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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

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Keywords

Comprehension; Syntax; Noun-Verb Agreement; Electrophysiology; LAN; N400

1. Introduction

In the present research, we addressed the issue of the cerebral bases of processing noun-verb agreement during sentence comprehension. Noun-verb agreement can be described as a morphological modification of a verb conditioned by characteristics of one of its nominal arguments, most commonly the grammatical subject of the sentence. Different theoretical linguistic approaches proposed slightly differing formal views on the processes underlying the syntax of agreement, most notably expressed in the principles and parameters frame (e.g. Chomsky, 1995, 2000) or the head driven phrase structure grammar (e.g. Chung, 1998, cited in Franck, Lassi, Frauendelder and Rizzi, 2006). However, some recurrent aspects can be identified in these approaches: for example morphological characteristics called features, are explicitly represented in the mental lexicon. In this context, agreement was often described as a sharing of features, sometimes named Φ-features, between two lexical items, the noun and the verb (with Φ grouping different lexical properties as number, gender or person, see den Dikken, 2000 for a comprehensive review on the syntax of features). For example, in the simple sentence, *John loves Mary*, the [3rd person] feature of the subject *John* is shared with the verbal root *lov-* whose surface form is modified by the English 3rd person mark *–s*.

The existence in many languages, of reproducible noun-verb agreement error patterns during the production of sentences is at the origin of most of the experimental work that explored the psycholinguistic manifestations of agreement. Research in this domain focused mainly on the attraction phenomenon, quite frequently observed in spontaneous speech (see amongst many others, Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Fayol & Got, 1991; Fayol, Largy and Lemaire, 1994; Franck, Vigliocco and Nicol, 2002; Franck et al., 2006; Hupet, Fayol and Schelstraete, 1998; Vigliocco, Butterworth and Garrett, 1996; Vigliocco, Butterwoth and Semenza, 1995; Vigliocco & Nicol, 1998). This phenomenon

occurs when a noun is embedded inside the subject-verb agreement relation and erroneously causes the verb to agree with itself instead of the head subject as in (1).

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

This line of research could provide strong support for the syntactic hierarchical organization of agreement representation and processing. It also demonstrated linear distance effects, the further the embedded name from the Head Noun, the more probable the agreement mistake, suggesting the existence of a strong working memory component in this processing (see Franck et al., 2006 for recent developments). However, although much attention has been focused on agreement during sentence production, it also plays an important and slightly different role during sentence comprehension and therefore deserves peculiar attention in this context. In sentence (2) for example, the agreement of the verbal root *be*, sharing a [+plural] number feature with the noun *brothers*, allows parsing and interpreting this utterance in a radically different manner than for sentence (3).

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

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

In these examples, correct identification of the two feature sharing arguments allows successful syntactic parsing, leading to different interpretations. Therefore, morphological marks must be detected and agreement must be processed in real-time during sentence comprehension because agreement checking guides the correct attachment of incoming words into the syntactic representation of the sentence and can modify meaning assignment accordingly.

1.1 Psycholinguistic evidence of agreement processing during sentence comprehension

Studies of processing agreement errors or disagreements in sentence comprehension provided first evidence of immediate processing of subject-verb agreement (see Pearlmutter, Garnsey

and Bock, 1999). An asymmetrical effect of agreement processing during correct sentence comprehension was reported by Nicol, Forster and Veres (1997) studying sentences in which an embedded noun was marked in number either as the subject and verb (matching condition) or differently (non matching conditions). In this experiment, reading times (RTs) for non matching sentences as (4) were observed to be significantly higher (+ 124 ms) than for the corresponding singular matching condition (5). RTs were also significantly greater than those obtained for the two other conditions (6 and 7) that showed equivalent RTs.

(4) *The author of the speeches was subsequently well rewarded.*

(5) *The author of the speech was subsequently well rewarded.*

(6) *The authors of the speeches were subsequently well rewarded.*

(7) *The authors of the speech were subsequently well rewarded.*

These results clearly suggest that in English, singular and plural features are not equivalently processed or that the agreement checking procedure triggered by the [+singular] feature differs from that associated with the [+plural] feature. This observation as well as other indices from production errors (Eberhard, 1997) and developmental studies (Franck et al., 2004), led authors to propose that agreement marking was asymmetrical, singular count nouns being hypothesized as being unmarked and plural count nouns as being marked. The observation of mismatching number features interfering with the processing of a subsequent verb could, however, be accounted for by various processing models of feature tracking (Pearlmutter, 2000). In the concluding chapter of their experimental paper, Nicol et al. (1997), suggested that the nature of the computation of subject-verb agreement was "forward-specifying" in production and "backward-checking" in comprehension. According to this hypothesis, features would be extracted from the marked or unmarked verb and then

eventually compared to 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). Forward assigning models state on the contrary that features of the head noun are passed down the syntactic tree and kept in a syntactic working memory buffer until the verb enters the parser, during its forward movement along a sentence. 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). In a recent experiment however, Solomon and Pearlmutter (2003), compared reading times for non-overtly marked singular-biased verbs (*could*, *may,* etc.) which occur with singular participants approximately 70% of the time vs. equibiased modals (*can*, *must,* etc.) occurring equally with plural or singular participants. 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 in a forward process. According to the same authors, subject NP number 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. Therefore, the debate is still largely open to determine: i) if one can identify correlates of asymmetry of markedness in the context of noun verb agreement in order to determine if checking is a processing step that is necessary and automatic or optional and driven by the status of certain features and ii) how this is done during real time sentence comprehension.

In the current experiment we directly addressed these questions using the recording of event related potentials (ERPs). ERPs, thanks to their high temporal resolution (often around 500 samples per second) allow the real time measurement of cortical processes involved in a

variety of cognitive tasks and can for example allow comparing for each single word in a sentence, the presence and dynamic distribution of implicated processes. Using ERPs, some experiments started addressing the cognitive bases of noun-verb agreement during sentence comprehension.

