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Morphosyntax can modulate the N400 component: Event related potentials to gender-marked post-nominal adjectives

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Abstract

Event-related potential studies of grammatical gender agreement often report a left anterior negativity (LAN) when agreement violations occur. Some studies have shown that during sentence comprehension gender violations can also interact with semantic processing to modulate a negativity associated with processing meaning – the N400. Given that the LAN and N400 overlap in time, they are identified by their scalp distributions and purported functional roles. Critically, grammatical gender violations also elicit a right posterior positivity that can overlap temporally with and potentially affect the scalp distribution of the LAN/N400. We measured the effect of grammatical gender violations in the LAN/N400 window and late positive component (LPC) during comprehension of Spanish sentences. A post-nominal adjective could either make sense or not, and either agree or disagree in gender with the preceding noun. We observed a negativity to gender agreement violations in the LAN/N400 window (300–500 ms post stimulus onset) that was smaller than the semantic-congruity N400, but overlapped with it in time and distribution. The early portion of the LPC to gender violations was modulated by sentence constraint, occurring as early as 450ms in highly constraining sentences. A subadditive interaction occurred at the later portion of the LPC with equivalent effects for single and double violations (gender and semantics), reflecting a general stage of reprocessing. Overall, our data support models of language comprehension whereby both semantic and morphosyntactic information can affect processing at similar time points.

Keywords

Event related potentials (ERP); N400; left anterior negativity (LAN); late positive component (LPC/P600); grammatical gender agreement; sentence comprehension

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Conflict of interest

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1. Introduction

Understanding the time course of syntactic and semantic processes is critical for any account of sentence comprehension. There are two issues that affect our understanding of this time course. The first is the points in processing at which semantic and syntactic information independently affect comprehension of a word in the sentence context. Some have argued that these levels of processing occur at clearly delineated serial time points (e.g., Ferreira & Clifton, 1986; Frazier, 1987), while others have argued that all information is used as soon as and whenever possible (e.g., Tyler & Marslen-Wilson, 1977). The second issue is the point(s) in processing at which semantic and syntactic processes interact. While some argue that these levels of processing are independent and modular in early processing stages (e.g., Friederici, 2011; Friederici, Gunter, Hahne, & Mauth, 2004; Friederici, Hahne, & Mecklinger, 1996), others have argued that they can interact from early on (e.g., Hagoort, 2003; Wicha, Moreno, & Kutas, 2004). These two issues are intertwined and are most often posed as opposing views as follows. Is sentence parsing modular, prioritizing one type of information, be it semantic or syntactic? Or is the parser blind to the information source, using whatever is available to guide sentence processing at any point? This study uses event related potentials (ERP), a measure of real time brain activity, during sentence comprehension to assess the time course of syntax and semantics while processing a post-nominal adjective in a sentence context. Post-nominal adjectives provide an understudied point in processing, allowing us to observe the effects of manipulating both semantic and morphosyntactic information at the same position in the sentence. Specifically, we manipulated grammatical gender agreement and semantic congruity to measure when each of these factors affects comprehension. ERPs are particularly useful for studying these issues given their sensitivity to different linguistic factors and high temporal resolution on the order of milliseconds. Specific ERP components – positive or negative voltage deflections – have been ascribed to specific linguistic processes based on what factors modulate their amplitude (Osterhout & Nicol, 1999). We take advantage of these components to determine when semantic and morphosyntactic cues affect comprehension of a post-nominal adjective, and when they interact.

1.1 ERP indices of gender agreement and semantic congruity

A small number of ERP components have been identified as indices of sentence comprehension, namely the N400, P600, also referred to as the late positive component (LPC), and the left anterior negativity (LAN). The physiological nature of these components and the cognitive processes that they reflect are still being understood. Nevertheless, they tend to occur in response to specific linguistic events, making them useful in inferring different stages of processing, such as morpho-syntactic agreement and semantic congruity. The N400 is a robust ERP component related to semantic processing – a broadly distributed negativity that peaks around 400ms after stimulus onset (Kutas & Hillyard, 1980). The N400 occurs in response to comprehending any meaningful or potentially meaningful word, but it is not specific to linguistic stimuli (see Kutas & Federmeier, 2011). The N400 is thought to be an index of multimodal access to meaningful information from memory, given that it is observed to both linguistic and non-linguistic stimuli (Kutas & Federmeier, 2011; Niedeggen, Rösler, & Jost, 2003; Salillas & Wicha, 2012; Sitnikova, Holcomb, Kiyonaga, & Kuperberg, 2008). The amplitude of the N400 is inversely related to the fit of a word in its preceding sentence context, with anomalous or less probable words eliciting larger amplitude than congruous ones. The other two ERP components have been related more to syntactic than semantic processes, but their specificity to syntactic or even linguistic stimuli is still debated. The LPC is a slow positive wave that varies in onset and duration, but occurs after the N400. It was originally described with maximum amplitude at 600ms after stimulus onset over posterior electrodes, and was thought to reflect processes specific to syntax

(Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). However, there is accumulating evidence that the LPC reflects general cognitive processes related to language comprehension (e.g., Coulson, King, & Kutas, 1998; Friederici & Weissenborn, 2007; for a review, Kuperberg, 2007). Finally, the LAN is a negativity that occurs between 300 and 450ms after stimulus onset. The name reflects its typical scalp distribution over left anterior recording sites, though some have observed a bilateral (Hagoort, Wassenaar, & Brown, 2003) or more widespread distribution of a LAN-like effect (Molinaro, Barber, & Carreiras, 2011; Münte, Matzke, & Johannes, 1997). The LAN is thought to index either first-pass, initial syntactic-structure building (e.g., the left anterior negativity, Friederici, 1995, 2011; Friederici et al., 1996) or a more general cognitive process, such as working memory (Kluender & Kutas, 1993). There is also some debate over whether the LAN is a separate component from the N400 (Service, Helenius, Maury, & Salmelin, 2007). We discuss the relevance of each of these components to the current study of gender agreement and semantic congruity in comprehending post-nominal adjectives.

Grammatical gender is an inherent syntactic property of lexical items in languages that have a grammatical gender system, like Spanish (Corbett, 1991; Hockett, 1958). Although grammatical gender can have a semantic basis (e.g., biologically female things tend to be marked with feminine gender), genders are essentially classes of nouns that require other words to agree with them syntactically. Every noun in Spanish, both animate (e.g., *perro*/*perra* – dog_{masc}/dog_{fem}) and inanimate (e.g., mesa/carro – $\text{table}_{\text{fem}}$/$\text{car}_{\text{masc}}$), is either masculine or feminine, and adjectives and determiners must agree in gender with the nouns they modify. This renders gender agreement a morphosyntactic rule of Spanish, similar to person and number agreement. In the case of Spanish, the rules for gender assignment are largely based on the phonological features of a noun (e.g., 99.9% of words ending in –o are masculine, while 96.4% of words ending in –a are feminine, Harris, 1991). Spanish adjectives are more often post-nominal than pre-nominal, and are marked for the gender of the modified noun (e.g., *la mesa larga* 'the_{fem} $\text{table}_{\text{fem}}$ long_{fem}'; *el carro largo* 'the_{masc} car_{masc} $\text{long}_{\text{masc}}$'). Speakers of languages like Spanish are very sensitive to these morphological cues during comprehension (Barber & Carreiras, 2003; Bates, Devescovi, Pizzamiglio, D'Amico, & Hernandez, 1995; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005). There is even evidence that grammatical gender, despite being a syntactic element, can influence semantic processes during comprehension (Hagoort, 2003; Wicha et al., 2004; Wicha et al., 2005) and that native speakers of gender-marked languages use these cues to assess expectations, made based on context, for upcoming words in the sentence (Van Berkum et al., 2005; Wicha, Bates, Moreno, & Kutas, 2003; Wicha, Moreno, & Kutas, 2003). Yet, there is still debate over the temporal dynamics of processing morphosyntactic cues, like gender, and whether or not morphosyntactic processes can influence semantic processes.

