Where agreement merges with disagreement: fMRI evidence of subject–verb integration

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ABSTRACT

Language comprehension is incremental, involving the integration of information from different words together with the need to resolve conflicting cues when unexpected information occurs. The present fMRI design seeks to segregate the neuro-anatomical substrates of these two processes by comparing well-formed and ill-formed sentences during subject–verb agreement computation. Our experiment takes advantage of a particular Spanish feature, the *Unagreement* phenomenon: a subject–verb agreement mismatch that results in a grammatical sentence ("Los pintores trajimos…" [The painters$_{3.pl\ (we)}$brought$_{1.pl}$…]). Comprehension of this construction implies a shift in the semantic interpretation of the subject from 3rd-person to 1st-person, enabling the phrase "The painters" to be re-interpreted as "We painters". Our results include firstly a functional dissociation between well-formed and ill-formed sentences with Person Mismatches: while Person Mismatches recruited a fronto-parietal network associated to monitoring operations, grammatical sentences (both *Unagreement* and *Default Agreement*) recruited a fronto-temporal network related to syntactic–semantic integration. Secondly, there was activation in the posterior part of the left middle frontal gyrus for both Person Mismatches and *Unagreement*, reflecting the evaluation of the morpho-syntactic match between agreeing constituents. Thirdly, the left angular gyrus showed increased activation only for *Unagreement*, highlighting its crucial role in the comprehension of semantically complex but non-anomalous constructions. These findings point to a central role of the classic fronto-temporal network, plus two additional nodes: the posterior part of the left middle frontal gyrus and the left angular gyrus; opening new windows to the study of agreement computation and language comprehension.

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Introduction

When we are reading a text such as "…*como si sobre sus cabezas hubiera caído la gota de agua que forman las estalactitas…*" (literally: "…as if on their heads had fallen [the drop of water][1]$_{singular}$ that form$_{plural}$ stalactites…") (Lezama Lima in Paradiso, page 486–487) with apparent incongruities between subject and verbal information, we become aware of the constant computation of grammatical relations (i.e., agreement) that is necessary to combine the different words and grasp the idea that the author wants to convey. The role of agreement computation, one of the pillars of language structure, is to highlight the mutual dependence between different sentence constituents, such as verbs and nouns that display the same number (singular, plural), person (first, second and third) and gender (feminine, masculine) information (also called

agreement features) in many European languages (see MacWhinney et al., 1989, for a discussion of the importance of agreement cues across languages).

Thus, subject–verb agreement plays a crucial role in the multifaceted process of language comprehension because it indicates "who does what" in the sentence. Critically, doing this requires careful unpacking of the linguistic input so that information about participants and their role in discourse is extracted from morphosyntactic cues (Mancini et al., 2013). For example, a first person pronoun or a first person verb are typically linked to the presence of a speaker; similarly, second person is associated with an addressee, while third person invokes the individual(s) being talked about by the speaker and addressee, hence non-participant(s) in discourse (Benveniste, 1966; Harley and Ritter, 2002).

The neurophysiological correlates of subject–verb agreement comprehension have mainly been investigated by comparing the comprehension of ungrammatical sentences which present *agreement feature* mismatches with correct sentences such as in (1) and (2) below (Friederici, 2011, 2012; Friederici et al., 2003; Molinaro et al., 2011).

However, this approach critically confounds the neurophysiological routines involved in agreement comprehension with the ones triggered by the detection of syntactically ill-formed constructions.

(1) *[2]El pintor trajiste los cuadros a la galería *Person Mismatch*
*The painter$_{3.sg}$ brought$_{2.sg}$ the paintings to the gallery

(2) Los pintores trajeron los cuadros a la galería *Default Agreement*
The painters$_{3.pl}$ brought$_{3.pl}$ the paintings to the gallery.

However, a new perspective in understanding these mechanisms is possible if we take advantage of "legal" agreement mismatches (i.e. agreement mismatches that are nevertheless *grammatically correct*) that are available in some languages. One such case is *Unagreement* in Spanish, an agreement pattern characterized by the presence of a morphosyntactic *Person Mismatch* between the subject and the verb (Höhn, 2012; Mancini et al., 2011a, 2013). In (3) below, despite the fact that a third person plural subject is followed by a first person plural verb, a well-formed grammatical Spanish sentence is generated. This morphosyntactic mismatch is overcome by assigning to the 3rd person subject argument a 1st person plural interpretation (from "*The painters*" to "*We painters*"). From the point of view of the discourse representation of the sentence, this person shift for the subject implies a covert integration operation through which the speaker underlying the 1st person plural verb is included in the group of individuals referred to by the subject argument (from "*they*" to "*they + myself*"). In contrast, no such integration operation can be performed in (1), where the non-participant status of the subject form ("*he/she*") is incompatible with the addressee role invoked by the 2nd person verb ("*you*").

(3) Los pintores trajimos los cuadros a la galería *Unagreement*
The painters$_{3.pl}$ brought$_{1.pl}$ the paintings to the gallery.