1.2 ***Electrophysiological manifestations of agreement processing***

Few studies, mainly concentrating on incongruity detection paradigms, have been dedicated to the exploration of noun-verb agreement. All could show the presence of an LAN/P600 complex for the processing of agreement violations (Gunter, Stowe and Mulder, 1997; Münte, Szentkuti, Wieringa, Matzke and Johannes, 1997; Rossi, Gugler, Hahne and Friederici, 2005; Morris & Holcomb, 2005) suggesting the implication of the LAN effect in agreement checking, at least in conditions of agreement violations. The LAN (for Left Anterior Negativity) is an ERP marker that was classically associated to the processing of morphosyntactic marks (see Friederici, 2002) and grammatical items indicating syntactically complex phrasal structures (Rösler, Pechmann, Streb, Röder and Hennighausen, 1998; Hoen & Dominey, 2000, 2004). The P600 effect is the ERP marker associated to the processing of syntactic violations (Osterhout & Holcomb, 1992 and see Stemmer & Whitaker, 1998 for review). Kaan (2002) explored the correlates of agreement checking in more detail and used ERP recordings to disentangle the effects of distance and number interference in the processing of subject-verb agreement. In this experiment, linear effects of distance affected participants' behavior but did not influence the amplitude of either the LAN or the P600 effects, suggesting that linear effects did not directly interact with the processes of feature retrieval or repair following the detection of a mismatch. However it remains unclear if the processing of agreement violations is engaging the same feature checking process than correct agreement checking.

From all these observations, it seems that the implication of the LAN effect in online feature tracking during subject-verb agreement is still unclear. Almost all of the mentioned studies are based on violation protocols, or are using extreme language examples as garden-path sentences, known to put a particularly heavy load on the verbal working memory system, hence potentially triggering LAN effects for non-specific mnemonic rather than syntactic reasons. At this point it seems necessary to elaborate paradigms demonstrating immediate feature extraction on the verb in the context of (i) normal sentence processing in (ii) frequent sentence constructions in order to better understand the cortical dynamics and organization of feature tracking.

2. The current study

In order to address this issue, we ran a visual word-by-word ERP experiment on French passive sentences that implicated past participle subject-verb agreement, constituting a well-known example of morphosyntactic marking of a Verb in French (8a, 8b).

2.1 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 prononcé**es** par le président.*

"Insanities [+fem., +plur.] were pronounced [+fém. (***-e***), +plur. (***-s***)] by the President."

In this particular example, the first noun is the syntactic subject of the sentence and agrees in gender and number with the main Verb (*prononcer*). In (8a) the subject *discours* is masculine and singular [+masc., +sing.] and the verb agrees with this subject with a [+masc., +sing.]

covertly marked ending ***-é***. In (8b) the subject *idioties* is feminine and plural [+fem., +plur.] and the verb now agrees with this subject by showing 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 (for example Jakubowicz & Faussart, 1998). In this experiment, we wanted to avoid the distinction between gender agreement and number agreement, in order to stay focused on the general topic of feature checking in agreement and its electrophysiological counterparts. Other authors having demonstrated that ERPs were not dramatically modified by the type of agreement error applied (e.g. Barber & Carreiras, 2003; 2005). We thus decided to compare sentences differing on both features: gender [masc. *vs*. fem.] and number [sing. *vs*. plur.] as in the previously mentioned example (8.a vs. 8.b). 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*. This allowed us to separate thematic structure determination (occurring on the second auxiliary) and agreement feature checking (occurring on the main verb), these two processes being 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 sentence violation detection paradigm mixing semantic and structural violations always occurring after the verbal group in our sentences. Moreover, our test-sentences comprised active and passive voice sentences. That way, the processing of syntactic structures and particularly agreement, was performed outside the scope of the task, therefore any observable effects on normal sentence processing are assumed

[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 pr**ises*** (pronounced /iz/ - "The photos that you took" [+fem., +plur.]) vs. *Le*

to be imputable to natural syntactic/sentential processes, not to any specific task demand (see for example Shtyrov, Pulvermuller, Naatanen and Ilmoniemi, 2003; see also Picton et al., 2000 for methodological concerns).

2.2 Hypotheses

In this experiment, we will restrain our analysis to words from the past participle verbal group, including the two auxiliaries and the main verb of passive sentences. We compare conditions of overt agreement, where the verb exhibits morphosyntactic marks of gender and number agreement (e.g. *prononcées* [+fem., +plur.]) and conditions of covert agreement, where the agreement in gender and number does not implicate extra marking on the verb (e.g. *prononcé* [+masc., +sing.]). Our hypotheses were directly derived and extended from previously mentioned behavioral observations (Nicol et al., 1997; Clifton, Frazier and Deevy, 1999; Pearlmutter et al., 1999; Deevy, 2000; Pearlmutter, 2000).

1- **Immediate Feature Checking:** a finite verb with overt agreement features is checked immediately. Agreement Checking should thus be associated with specific ERP responses, the temporal dynamics of which could help determine when agreement checking occurs.

2- **Selective Feature Checking:** as previously observed in English, checking does not occur for any 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 an LAN effect for the checking of overtly marked features.

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*billet que tu as pr**is*** (pronounced /i/ - "The ticket that you took [+masc.]").

3. Materials and Methods

3.1 Participants

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

3.2 Stimuli

160 French sentences were visually presented word by word, each lasting 400 ms with a 400 ms blank between two successive words (ISI = 800 ms). Amongst those sentences, half (80) were active voice 8 to 9 words sentences following the general schema (Determiner1 - Noun1 – Auxiliary – Verb – Determiner2 - Noun2 – Preposition – (Determiner3) - Noun3) (9). Half (80) were the corresponding 10 to 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."