A common method for studying this time course is to invoke errors of syntax or semantics as probes into the points in comprehension where these processes occur. That is, it is assumed that the violations elicit a brain response (or a disruption in performance) at the time when this type of information is relevant for comprehension. The primary ERP component associated with gender agreement violations in sentence comprehension is the LPC. Although the LPC is reliably elicited by agreement violations (e.g., Hagoort et al., 1993; Osterhout & Holcomb, 1992; Vos, Gunter, Kolk, & Mulder, 2001; Wicha, Bates, et al., 2003), it is not specific to agreement processes (Coulson et al., 1998; Friederici, Pfeifer, & Hahne, 1993; Gunter, Stowe, & Mulder, 1997; Hahne & Friederici, 1999; Neville, Nicol, Barss, Forster, & Garrett, 1991), nor is it specific to syntactic processes (Coulson & Kutas, 2001; Hoeks, Stowe, & Doedens, 2004; Kim & Osterhout, 2005; Kolk, Chwilla, van Herten, & Oor, 2003; Kuperberg, 2007; Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Münte, Heinze, Matzke, Wieringa, & Johannes, 1998; Stroud & Phillips, 2012; Van Herten, Kolk, & Chwilla, 2005), or even to linguistic stimuli (Patel, Gibson, Ratner, Besson, & Holcomb, 1998). It has been suggested that the LPC may consist of at least two separate processing stages, the first related specifically to syntactic-like processes (LPCa) and the second reflecting a more general reanalysis or integration stage of processing (LPCb) (Barber & Carreiras, 2005; Hagoort, Brown, & Osterhout, 1999). Based on this two-stage processing hypothesis, gender-agreement violations, but not semantic congruity violations, should modulate LPCa amplitude, while both syntactic and semantic violations should modulate LPCb amplitude, especially since post-nominal adjectives may necessarily invoke reprocessing of the preceding noun.

Although it has been argued that languages that rely more heavily on morphosyntax are likely to show a LAN (Friederici & Weissenborn, 2007), the LAN has been less reliably observed than the LPC in response to morphosyntactic violations during sentence comprehension (e.g., Bañón, Fiorentino, & Gabriele, 2012; Barber & Carreiras, 2005; Hahne & Friederici, 1999; Koester, Gunter, & Wagner, 2007; Morris & Holcomb, 2005; Rösler, Pütz, Friederici, & Hahne, 1993; Wicha et al., 2004). Given that the LAN overlaps in time with the N400, these components are distinguished primarily based on scalp topography (the N400 generally occurs more posteriorly than the LAN), and are functionally defined based on the stimuli or task that invoke them (syntactic versus semantic, respectively). N400-like responses to syntactic violations have been reported, but rarely and generally in experiments of second language acquisition, where an N400 occurs to syntactic violations early in acquiring a second language, then is replaced by an LPC with further second language attainment (Osterhout et al., 2008). There are however some reports of robust effects of gender-agreement on the N400 in native speakers of a language. Barber and Carreiras (2005) observed an N400 effect to gender-agreement violations for article-noun and noun-adjective word pairs in native Spanish speakers (e.g., *el/la piano* – the_{masc}/the_{fem} $\text{piano}_{\text{masc}}$; *faro alto/alta* – $\text{lighthouse}_{\text{masc}}$ $\text{tall}_{\text{masc}}$/$\text{tall}_{\text{fem}}$). They argued that when word pairs were presented in isolation there was no syntactic structure to support them, causing a local lexical integration problem, indexed by an N400. In contrast when the word pairs were embedded in a sentence context they elicited a negativity with a left anterior distribution followed by a LPC. The authors argued that this negativity was a LAN, indexing syntactic structure building for the words embedded in a sentence context, and not an N400.

However, some researchers have proposed that the LAN may be related to the N400 (Osterhout & Nicol, 1999), and there is some evidence that the LAN and N400 have overlapping neural sources (Service et al., 2007). Moreover, the LPC to syntactic violations is often larger and starts earlier than that for semantic violations (e.g., Hagoort, 2003; Wicha et al., 2004), causing temporal overlap of the N400/LAN and P600/LPC. If the neural generators of the N400 and LPC produce activity that overlaps in time, then the activity visible at the scalp will be the summation of these two latent sources (i.e., Helmholtz superposition rule). Given that the LPC tends to have maximum amplitude over right posterior sites, it may obscure a small negativity for syntactic violations in this region. This could create the appearance of a left anterior distribution in the N400/LAN time window. In the current study we measure the activity elicited by gender agreement in the N400/LAN time window and determine the extent to which an overlap in time with the LPC affects its scalp distribution. We manipulate contextual constraint, which modulates LPC amplitude but not the N400 (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007), in an attempt to temporally dissociate the effects of gender agreement on the overlapping LPC and N400/LAN.

Thus far we have discussed the temporal dynamics of semantic congruity and gender agreement independently. With regard to the interaction between syntax and semantics, there is accumulating evidence that both sources of information can affect multiple ERP components, and by inference multiple stages of processing, with interactions between syntax and semantics as early as the N400 (Hagoort, 2003; Palolahti, Leino, Jokela, Kopra, & Paavilainen, 2005; Wicha et al., 2004; Zhou et al., 2010). Importantly, gender agreement violations have been shown to modulate the N400 in interaction with semantic congruity violations (Hagoort, 2003; Wicha et al., 2004) – though not always (Martin-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006). Hagoort (2003) referred to this interaction between gender and semantics as a "syntactic boosting" of the N400, and interpreted this as evidence that syntactic information can influence semantic processes. In his study, a critical noun in Dutch sentences either agreed or disagreed in gender or number with the preceding determiner, and either made sense or not with a preceding (pre-nominal) adjective (e.g., English translation – *The*$_{common/neutral}$ *broken/honest umbrella*$_{common}$ *is in the garage*). The critical finding was that nouns that disagreed grammatically with the determiner and semantically with the adjective elicited an N400 amplitude that was significantly larger compared to the semantic violations alone. Interestingly, when the gender-agreement violations occurred in sentence final position, there was a main effect of gender agreement, rather than an interaction with semantic congruity, on the N400 amplitude. The author argued that this effect might have resulted from sentence wrap up, similar to what was observed for sentence final semantic violations. Wicha, Moreno and Kutas (2004) also observed a syntactic boosting effect on the N400 for nouns in Spanish sentences. Here sentence medial article-noun pairs either matched in grammatical gender or not, and either made sense with the preceding context or not (e.g., *Caperucita Roja cargaba la comida para su abuela en una/un canasta/corona…* – Red Riding Hood carried the food for her grandmother in a$_{fem}$/a$_{masc}$ basket$_{fem}$/crown$_{fem}$…). A boosting effect on the N400 amplitude, similar to that found by Hagoort (2003), was observed for combined violations relative to semantic violations at the target noun (i.e., a$_{masc}$ crown$_{fem}$ versus a$_{fem}$ crown$_{fem}$).