The uniqueness of the *Unagreement* pattern in (3) resides in the fact that it shares properties with both *Default Agreement* (i.e. grammaticality) and *Person Mismatch* (i.e. morpho-syntactic mismatch), but at the same time it differs from both (as illustrated in Table 1). On the one hand, *Unagreement* shares a subject–verb morpho-syntactic mismatch with person violations but differs from them because it can be successfully integrated. Thus, both person violations and *Unagreement* should trigger processing difficulties in the evaluation of the morpho-syntactic consistency of subject and verb, independently of the grammaticality of the utterance. On the other hand, *Unagreement* shares grammaticality with *Default Agreement*, but unlike this, it requires additional semantic-discourse analyses to overcome the morpho-syntactic incongruity and to perform the person shift (from "*they*" to "*they + myself*", a process referred to as "person anchoring" by Mancini et al., 2013). From the perspective of sentence processing, the "grammatical mismatch" status of *Unagreement* offers therefore the opportunity to isolate the neural mechanisms supporting successful semantic integration that characterize correct sentences, from those underlying the evaluation of the morpho-syntactic subject–verb consistency. Importantly, these two processing steps cannot be disentangled using traditional contrasts between correct and agreement-anomalous sentences because of the impossibility of integrating two utterly mismatching values into a common and meaningful semantic representation.

In the following paragraph, we outline the main electrophysiological and functional neuroimaging findings emerging from the literature on agreement computation and explain the role of this study in filling the gaps of this literature.

Electrophysiological correlates of agreement processing

Agreement processing has been extensively studied using ERPs (Event-Related Potentials), highlighting two different time intervals

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Table 1
Increased processing (+) sensitive to the different linguistic properties of the subject–verb agreement constructions for each experimental condition.

Process	Def. Agreem.	Unagreem.	Person Mism.
Morpho-syntactic consistency evaluation	+	++	++
Grammatical error detection	−	−	+
Semantic-discourse integration	+	++	−

that are sensitive to the presence of subject–verb agreement violations (see Molinaro et al., 2011 for a review). Specifically, in an earlier time interval (between 300 and 500 ms) two effects have been reported. The first is a negative effect with a typical left anterior topographical distribution (Left Anterior Negativity, LAN) (Kutas and Hillyard, 1983) that has been associated to the detection of morphosyntactic violations (Friederici, 2011, 2012; Molinaro et al., 2011; Silva-Pereyra and Carreiras, 2007). The LAN effect differs from a more posteriorly distributed component (N400) found in a similar time interval (Clements-Stephens et al., 2012; Kutas and Federmeier, 2000; Kutas and Hillyard, 1983) and is usually thought to reflect lexical-semantic processing difficulties, as well as contextual and world-knowledge predictability (Hagoort et al., 2004; Kutas and Hillyard, 1984; Molinaro et al., 2010, 2012).

In a subsequent temporal interval, agreement mismatch-related processing has normally been found to give rise to a positive deflection, arising about 600 ms post-stimulus onset (P600) (Barber and Carreiras, 2005; Mancini et al., 2011a,b; Silva-Pereyra and Carreiras, 2007). Several lines of evidence have indicated that the P600 is related to integration efforts between the presently-processed elements and the previous context, based on both semantic and syntactic information (Friederici, 2011; Kaan et al., 2000; Kim and Osterhout, 2005; Kolk et al., 2003; Kuperberg et al., 2007), re-analysis processes (Barber and Carreiras, 2005; Carreiras et al., 2004; Molinaro et al., 2011), or access to discourse-related information (Brouwer et al., 2012; Kaan and Swaab, 2003). From a domain-general perspective, the P600 has been functionally interpreted as indexing conflict-monitoring processes aimed at detecting errors, and triggering corrective actions when there is a mismatch between the predicted and the observed event (van de Meerendonk et al., 2009, 2010, 2011).

While all these studies have investigated the process of subject–verb agreement by comparing anomalous and grammatically correct sentences, Mancini et al. (2011b) used *Unagreement* sentences and compared them to *Default Agreement* and ill-formed patterns (see examples 1, 2 and 3). These authors found an N400 component for both the *Unagreement* and the *Person Mismatch* conditions compared to *Default Agreement*. However, while the negativity elicited by the *Unagreement* extended between 350 and 750 ms mainly in the left posterior electrodes, the *Person Mismatch* elicited a widely distributed and larger negative effect between 350 and 500 ms that was evident also in bilateral frontal and posterior scalp regions. Mancini et al. (2011b) also reported that in contrast to *Unagreement*, person violations generated a P600 effect widely distributed over the scalp.

As for the N400 effect, the differences found in the timing and the topographic distribution of the *Unagreement* and *Person Mismatch* effects could reflect a functional dissociation between the two conditions after around 350 ms. Mancini et al. (2011b) consider that the N400 could be associated in both conditions with the violation of the expectation about the morpho-syntactic verb feature, triggering semantic–pragmatic difficulties in the composition of the speech act participant representation. Nonetheless, these authors note that while in the case of *Person Mismatch* the speech participants underlying subject and verb cannot be integrated into one unitary discourse representation, integration clearly occurs in *Unagreement*. Here, the first person plural interpretation results from including a speaker within the group referred to by "The painters". This functional dissociation possibly implies the engagement of different neural generators (underlying the topographically and temporally dissociable N400 effects) that are respectively