The two target conditions were included in the passive voice sentences where half (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 all sentences, half contained a structural violation (word position exchange: *The post was given to **by** John the postman*) or a semantic violation (semantically incongruent word insertion: *The post was given to John by the **squirrel***). 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 consequently analyzed ERPs on all passive voice trials.

3.3 Procedure and Task

Participants sat comfortably in a silent room. The 160 sentences were pseudorandomly presented on a 14-inch video screen. The recording session was divided in 4 recording blocks of 80 sentences, separated by three five minute breaks. The total duration of the recording was around 30 minutes. 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.

3.4 EEG recording

During the whole experiment, 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 analogue 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.

3.5 EEG Analysis

3.5.1 Segmentation

Raw EEG recordings were segmented into 1s recording windows, starting 100 ms before and ending 900 ms after target word onset, using the in-built tool from EGI (Netstation ™).

3.5.2 Automatic artifact rejection

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 +/- 200μV; ii) eye blinks, defined as deflections of +/- 70 μV on the EOG electrodes; iii) movements, defined as deflections of +/- 70 μV on all electrodes; iv) transitory amplitude variations of +/- 100 μV and v) ten or more simultaneously artifacted electrodes. Surviving segments were then imported within the software BESA 2000 (MEGIS Software GmbH, Munich, Germany), in its 4.2.24 version, 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 (8m, 8f) out of 21, provided recordings of sufficient quality to be included in further analyzes.

3.5.3 Averaging and Grand-Averaging

Surviving segments were then 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 30Hz. Segments corresponding to correct trial, 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, using the software BESA 2000 (MEGIS Software GmbH, Munich, Germany), in its 4.2.24 version.

3.5.4 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 analyzes 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, $\alpha = .05$) under the software STATISTICA 5.1 (© Statsoft France 1984-1998). 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.

4. Results

In the results section, we will first briefly report the behavioral results observed for the general violation detection task participants, as these assert that participants carefully read and judged the sentences, thereby also accurately parsed them. In a second section we will 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.

4.1 Behavior

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.

4.2 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 to 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.

********** Insert (Fig.1). Approximately here **********

A repeated measures ANOVA analysis was performed on scalp voltage values averaged over time-window 400 to 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 ($F(1, 15) = 12.22$, $p < .05$) suggesting that the effect observed for factor Agreement depended on the spatial domain considered. Subsequent post-hoc analysis using a *Scheffé* test ($\alpha = .05$) revealed an effect of Agreement in the spatial domain Anterior Left ($p < .05$), 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 Graph. 1).

********** Insert (Graph. 1). Approximately here **********

In time window 400 to 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. 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).

********** Insert (Fig.2). Approximately here **********

4.3 ERP recordings obtained on 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."

Visual inspection of evoked traces in time-window 400 to 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).

********** Insert (Fig.3). Approximately here **********

We performed an ANOVA on the same previously mentioned factors. 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 ($F(1, 15) = 14.51$, $p < .05$), 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 (Graph. 2).

********** Insert (Graph 2). Approximately here **********

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

********** Insert (Fig.4). Approximately here **********

4.4 ERP recordings obtained on 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 & 9). The first auxiliary changes morphology, but is not a verb so checking shouldn't occur. The first auxiliary is also present both in active voice and passive voice sentences so it does not constitute a function word giving 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."

(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 to 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).

********** Insert (Fig.5). Approximately here **********

The same statistical analysis including the same factors as described above revealed no main effect of factor Agreement ($F < 1$), the reading of both forms of the first auxiliary being globally associated to negative waves. The main effect of Spatial Domain show a clear tendency ($F(1, 15) = 3.71$, $p = .07$), 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 also 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 to 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).

********** Insert (Fig.6). Approximately here **********

5. Discussion

The current experiment was designed to determine via ERP recording, the cerebral bases of real-time subject-verb agreement checking. In particular, we wanted to identify the involvement of an ERP marker in agreement checking to obtain information about the status of agreement checking in covertly vs. overtly marked conditions as well as to identify the temporal dynamics of this process. We recorded ERPs while volunteers read passive voice sentences containing past participle subject-verb agreement that was covertly (masculine, singular) or overtly (feminine, singular) marked. In order to ensure that participants correctly read and parsed sentences and that they did not specifically focus on agreement as being the main scope of the experiment, we inserted, outside the agreement sensitive portions of test sentences, semantic or syntactic violations. Analyzes 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.

5.1 ERP components observed on auxiliaries

We analyzed the ERP traces obtained for the reading of the three words present in the verbal group of passive voice sentences, the first and second auxiliary and the main verb. 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. This result is

consistent with former research that has shown that the LAN effect was associated to the reading of function words indicating complex, non canonical syntactic constructions (Kluender & Kutas, 1993; King & Kutas, 1995; Rösler et al., 1998; Matzke, Mai, Nager, Russeler and Munte, 2002; Schlesewski, Bornkessel and Frisch, 2003). Indeed in French, 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 (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 lexical item (the verb) is encountered, otherwise they would have a verbal status (verb

avoir "to have"). Thus the electrophysiological response to these items can hardly be hypothesized to be a clear cut LAN, even if in our experiment, all auxiliaries encountered were actually to be processed as auxiliaries. Furthermore, auxiliary verbs in French are marked by number (*a* vs. *ont*) but not gender, and as shown on the main verb ERPs, agreement marking is associated to an LAN. Finally, also they participate to indicate the passive voice of the sentence; first auxiliaries are not completely relevant as the second auxiliary *été* must be encountered to make the final decision. Therefore we propose that both the lexical status ambiguity of the items *a* and *ont* and its statistically weak relevance in our examples caused the appearance of this rather undetermined ERP response, with low intensity broad distributed peaks.