Given that the N400 has traditionally been associated with semantic processing, what might this syntactic boosting of the N400 reflect? Gender agreement in Dutch and Spanish, the 2 languages where this boosting was observed, is purely a syntactic property of a word, and does not contribute directly to the meaning of a word (e.g., there is no inherent difference in meaning between *un* and *una* – 'the$_{masc/fem}$'). Therefore, the boosting must reflect that syntactic level information influences semantic processing in real time. Hagoort (2003) argued that this boosting effect indicates that syntax can influence semantic integration, in particular when the syntactic process is deterministic – e.g., an article and noun either agree in gender or they do not, making a judgment about the anomaly straightforward and influential in the process of semantic integration. In other words, semantic integration is more difficult in the presence of a syntactic processing problem. An alternative explanation for the boosting effect may come from the accumulating evidence that the N400 reflects prediction of specific words (DeLong, Urbach, & Kutas, 2005; Federmeier, 2007; Federmeier & Kutas, 1999; Kutas & Federmeier, 2000, 2011; Lau, Almeida, Hines, & Poeppel, 2009; Lau, Phillips, & Poeppel, 2008), including their morphosyntactic properties (Otten, Nieuwland, & Van Berkum, 2007; Otten & Van Berkum, 2008; Van Berkum et al., 2005; Wicha, Bates, et al., 2003; Wicha, Moreno, et al., 2003; Wicha et al., 2004; Wicha et al., 2005). In these studies, a target noun was moderately or highly expected based on sentence context, and a gender-marked article (or pre-nominal adjective) could either match in gender with the upcoming noun or not. Articles that mismatched in gender with the anticipated, but yet unseen noun elicited a violation of expectation, typically (but not always) an N400, compared to articles that matched in gender. This indicates that readers were anticipating a specific gender-marked word by the time the article was presented. Thus, it is plausible that this syntactic boosting of the N400 is caused by a violation of lexical expectation. That is, violating an expectation for a specific gender-marked word may create additional processing costs at the stage reflected by the N400, compared to violating the semantic expectation alone.

A third potential explanation for this boosting effect may be an idiosyncrasy in the stimuli used in these 2 studies. A subsequent study argued that the syntactic boosting of the N400 was a product of how the violations of gender and semantics were created (Martin-Loeches et al., 2006). Hagoort (2003) and Wicha et al (2004) used article-adjective-noun and article-noun pairs, respectively, where the gender-agreement and semantic congruity violations were created using different words in the noun phrase. For example, Wicha et al (2004) manipulated the article to create a gender agreement violation (e.g., *una*, un) and the noun to create a semantic anomaly (e.g., *canasta/corona*). Martin-Loeches et al (2006) conducted a study based on the Wicha et al study, but manipulated both gender and semantics at a post-nominal adjective in short Spanish sentences (e.g., *El sentimiento profundo/profunda / peludo/peluda emociona* - The$_{masc}$ deep$_{masc}$/deep$_{fem}$/hairy$_{masc}$ /hairy$_{fem}$ feeling$_{masc}$ moves.). They observed no effect of gender-agreement on the N400, either alone or in interaction with semantic congruity. An interaction occurred only at the LPC. The authors argued that this was evidence for early independent processing of syntax and semantics, yet the stimuli may again explain this difference in results.

First, it is not clear that the effects from the nouns in the first two studies are directly comparable to the effects from the adjectives in the third study. Adjectives elicit reliable but smaller N400 amplitude than nouns (Prior & Bentin, 2006), which could damp down a small effect of a gender agreement violation. Second, the amount of context leading up to the target word differed significantly across the studies. Hagoort (2003) and Wicha et al (2004) used rich natural sentence contexts with sentence medial or sentence final target noun phrases. In the Martin-Loeches et al study (2006), sentence initial noun phrases were used. The target adjective was preceded only by an article and noun, creating weakly constraining (and somewhat unnatural) contexts. The average cloze probability, only 20% on average, elicited relatively small N400 amplitude even for semantic violations (c.f., Hagoort, 2003). This could have impacted any N400 effect from gender agreement violations, either by again damping down the much smaller boosting effect, or by not allowing the expectation of a specific gender-marked word. The goal of the current study was to determine if gender agreement violations can modulate the N400 to post-nominal adjectives embedded in richer and more natural sentences.

In the current study, native speakers of Spanish read sentences with a target post-nominal adjective that could create a gender agreement violation, semantic congruity violation or both, similar to Martin Loeches et al (2006). Critically, the sentences were written to range in expectation for the post-nominal adjective with high expectation on average, see Table 1. We predicted that we would observe “syntactic boosting” of the N400 in these more constraining sentences, as did Hagoort (2003) and Wicha et al (2004), and an interaction between semantic and gender agreement at the LPC similar to Wicha et al (2004).

2. Materials and Methods

2.1 Participants

Thirty-two right-handed (based on an abridged Edinburg Handedness questionnaire), native speakers of Spanish (exposure to Spanish from birth) were recruited from the University of Texas at San Antonio (15 female; mean age 20.6 years, range 18 to 35 years). Six additional participants’ data were excluded from analysis due to excessive data loss. All participants had normal or corrected-to normal vision and no cognitive or neurological impairments that could affect the task. The participants’ daily language environment consisted of both Spanish and English. Therefore, several measures of language proficiency were used to ensure that all participants were fluent in Spanish: the Boston Naming Test in English and Spanish (Kaplan, Goodglass, & Weintraub, 1983; Kohnert, Hernandez, & Bates, 1998), the Verbal Fluency Test in English and Spanish (Benton, Hamsher, & Sivan, 1994; Moreno, Federmeier, & Kutas, 2002), and an extensive language history questionnaire, similar to LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007). All participants received on average 11 years of formal education in Spanish (s.d. 4 years), rated themselves as having native proficiency in Spanish (on a scale of 1–7 with 7 being native; mean score 7, range 6–7, in each of the following: reading comprehension, listening comprehension, writing and speaking) and used Spanish daily (mean 65%, range 35–98% daily use). Participants were considered fluent in Spanish and were included in the study if they correctly named at least 40 out of 60 pictures on the BNT in Spanish, and had a 10-point minimum advantage in Spanish over English on the corresponding versions of the BNT. To avoid engaging the participants in a bilingual mode (François Grosjean, 1989; Francois Grosjean, 2001), Spanish was used to communicate with the participants at all times, except when administering the language assessments in English, which occurred separately from the EEG recording session. Participants received monetary compensation for their participation. Written consent was obtained from all participants prior to conducting any procedures. This study was approved and supervised by the University of Texas at San Antonio Institutional Review Board for the protection of human subjects.

2.2 Materials

The stimuli consisted of 200 experimental items and 100 filler items. Each stimulus was a Spanish sentences containing a target gender-marked post-nominal adjective, as in Table 1 (e.g., … *una actitud positiva*; English gloss, …a$_{\text{[fem]}}$ attitude$_{\text{[fem]}}$ positive$_{\text{[fem]}}$). Half of the stimuli had masculine adjectives and half feminine. Adjectives were never placed in sentence-final position to avoid wrap-up effects. A separate sample of 20 native Spanish speakers were given the experimental sentences as fragments up to the critical noun and were asked to complete the sentence with a single word that best continued the sentence. Mean cloze probability for the target adjectives was 0.65 (range 0.13–1). Four versions of each sentence were created by manipulating the target adjective, so that it agreed in gender with the preceding noun or not (e.g., *positiva /positivo*; positive$_{\text{[fem]}}$/positive$_{\text{[masc]}}$*)* and was expected based on meaning from the preceding sentence context or not (unexpected: *griega / griego*; greek$_{\text{[fem]}}$/greek$_{\text{[masc]}}$). For the semantic manipulation, pairs of same-gender adjectives were closely matched on length and frequency; the adjectives were then swapped across sentences so that each appeared as congruent and incongruent across different sentences. An additional 20 native Spanish speakers judged the acceptability of the incongruent sentences using a Likert scale to ensure that the semantic violation was effective (1 acceptable to 7 unacceptable); mean acceptability was 6.19/7 (range 1–7 with 15 sentences scoring lower than 5). Participants saw each sentence and target adjective once with 50 items per condition, such that all experimental items were viewed across 4 individuals using 4 unique lists of items. An additional 100 congruent sentences were included in each list as fillers, to equate the number of correct and incorrect sentences overall, for a total of 300 sentences per list. In this way the total number of congruent and incongruent sentence was equal in each list.

