hoen, 2006). This detection would trigger an agreement checking procedure verifying that the presented verb is valid given the features of the syntactic subject. If the features match, the agreement is still identified as being grammatically valid and no syntactic repair processes are needed. This explains why we did not observe a P600 wave in our examples. Together with former observations, these observations confirm the existence of brain mechanisms underlying agreement checking during the comprehension of sentences and provide strong experimental support to the backward-checking processing model during comprehension. Our results show that agreement features can modify ERP in normal agreement cases, outside the context of syntactic violation detection. The LAN is implicated in normal agreement checking, notably in French which marks feminine and plural. Agreement might be processed differently in languages encoding gender or number agreement differently. This confirms the necessity of comparing languages (see for example: Déprez (1998); Franck et al., 2002; Franck, Vigliocco, Anton-Mendez, Collina, & Frauenfelder, 2007 in press). Further works should however be dedicated to better specifying the difference between unexpected morphological marks and the processing of bound functional morphemes in the context of correct sentence processing.

7. Conclusion

Using ERP recordings we identified a left anterior component peaking around 500 ms, a LAN effect, reflecting the process of real-time agreement checking in French passive sentences. Our observations confirmed the experimental reality of feature checking and identified the electrophysiological correlates of this process. Our results also provide substantial evidence for the observation of an asymmetry between marked and unmarked features as only marked features (feminine, plural) were associated to a LAN effect whereas unmarked features were associated to a classical N400 effect reflecting lexical integration. Finally, we discussed how this result constitutes strong experimental support for a backward-checking model underlying agreement checking during real-time sentence comprehension.

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