5.2 ERP manifestations of agreement checking on the main verb

The only clear effect of overt agreement was obtained for the reading of the main verb where an LAN, peaking around 500 ms over F7 appeared in the case of overt agreement (*prononc-**ées***), and a central-parietal, peaking around 450 ms at CPz was observed in the case of covert agreement (*prononc-**é***). We propose that this second wave is a classical N400 effect associated to semantic integration of lexical items even if no clear semantic violation is present (see Kutas & Federmeier, 2000 for a review). We thus observed that the processing of a normal verb with covert agreement is associated to an N400 effect whereas the reading of a verb with an overt agreement mark is associated to an LAN ERP marker. This firstly demonstrates that agreement features can modify ERP waveforms in normal agreement cases, outside the context of syntactic violation detection. Secondly, this result shows that the LAN is implicated in normal agreement checking. This extends the different former observations from ERP experiments that demonstrated LAN effects associated to the processing of agreement violation detection (Gunter et al., 1997; Münte et al., 1997; Rossi et al., 2005,

Morris & Holcomb, 2005). Thirdly, the asymmetrical observation of the LAN effect being present in the case of overt marking *-ées* and not whenever covert marking is encountered *-é*, suggests that agreement checking is not obligatory but occurs only for certain features as feminine and plural marking in French. This is in line with the studies having shown asymmetric effects of features in English where plural would be a marked feature whereas singular would remain unmarked (Nicol et al., 1997; Clifton et al., 1999; Pearlmutter et al., 1999; Pearlmutter, 2000). It therefore appears that the LAN effect observed in our experiment reflects agreement checking of overtly marked morphosyntactic features.

5.3 Implications for neurolinguistic models of agreement

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. Indeed, the classical N400 effect, observed in our case for the reading of a verb with covert agreement marking and peaking around 400 to 450 ms, was 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 lexical properties (Chomsky, 1995, 2000; den Dikken, 2000). The observation of asymmetrical ERP results showing that processing overtly or covertly marked verbs trigger different physiological responses could be of support for backward tracking models. Indeed, if feature checking was an obligatory stage, one would have expected an LAN effect in both cases, however checking seems to occur only for overtly marked verbs. For an economy reason, it seems not optimal to store all features encountered during the

reading of the sentence if checking actually occurs only in a low proportion of cases (Pearlmutter et al., 1999). Therefore, our observation could support the idea that agreement checking occurs only for marked features and thanks to a backward tracking mechanism. However, an alternative explanation could be that only marked features are stored in a working memory buffer and passed down the syntactic tree, according to a Forward processing model. Further experiments on agreement processing in correct sentences using ERPs will be dedicated to clarify these issues.

Finally, we might assume that left anterior negative ERP markers as the LAN are generated in the inferior frontal gyrus of the left hemisphere, which is a hypothesis supported by different imaging and clinical observations (see amongst others, Friederici, 2002; ter Keurs, Brown, Hagoort, and Stegeman, 1999). This observation would be in line with clinical observations that have already and for a long time suggested the involvement of the left inferior frontal gyrus (L-IFG; Broca's area) in the on-line processing of morphosyntax as suggested by agrammatic aphasic patients that, consecutively to a lesion in the left perisylvian region, show significant deficits in the processing and production of morphosyntactic markers, including noun-verb agreement (Miceli, Silveri, Villa, and Caramazza, 1984; Miceli, Silveri, Romani and Caramazza, 1989). Using ERP recordings, different authors have demonstrated the implication of an LAN effect for the processing of function-words that disappears, or is replaced by more centro-parietal N400 wave in agrammatic-aphasic patients. These observations all confirm the involvement of Broca's region in the processing of syntactic information (Stromswold, Caplan, Alpert and Rauch, 1996; Just, Carpenter, Keller, Eddy and Thulborn, 1996; Caplan, Alpert and Waters, 1998; Fiebach, Schlesewsky and Friederici, 2001; Röder, Stock, Neville, Bien and Rösler, 2002; Hoen, Pachot-Clouard, Segebarth and Dominey, 2006; Dominey, Hoen, and Inui, 2006).

6. Conclusion

Using ERP recordings we identified a left anterior component peaking around 500 ms, an LAN effect, reflecting the process of online agreement checking in French sentences. Our observations confirmed the experimental reality of feature checking and identified the electrophysiological correlates of this process. In French as in English, certain features as feminine gender and/or plural number seem to be marked and hence potentially trigger checking processes reflected by the LAN effect. Other features as masculine gender and/or singular number seem to be unmarked or at least do not trigger checking in the same circumstances if ever. Future experiments will aim at further clarifying the implication of the LAN effect in agreement checking and will test effects of syntactic structure and distance on the modulations of the LAN effect as well as compare the potential differences between gender and number features marking and checking in French.

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Figure Captions

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.

Graph.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 to 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.

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.

Graph.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 to 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.

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.

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.