2.3 Procedure

Participants were seated in a sound-attenuating electrically shielded recording chamber approximately 3 feet from a 19-inch CRT monitor. Participants were monitored over a closed circuit camera and intercom. The sentences were presented one word at a time in the center of the monitor in white Arial font on a black background. The primary task was to silently read the sentences for comprehension. The experiment session was divided into 10 blocks, each containing 30 sentences. To monitor attention to the stimuli through out the recording session, a secondary 10-word recognition memory test (half old and half new open-class words; old words were present in the previous 30 sentences) was presented after each block and participants judged, with a button press, whether they had read the words in the previous block of sentences or not. Each trail began with a fixation cross ("+", duration 500ms) to orient the participant to the center of the screen. Each word appeared for 300ms, followed by a 200ms blank inter-stimulus interval. At the end of each sentence there was a 1500ms inter trail interval before the next sentence. Participants were asked to try to avoid blinking during the sentence. The ERP recording session lasted approximately 1 hour and the entire experimental session lasted approximately 3 hours.

2.4 Electrophysiological Recording Parameters

Continuous electroencephalogram (EEG) was recorded from 26 geodesically spaced tin scalp electrodes (distribution depicted in Figure 1, bottom right) embedded in a standard electrode-cap (Electro-cap International, Inc.). Six additional electrodes were used for reference (left and right mastoid) and eye-artifact monitoring (on the outer canthi for lateral eye movements and below each eye for blinks). All electrodes were referenced online to the left mastoid process and re-referenced offline to the average of the left and right mastoid processes, except for the lateral eye channels, which were recorded referenced to each other. Electrode impedances were maintained below 5 KΩ. The EEG was amplified at 20K gain using an analog bioamplifier (SA Instrumentation Co.) with an analog band-pass filter set to 0.01 to 100 Hz, and digitized at a sampling rate of 250 Hz using a KPCI card in a data acquisition PC.

Trials with lateral eye movements, blinks or excessive muscle artifact were excluded from analysis (mean percentage of data rejected 15%). To do this we ran all EEG data through a set of algebraic tests (e.g., polarity inversion from forehead to lower eye for blinks, peak-to-peak maximum amplitude for lateral eye movements) with thresholds set to maximize the signal-to-noise ratio for each subject (S. Hillyard ERPSS artifact rejection tools). Trials that exceeded these thresholds were automatically removed from the data. Data were band pass filtered off-line at 0.1 to 30 Hz prior to analysis.

3. Results

Mean accuracy on the word recognition task was 75% (range 60%–91%) confirming that participants were attending to the sentences during the EEG recording. EEG data was averaged by condition from the onset of the target adjective relative to a 100ms pre-stimulus baseline. The resulting grand average ERP waveforms, shown in Figure 1, were characterized by P1–N1–P2 early sensory components, followed by a robust negativity that started as early as 200ms and peaked around 450ms (the N400) and a late positive component (the LPC) that started as early as 450ms and lasted through the end the recording epoch. The N400-LPC biphasic waveform was measured across 3 time windows: 300–500ms for the N400, and 500–700ms and 700–900ms coinciding with previously reported functionally distinct LPCa and LPCb subcomponents (Barber & Carreiras, 2005; Hagoort et al., 1999).

A methodological dilemma has been noted concerning how to measure the LPC in the presence of an N400 (e.g., Wicha et al., 2004). Researchers have questioned whether the correct way to measure the LPC is relative to a prestimulus baseline, or relative to the peak amplitude of the N400, which varies across conditions. Wicha et al (2004) measured the LPC both ways. They reported a subadditive interaction between gender and semantics when measured relative to the prestimulus baseline, similar to Martin-Loeches et al (2006). Specifically, double violations elicited an LPC that was larger than semantic-only violations and smaller than gender-only violations. In contrast, no interaction was observed at the LPC when measured relative to the peak of the N400, similar to Hagoort (2003). Here, the smallest LPC compared to control sentences was observed for semantic violations, followed by a larger effect for gender agreement violations, and the largest effect for double violations, in a simple additive fashion. These 2 sets of results for the same data have fundamentally different implications about the interplay between gender and semantics at this stage of processing.

Figure 4 shows the grand average ERPs for the current study with the LPC plotted relative to a 100 ms prestimulus baseline, on the left, and baselined to the peak amplitude of the N400, on the right. An interaction between gender and semantics occurs using either baseline, the main difference being the LPC effect to gender agreement violations. The prestimulus baseline results in equivalent LPC effects for all 3 of the violation conditions (discussed below). In contrast, given that the N400 effect for semantic violations was much larger than that for gender agreement violations, rebaselining to the peak of the N400, as done previously in (Hagoort, 2003), greatly exaggerates the LPC amplitude for semantic violations. Measured in this way, semantic violations and double violations elicit equally larger LPC amplitude than gender agreement violations alone. To our knowledge this would be the first observation of a larger LPC to semantic than gender agreement violations, which could imply that the semantic anomalies in this study were more challenging to reprocess than the gender agreement violations. This is certainly plausible given the high cloze probability for these target adjectives, and could be tested in future research with behavioral measures. Yet, given the vast literature stating the contrary, we defer to the standard 100 ms prestimulus baseline as the appropriate measurement for the following analyses.

3.1 Statistical analyses by time window

For each of the time windows, separate 2 (Semantic Congruity) × 2 (Gender Agreement) × 26 (Electrode site) repeated-measures ANOVAs were performed using mean amplitude as the dependent variable (IBM SPSS Statistics, SPSS Inc). Repeated measures with greater than 1 degree of freedom are reported with the Huynh-Feldt correction for errors of sphericity. Bonferroni corrected post hoc tests between the experimental conditions were computed to determine the source of interactions. Effects with corrected p-values of 0.05 or smaller were considered significant. Scalp distribution analyses were performed for interactions with Electrode. These ANOVAs included 2 levels of Semantic Congruity, 2 levels of Gender Agreement, 2 levels of Hemisphere (left and right), 2 levels of Laterality (medial and lateral) and 4 levels of Anteriority (prefrontal, frontal, central and occipital scalp sites) for a subset of 16 electrodes[1], shown in Figure 2 (as per Wicha, Moreno, et al., 2003).

Figure 2 shows the main effects of Semantic Congruity and Gender Agreement as overlaid difference ERPs. Figure 3 shows the scalp distribution for the main effects of semantic congruity and gender agreement in each of the time windows.

3.1.1 The N400: 300–500ms—A main effect of Semantic Congruity was observed, $F(1, 31) = 103.25$, $p< .001$, with larger negative amplitude for semantically incongruent than congruent adjectives. A Semantic Congruity by Electrode interaction, $F(25, 775) = 22.55$, $p < .001$, reflected a widely distributed N400 effect that was maximal at medial central and parietal sites over the left hemisphere, Semantics × Hemisphere × Laterality × Anteriority, $F(3, 93) = 5.92$, $p = .001$. A main effect of Gender Agreement was observed, $F(1, 31) = 4.71$, $p = .038$, with larger negative amplitude for gender incongruent than congruent adjectives. This effect cannot be attributed to sentence wrap-up effects, as in Hagoort (2003), given that the post-nominal adjectives were never sentence final. There was no

[1]The 16 electrodes (Figure 2) were clustered as follows: Hemisphere = 8 left hemisphere electrodes versus 8 right hemisphere electrodes; Laterality = 8 left and right medial electrodes versus 8 left and right lateral electrodes; Anteriority (from front to back of the head) = 4 prefrontal electrodes, 4 frontal electrodes, 4 central-temporal electrodes and 4 occipital electrodes.

interaction between Gender Agreement and Electrode in the omnibus ANOVA, $F(25, 775) = 1.73$, $p = .118$, however, the distributional analysis revealed that the gender agreement negativity was largest at medial frontal electrodes, and smallest at lateral frontal and central-parietal sites, Gender × Laterality × Anteriority, $F(3,93) = 4.67$, $p = .006$. The interaction between Semantics and Gender did not reach significance, $F(1, 31) = 1.01$, $p = .323$, nor did Semantics by Gender by Electrode, $F(25, 775) = 1.43$, $p = .233$.

3.1.2 LPC onset latency analysis—Visual inspection of Figure 2 shows an earlier positivity for the gender agreement violations than semantic congruity violations. We performed an onset latency analysis of these main effects (incongruent minus congruent) between 400–900 ms post stimulus onset. The first 10 consecutive positive samples (i.e., 40 ms window) were considered the onset of the LPC effect. This analysis confirmed that the LPC effect began between 170 to 220 ms earlier for gender-agreement than semantic-congruity violations across the scalp. The largest difference was measured over the 9 medial central-parietal and occipital electrodes, where mean amplitude of the LPC was maximal; gender agreement 455ms versus semantic congruity 668ms ($t<0.001$). This indicates that the N400 and LPC for gender agreement violations overlap as early as 450 ms post stimulus onset, whereas they do not for semantic agreement violations. This will be come relevant in the discussion of the distribution of these effects below.

3.1.3 The LPCa: 500–700ms—A main effect of mean amplitude for Semantics was observed, $F(1, 31) = 9.13$, $p = .005$, which reflected the conclusion of the N400, with more negative amplitude for incongruent than congruent adjectives. Figure 3 shows how the effect in this time window moved rightward compared to the previous window [Semantics × Electrode, $F(25, 775) = 4.98$, $p = .001$;Semantics × Hemisphere × Laterality × Anteriority, $F(3, 93) = 7.81$, $p = .001$]. The main effect of Gender did not reach significance, $F(1, 31) = 3.25$, $p = .081$, but the interaction between Gender and Electrode did, $F(1, 31) = 3.02$, $p = .020$. A larger positivity was observed for gender incongruent than congruent adjectives over central-parietal sites, Gender Congruity by Anteriority, $F(3, 93) = 4.83$, $p = .025$. Neither the Semantics by Gender, $F(1, 31) = 3.70$, $p = .064$, nor the Semantics by Gender by Electrode interaction were significant, $F(25, 775) = 1.675$, $p = .156$.

3.1.4 The LPCb: 700–900ms—The main effect of Semantics was not significant, $F(1, 31) = 2.56$, $p = .120$, but the interaction between Semantics and Electrode was, $F(25, 775) = 6.24$, $p < .001$. Larger positive amplitude for semantically incongruent than congruent adjectives was present over right medial central-parietal and occipital sites, Semantics × Hemisphere × Laterality × Anteriority, $F(3, 93) = 3.92$, $p = .019$. The main effect of Gender was not significant, $F(1, 31) = 1.79$, $p = .190$, but the interaction between Gender and Electrode was, $F(1,31) = 5.69$, $p<.001$. Larger positivity for gender incongruent than congruent adjectives was present over right lateral and occipital sites [Gender × Hemisphere × Laterality, $F(1, 31) = 6.27$, $p = .018$; Gender × Anteriority, $F(3, 93) = 10.83$, $p = .001$]. An interaction between Semantic Congruity and Gender Agreement, $F(1, 31) = 4.15$, $p = .050$, revealed that all 3 violation conditions were equally more positive than the fully congruent condition, with no interaction by electrode, Semantic Congruity × Gender Agreement × Electrode, $F(25, 775) = 1.27$, $p= .275$.

3.2 Contextual Constraint Analysis

A subset of the experimental sentences was selected to compare the effects at two levels of constraint – high and low – based on their cloze probability: 75–100%, and 10–50%, with 73 and 60 items, respectively. Independent repeated measures ANOVAs, with 2 levels of Contextual Constraint, 2 levels of Semantic Congruity, 2 levels of Grammatical Agreement, and 26 levels of Electrode were performed for each of the 3 time windows (N400, LPCa and

LPCb). There was no effect of Constraint on Semantic Congruity in any of the analysis windows. The Constraint by Gender Agreement interaction was significant for the LPCa (500–700ms) window, $F(1, 23) = 4.87$, $p= .038$; but not the LPCb (700–900ms) window. Gender violations elicited a larger positivity relative to gender congruent adjectives only in highly constraining sentences for the LPCa. In addition, the positivity elicited by gender violations began earlier in highly constraining sentences, reaching significance by 450–500ms, compared to weakly constraining sentences, which reached significance by 500–550ms. This further confirms the overlap in time between the N400 and LPC by 450 ms post stimulus onset.

3.3 Latent Component Analysis

In an attempt to determine if the gender and semantic modulations were sensitive to the same latent factors, we ran Principle Components Analysis (PCA) and Confirmatory Factor Analysis (CFA) with all 26 electrodes as individual factors between 300–450 ms post stimulus. The PCA results showed 3 dominant factors that accounted for 81% of the variance across electrodes, with the percent of variance explained by factors 1, 2, and 3 being 57.67% (eigenvalue of 29.99), 14.49% (eigenvalue of 7.54), and 8.87% (eigenvalue of 4.61), respectively. The factor pattern loadings from the PCA suggested that most electrodes measured multiple factors, thus producing a more complex factor structure. Reanalyzing the same data using CFA (restricting each electrode to load on the purported gender or semantic factors), each electrode significantly measured the appropriate factor (though 5 loading on the gender factor were smaller, $\lambda < .30$; all the semantic factor loadings were large). The interfactor correlation from the CFA suggested that gender and semantics were highly correlated ($r = 0.79$). Collectively, these findings could be interpreted as support for our proposal that both experimental variables are modulated by a very similar factor. However, this post hoc analysis with relatively few subjects should be interpreted only as preliminary evidence, and tested thoroughly in future studies.

4. Discussion

4.1 Summary of Results

The purpose of this study was to examine the time course of semantic and morphosyntactic processes, and any interaction between them, when comprehending a post-nominal adjective in a Spanish sentence. Semantic congruity violations elicited a classic N400 effect, with larger negativity for incongruent than congruent adjectives with a maximum over medial central-parietal electrodes. Semantic violations also elicited an LPCb effect, with larger positivity for incongruent than congruent adjectives from 700–900ms post stimulus onset. Gender agreement violations elicited an increased negativity between 300–500ms post stimulus onset, which was widely distributed with a maximum over medial frontal sites. The broad distribution of this negativity is more inline with an N400 than the left anterior negativity (LAN). The gender negativity was followed by a modulation of the LPCa and LPCb. The LPCa to gender agreement violations was modulated by sentence constraint, with a larger gender agreement effect in higher than lower constraining sentences. A subadditive interaction between semantic congruity and gender agreement was observed on the LPCb, with equivalent amplitude modulation for all violation conditions compared to the congruent control sentences. The LPCb effects may indicate that any violation on a post-nominal adjective invokes reprocessing by reference to the preceding noun. In brief, our ERP data indicate that meaning and morphosyntax affect comprehension in overlapping time points and at various points in processing.