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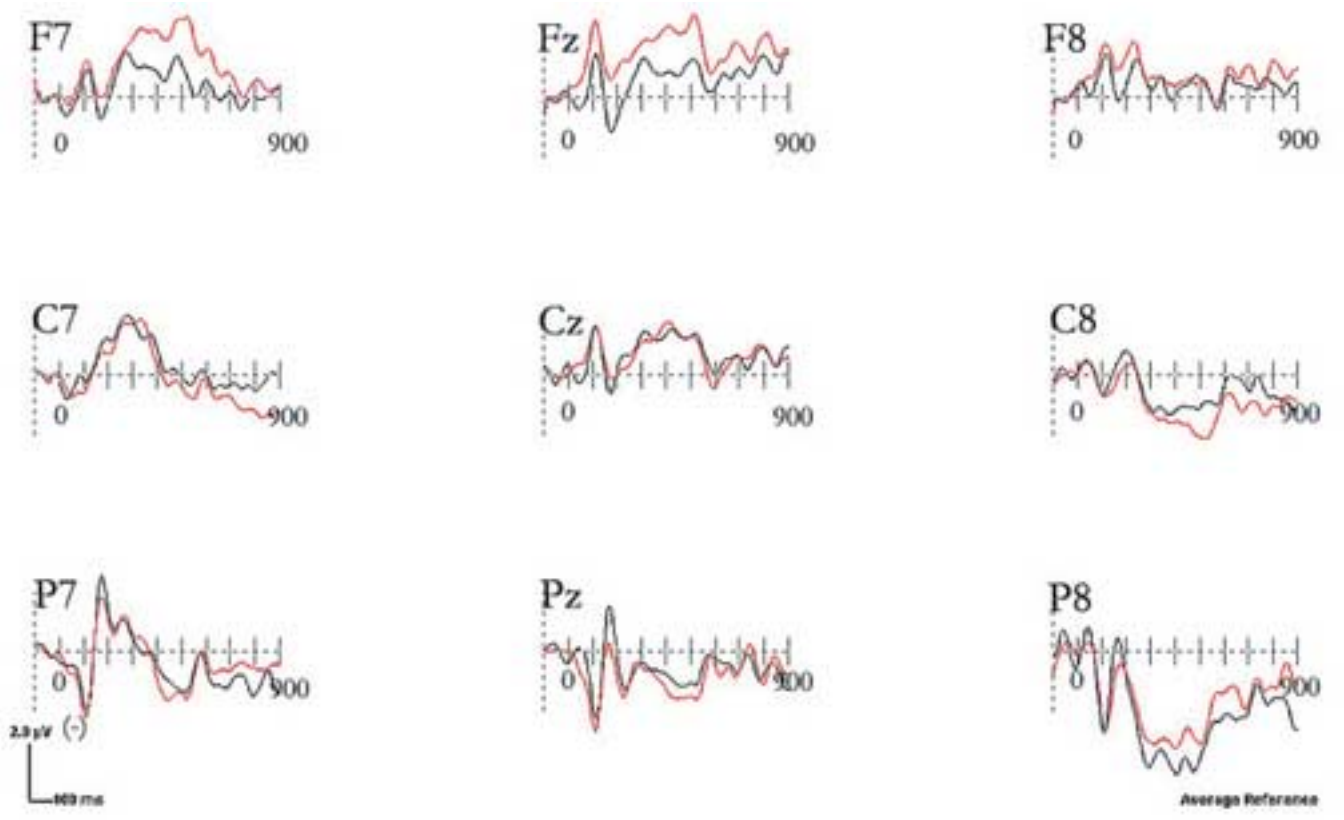

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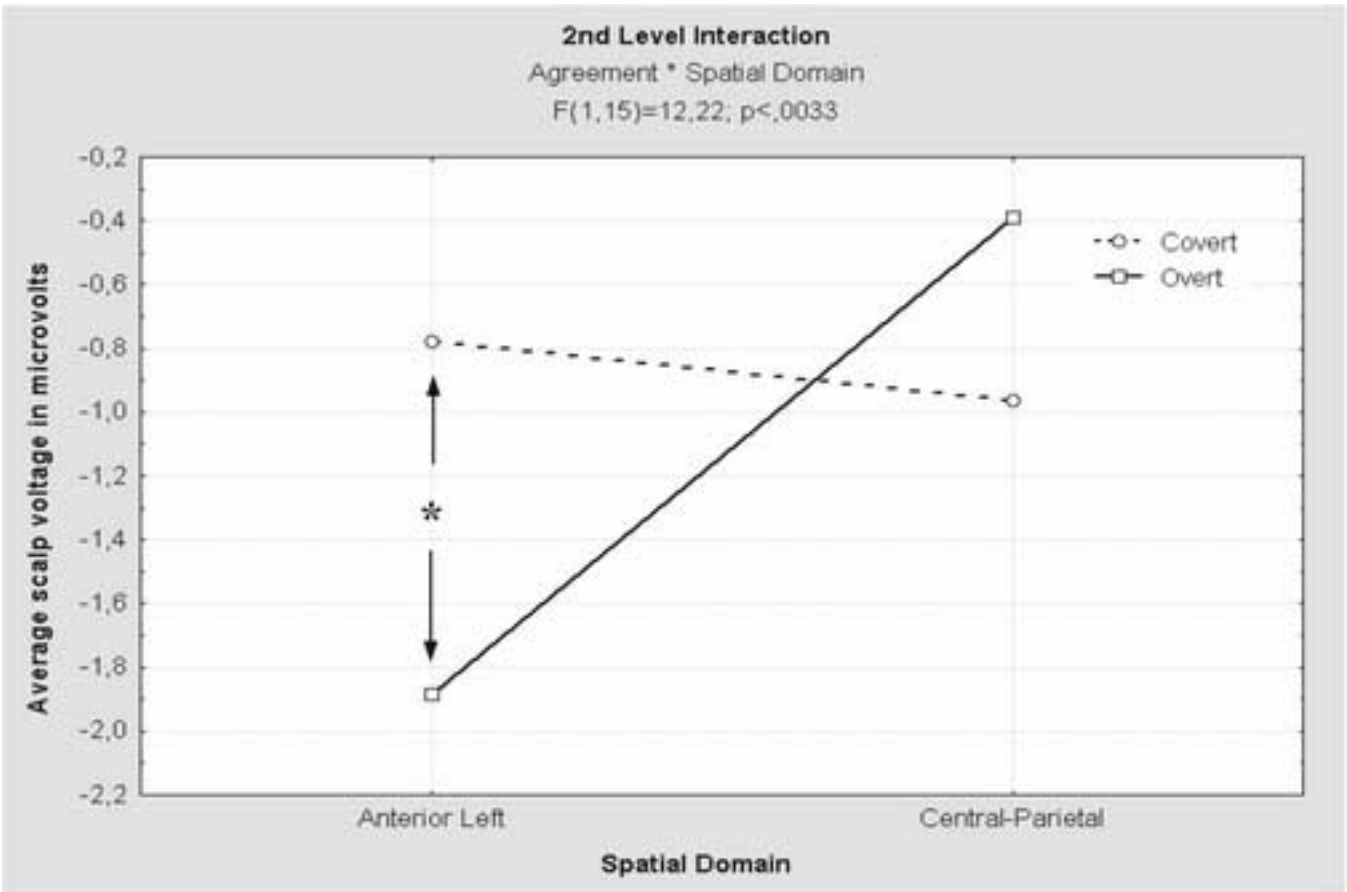