4.2 Morphosyntactic modulation of the N400

We predicted that we would observe a syntactic boosting effect at the N400, as did Hagoort (2003) and Wicha (2004) by using richer sentence contexts than Martin-Loeches et al (2006), who did not observe this effect. What we observed instead was a main effect of gender agreement on the N400. In addition to the 2 studies reporting a boosting effect, we are aware of only 2 prior reports of a gender-agreement N400. First, Hagoort (2003) reported a main effect on the N400 for gender agreement violations on sentence final nouns, but argued that this was due to sentence wrap up. Second, Barber and Carreiras (2005) argued that the N400 effect that they observed in response to noun-adjective pairs was due to the lack of sentence structure, eliciting a local lexical integration problem. They reported a negativity for the same noun-adjective pairs when embedded in a sentence structure, but argued that this was a LAN in response to syntactic structure building rather than an N400. We argue that our data is consistent with these findings, but that the effect is a morphosyntactic modulation of the N400.

Similar to studies reporting a LAN, the gender negativity in our data showed a left frontal maximum. However, unlike previous reports, the negativity was largest at medial, not lateral sites, and was present over right and posterior sites as well. Importantly, the gender negativity was small compared to the semantic N400, and overlapped temporally with the LPC (Figure 2). When we measured the negativity up to the onset of the LPC (450ms post stimulus onset) we observed a broadly distributed negativity, indicative of an N400 (Figure 3). It could be argued that the more frontal distribution of this negativity might reflect a combined LAN and N400 for the gender violations (e.g., Palolahti et al., 2005). However, recent evidence suggests that the LAN and N400 have overlapping neural sources (Service et al., 2007), and although the N400 is very stable in its timing, it can show distributional differences across sensory modalities and stimulus types, including a more anterior distribution (Kutas & Federmeier, 2011). Whether in combination with a LAN or not, the broad distribution of the negativity indicates that grammatical gender can influence meaning-level processing.

If grammatical gender can modulate the N400 directly, then why haven't more studies shown a morphosyntactic N400? One possibility is that many of the reported LAN effects followed by a LPC may actually be N400s (Molinaro et al., 2011; Münte et al., 1997; Osterhout & Nicol, 1999; Rösler et al., 1993). We would not be the first to suggest this possibility, although it remains a highly controversial argument. Friederici (2011) suggests that grammatical gender agreement violations only elicit a strong LAN when the morphosyntactic information is essential for assigning grammatical relations between words, as in Hebrew where gender agreement occurs between nouns and verbs. Then perhaps, these strong negativities within the time window of the N400 are not LAN effects in languages like Spanish and German where grammatical gender agreement relates to noun classification. This is not to say that the brain does not distinguish between morphosyntactic and semantic information, but rather that the brain integrates multiple sources of information at this stage of processing (e.g., Stroud & Phillips, 2012). Alternatively, given that grammatical gender is a lexical feature of nouns in Spanish, the N400 effect may index local lexical integration, as argued by Barber and Carreiras (2005). If however our N400 effect is the result of a local lexical integration problem, then the post-nominal adjectives in the sentence initial noun phrases (with no prior context) in the Martin-Loeches et al study (2006) should have also shown this effect. A critical difference between the current study and the Martin-Loeches et al study was the addition of richer sentence context preceding the target adjective. The sentence contexts used in this experiment allowed for the expectation of a specific gender-marked adjective (e.g., *Me gusta ir a la playa en un día soleado...* – 'I like to go to the beach on a day sunny…'). This may have allowed for gender agreement to affect semantic processing when an unexpected adjective was encountered. The gender N400 modulation may index a processing cost that is attributed to building the greater sentence meaning (Kutas & Federmeier, 2011). That is, gender information on the post nominal adjective, despite being a purely syntactic feature, may contribute to semantic processing as a function of the expectation from global meaning (Otten et al., 2007; Otten & Van Berkum, 2008; Pickering & Garrod, 2013; Wicha, Bates, et al., 2003; Wicha, Moreno, et al., 2003; Wicha et al., 2004; Wicha et al., 2005).

Importantly, the N400 and LAN overlap not only in time and polarity, but also in distribution. The argument we make is that the negativity that occurs in response to the gender violations is the same component that is elicited by the semantic violations, namely an N400. Generally ERP effects are considered components based on their functional role (what modulates them), timing, polarity and distribution of the effect. The fact that the distribution of the negativity is different for gender and semantic violations would imply that the underlying neural sources are different, and that perhaps then the gender and semantic negativities are not related. However, one way in which the underlying neural sources can be different is by adding a new source in the same time window. Our onset latency analysis indicates that the LPC and N400 effects overlap in time for the gender agreement violations, between 450–500 milliseconds, but not for the semantic congruity effect, where the LPC onsets around 600 milliseconds. Therefore, we argue that the difference in scalp distribution between the gender agreement and semantic congruity effects is due to summation of the scalp potentials generated by the N400 neural sources and the LPC neural sources, where the LPC is maximal at right posterior electrodes and much earlier for gender violations than semantic violations.

ERPs are not an ideal technique for source localization, especially with sparse sampling, and can only provide a mathematical estimate of the underlying electrical dipoles. Nevertheless, we conducted post hoc principle components and confirmatory factor analyses to determine if the effects for gender and semantics at each electrode were correlated. This analysis provided support that nearly all of the 26 electrodes were sensitive to the same latent factors in both the semantic and gender manipulations. We propose to test in future research using better localization techniques the hypothesis that the gender effect we reported here is an N400 and not a LAN. Specifically, based on our findings we propose that gender and semantic information can be processed along the same neural pathways. That is, either the same neural substrates are sensitive to both types of information, or alternatively, these two types of information are processed by highly interconnected neural sources along the same pathway. This proposal is in line with models of a highly interconnected language network with parallel processing of linguistic information at various levels (e.g., Hickok & Poeppel, 2000, 2004, 2007; Keller, Carpenter, & Just, 2001; Poeppel, Emmorey, Hickok, & Pylkkanen, 2012; Poeppel & Hickok, 2004), rather than models that propose multiple sequential stages of processing (e.g., Bornkessel & Schlesewsky, 2006; Friederici & Gierhan, 2013). In particular, recent models of speech comprehension propose ventral and dorsal neural pathways for speech comprehension with different functional roles. Although our study addresses reading comprehension, we borrow from these well-defined models to make predictions for reading comprehension. Based on Hickok and Poeppel (2004, 2007) the ventral stream of information, which traverses the middle and inferior temporal gyri, is involved in sound to meaning mapping, while the dorsal stream is involved in mapping sound to motor output. Although the neural substrates for grammatical gender agreement are not specifically detailed in this model, the ventral stream is purportedly responsible for meaning processes, as well as syntactic processes and integration of syntax and semantics. Therefore, it can be inferred that morpho-syntactic processes are either happening along the same pathway as meaning, or alternatively, gender agreement substrates may share

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bidirectional connections with the neural pathway responsible for reconstructing meaning from memory (Hickok & Poeppel, 2004, 2007; Poeppel & Hickok, 2004).