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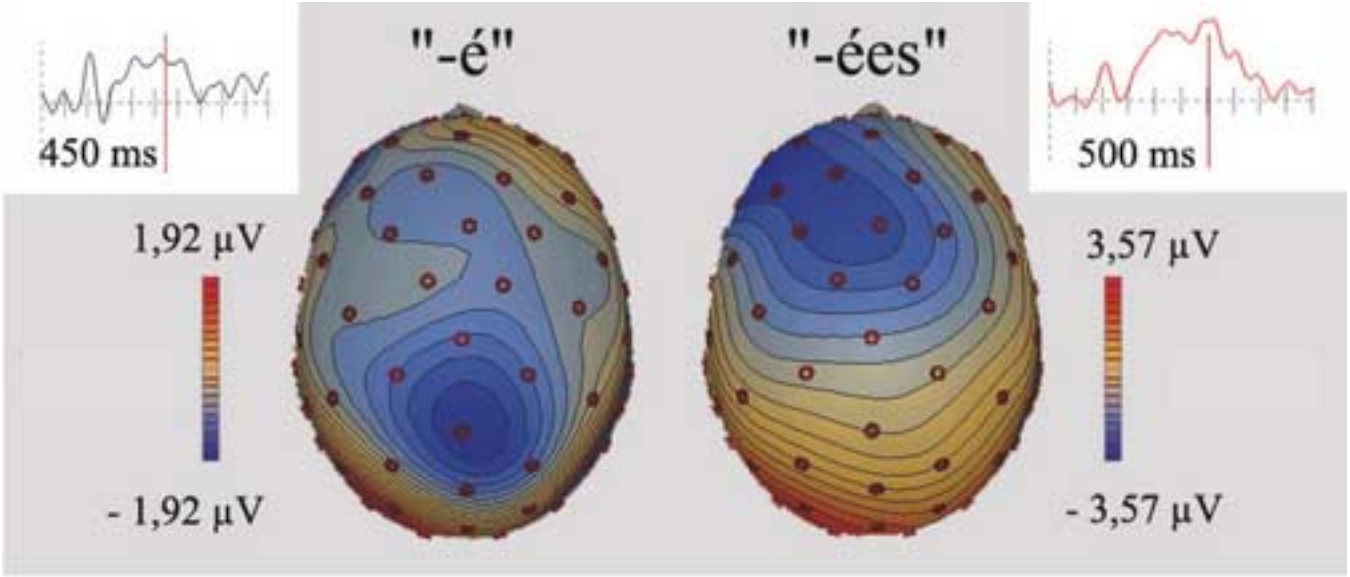

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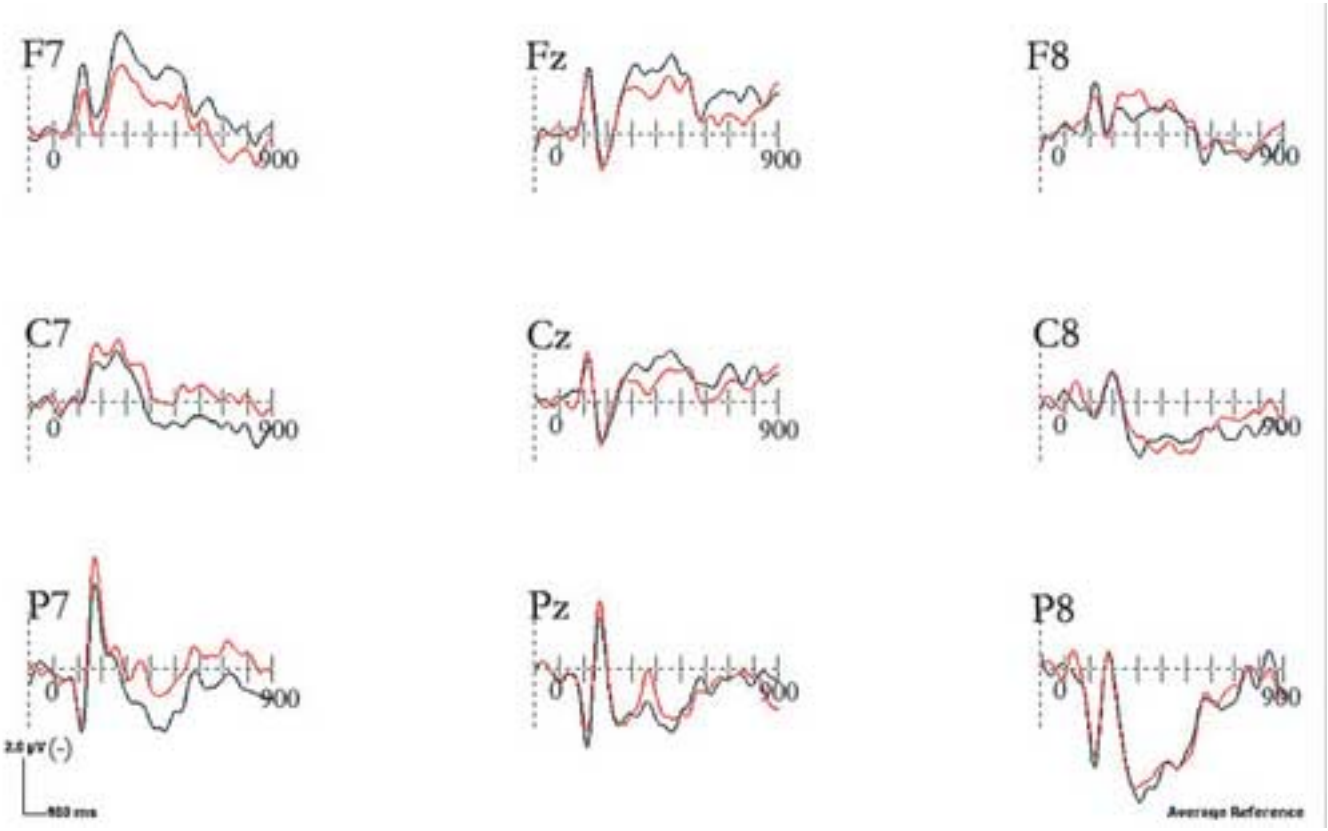