Friederici (Friederici, 2002, 2009, 2011, 2012; Friederici & Gierhan, 2013) has proposed a similar model of multiple ventral and dorsal pathways, although the placement of specific processes along these pathways differs between the models. Namely, basic syntactic structure building occurs along parallel ventral pathways with (and temporally preceding) semantic processes (Jeon & Friederici, 2013; see also Price, 2010), whereas morphosyntactic agreement is processed along a second dorsal pathway separate from a sound to motor mapping pathway (Friederici & Gierhan, 2013). In previous work, Friederici and Kotz (2003) suggested that the integration of semantic and morph-syntactic information happens in the posterior portion of the left superior temporal gyrus, and importantly that morpho-syntactic processing happens prior to and independent of access to meaning (Friederici & Weissenborn, 2007). Our data is more consistent with a neural mechanism that allows morphosyntactic agreement and semantic congruity processes to overlap in time, and perhaps also in space given the similarity in the type of ERP response generated by both. Nevertheless, these two proposals for the localization of real time processing of syntax and semantics require convergent evidence from both high temporal resolution data, such as ERPs, and high spatial resolution techniques. This is a technical challenge with which the field is still grappling, although significant progress in being made in efforts to merge data in space and time (e.g., Friederici, 2011; Friederici & Kotz, 2003).

4.3 Gender and semantics interact in later stages of processing – LPCa and LPCb

Subsequent to the N400 we observed amplitude modulations of the LPCa and LPCb that appeared to be functionally distinct phases of the P600/LPC. While both semantic and gender agreement violations led to an increased positivity in the LPCb window (700–900ms), only gender agreement and not semantic congruity lead to an increased positivity of the LPCa window (500–700ms). These findings fit with suggestions that the early portion of the LPC may be functionally specific to syntactic-like processes, while the later portion may reflect a more global processing stage, such as reanalysis (Barber & Carreiras, 2005; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001; Hagoort & Brown, 2000). In contrast, the robust LPCb may reflect the processing nature of post-nominal adjectives. The (perhaps surprising) equivalent amplitude modulation for both single and double violations may reflect a ceiling of maximum amplitude for the LPC. Critically, however, ours is the first observation of semantic violations eliciting the same LPC amplitude modulation as gender agreement violations. This is perhaps due to the fact that integration across the nominal phrase requires agreement, both semantic and syntactic, with the head noun that has already been presented. Therefore, we postulate that any type of violation on the postnominal adjective could require reference back to the head noun and reprocessing of the noun phrase to attempt to reconcile the unexpected adjective. In Wicha et al (2004), the double violation of semantics and gender agreement, when measured as we did here relative to a prestimulus baseline, elicited smaller LPC amplitude than the gender violations alone (also a subadditive effect). The semantic violations elicited a significant, but much smaller LPC than the gender violations relative to the control sentences. Perhaps the critical difference then between Wicha et al (2004) and the current study is that semantic violations on a postnominal adjective, with or without a gender agreement violation, elicit a higher processing cost than semantic violations on the head noun itself. This can be tested in future research using Spanish adjectives, which can appear both prenominally and postnominally. The prediction would be that prenominal adjectives should show a smaller LPC to semantic violations than postnominal adjectives.

Notably, the LPCb was the only component where we observed a direct interaction between gender agreement and semantic congruity, with a subadditive effect, i.e., equivalent LPCb amplitude for single gender and semantic violations as well as for double violations. This late interaction was observed by Martin-Loeches et al study (2006), and by Wicha et al (2004) when measuring the LPC relative to a prestimulus baseline[2]. Similar late interactions have been reported in many studies, and the absence of an interaction prior to the LPC has led some researchers to argue for the autonomy of syntax in early stages of processing (Gunter, Friederici, & Schriefers, 2000; Gunter et al., 1997). We did not observe an interaction between gender agreement and semantic congruity on the N400 in the form of the boosting effect that Hagoort (2003) and Wicha et al (2004) observed. Martin-Loeches et al may have been correct in assuming that manipulating both gender and semantics on the same word reduces the potential for interaction by eliminating the time to integrate these 2 types of information across multiple words. Yet, the main effect of gender agreement on the amplitude of the N400 complicates this argument. How do we interpret data that, on the one hand, indicate that gender agreement can affect the processing stage indexed by the N400, and on the other, show no interaction between syntax and semantics at the N400? Simply put, morphosyntax does not have to modulate the amplitude of the semantic N400 to have an effect on semantic processing. Treating semantics and syntax as 2 separate and independent processes biases us into thinking that in order to observe an interaction it must be in the form of a gender modulation of a semantic process (e.g., the N400) and/or a semantic modulation of a gender process (e.g. the LPC). We propose to rethink the problem as 2 different types of information that can affect a more general cognitive subprocess, such as access to information from long-term memory (e.g., N400) and integration of that information with the preceding sentence context (e.g., LPC) (e.g., Kutas & Federmeier, 2011). In this way, the subprocesses of comprehending a sentence can be affected by both semantic and morphosyntactic information, albeit more by one than another. This hypothesis depends, of course, on resolving what cognitive subprocesses exactly are indexed by the N400 and LPC, which many researchers are undertaking in novel ways (e.g., Hagoort, 2013; Jeon & Friederici, 2013; Kuperberg et al., 2006; Lau et al., 2008).

As for the LPCa, there was again a lack of an interaction between gender agreement and semantic congruity. However, the effect of gender agreement at the LPCa was modulated by sentence constraint, indicating that morphosyntactic agreement is affected by overall sentence meaning. The gender agreement LPCa effect was larger and had an earlier onset in higher than lower constraining sentences. This may reflect the predictability of a specific gender-marked word based on sentence context, as discussed above. Importantly, this entire late positive complex may reflect integrating information into a larger context, given that neither the LPCa nor LPCb effects are observed when processing word pairs (Barber & Carreiras, 2005).

In sum, our findings suggest that at least some morphosyntactic elements, namely grammatical gender, can influence the stage of processing reflected by the N400. Although we did not observe a boosting effect on the amplitude of the N400, we observed instead a small but reliable main effect of gender agreement. In addition, we observed an interaction between gender agreement and sentence constraint on the LPCa, with a larger effect for higher than lower constraint sentences, indicating that overall sentence meaning can affect syntactic processing. Finally, a subadditive interaction between semantic congruity and gender agreement was observed at the LPCb, where double violations elicit equivalent amplitude modulation as either single violation. We propose that these robust LPC effects may reflect the processing nature of post-nominal adjectives. Overall, our results indicate that both gender agreement and semantic congruity affect processing at similar time points,

[2]Neither Wicha et al (2004) nor Hagoort (2003) observed an interaction at the LPC when measuring the effect relative to the peak of the N400. Figure 4 indicates that a peak-to-peak analysis of the late positivity does not make methodological sense.

indexing a dynamic language comprehension system that can use meaning and morphosyntax in parallel.