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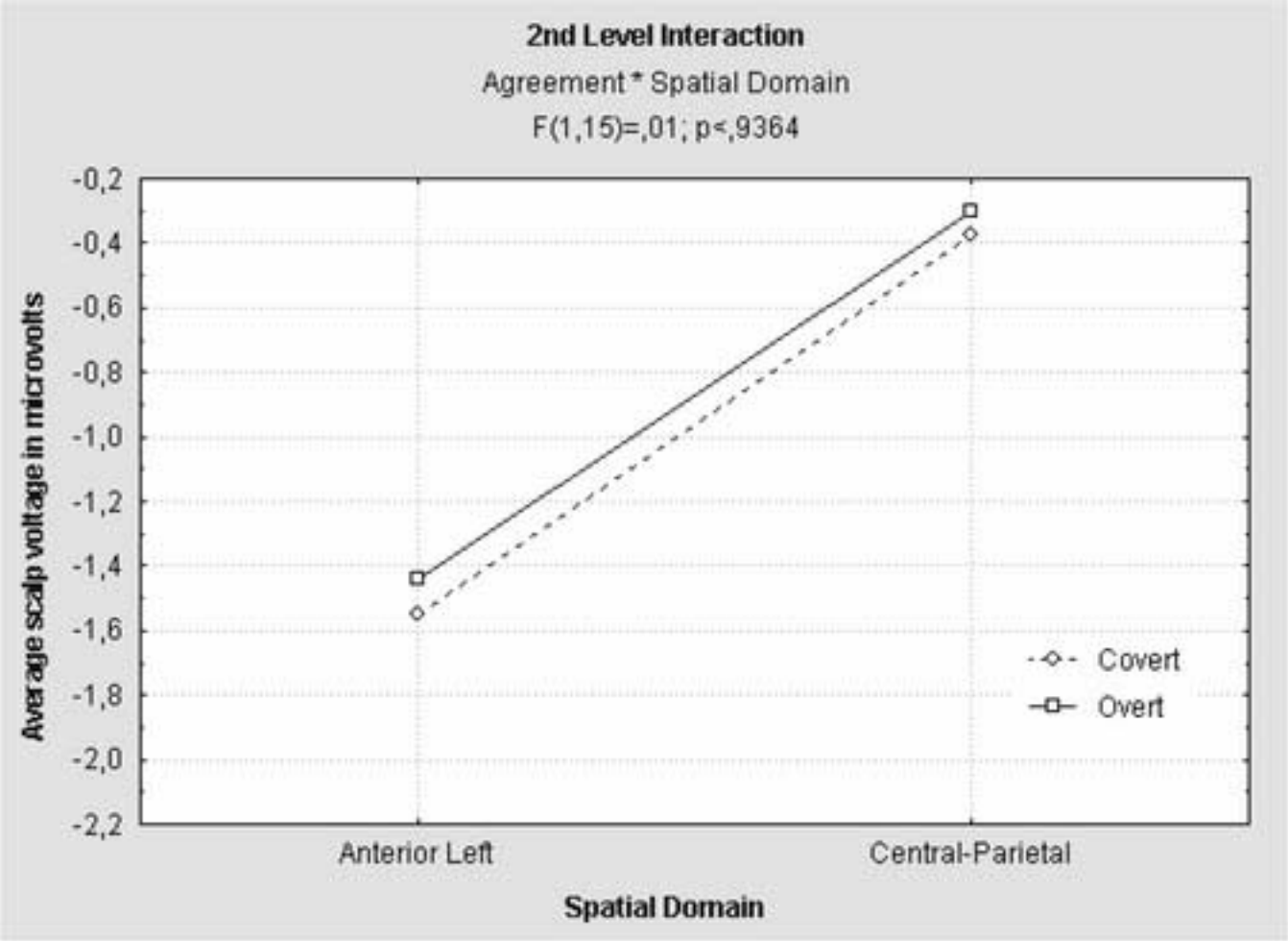

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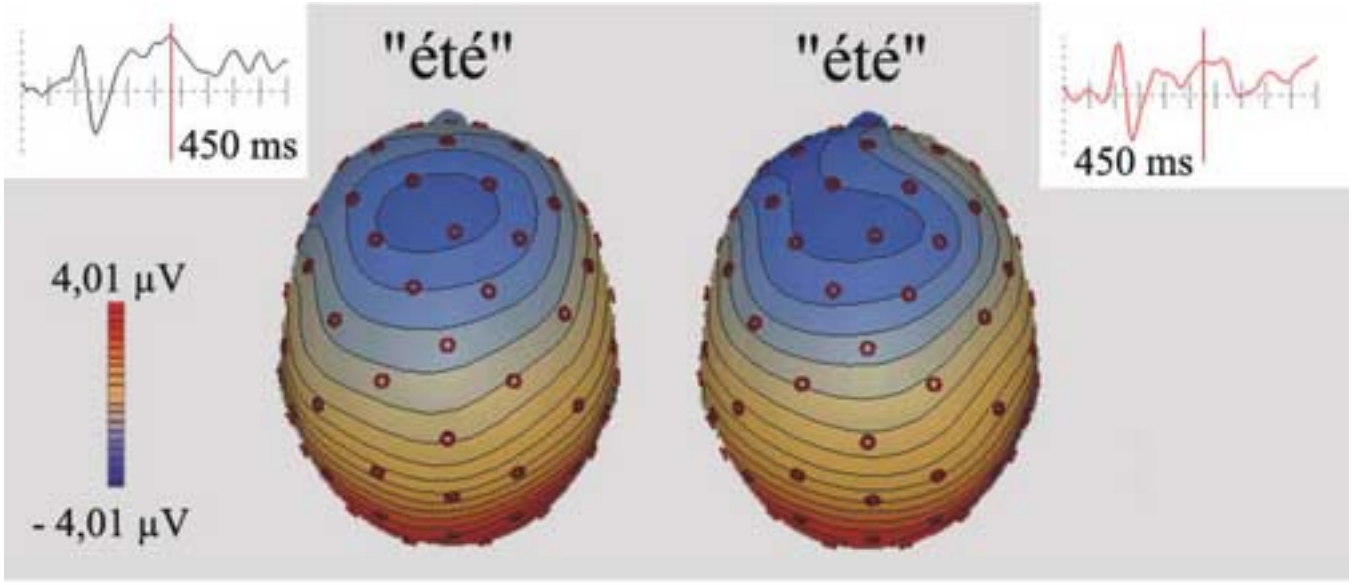

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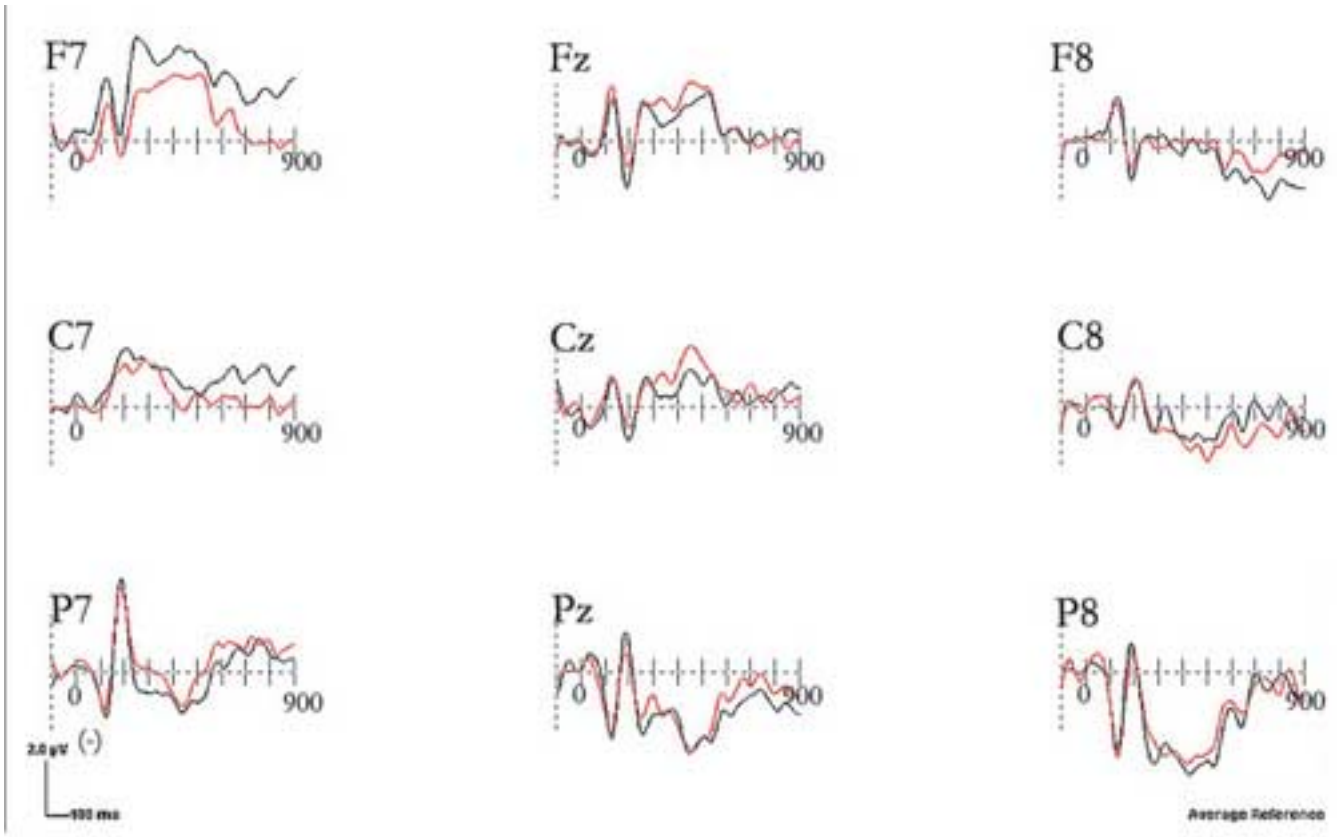

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