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Highlights

- Comprehending post-nominal adjectives: gender agreement and semantic congruity
- Gender agreement violations elicit an N400-like negativity
- Sentence constraint modulates LPCa for gender agreement violations
- Single and Double violations of gender and semantics elicit equivalent LPCb
- Results support effects of morphosyntax and meaning at similar processing time points

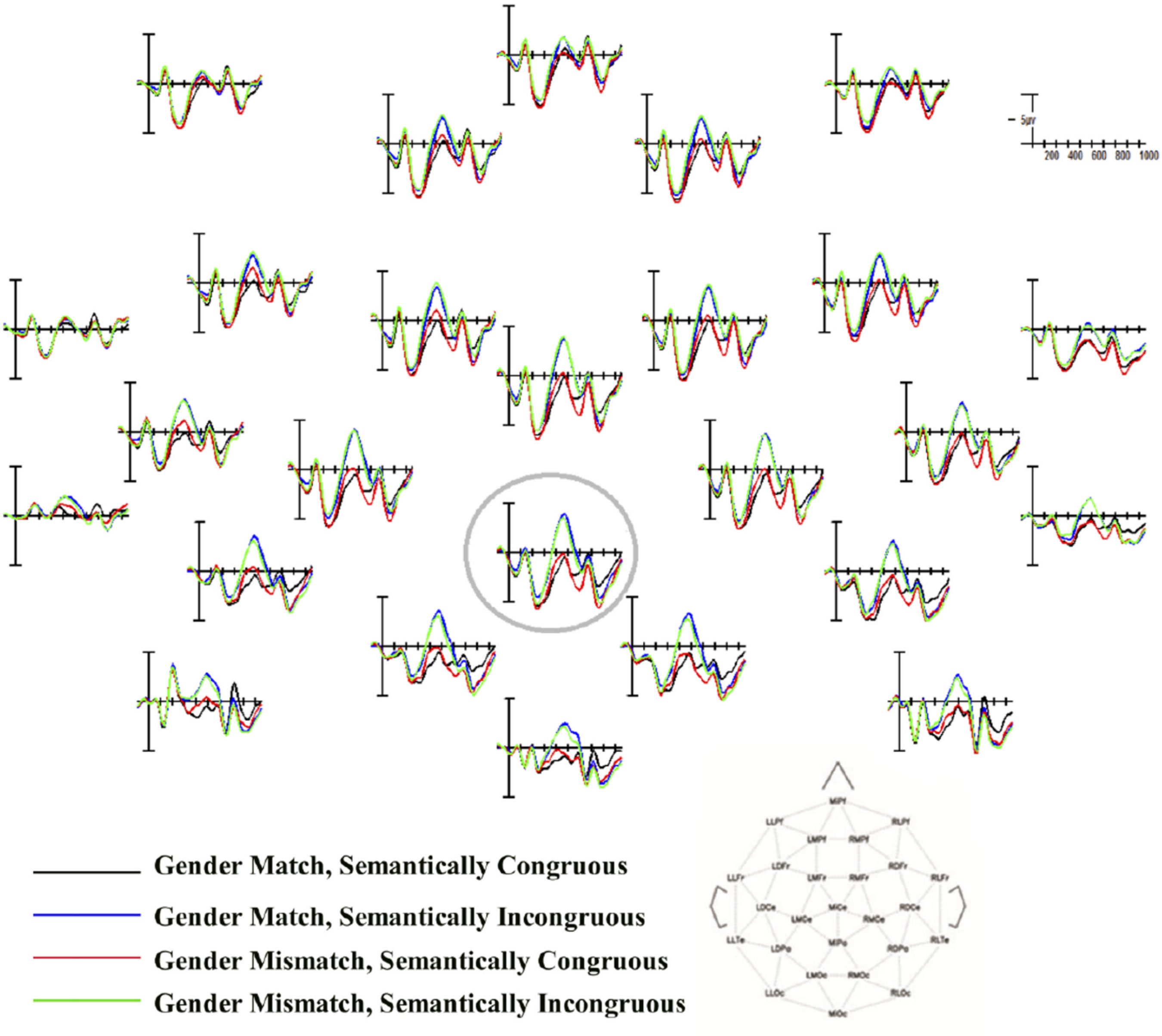

Figure 1. Grand average ERPs

Grand average ERPs across all 26 electrodes for target post-nominal adjectives with the 4 experimental conditions overlaid; electrode array shown at bottom right. Time in milliseconds is on the X-axis and amplitude in microvolts is on the Y-axis, with negative amplitude is plotted up. The circled electrode is shown enlarged in Figure 4.

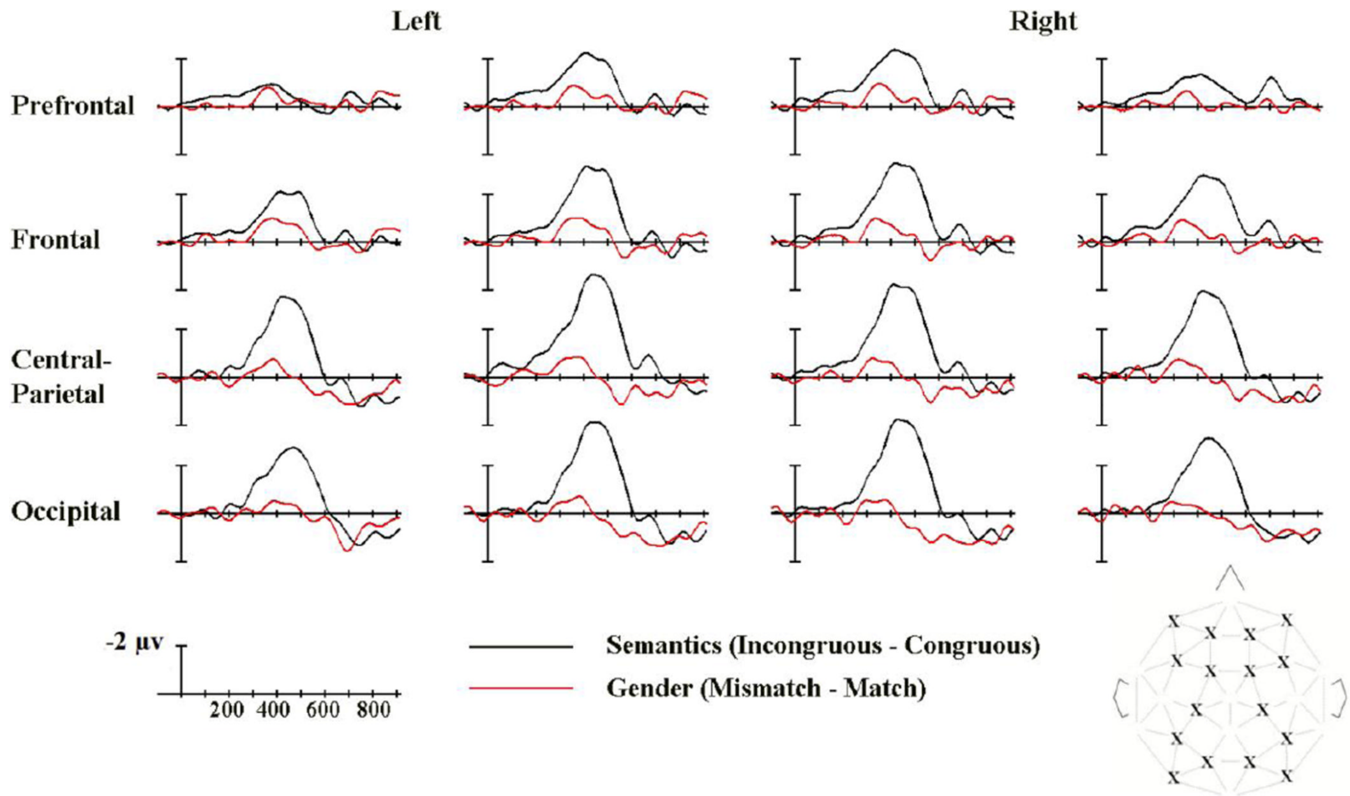

Figure 2. Main effects

Difference ERPs in microvolts show the main effects of Semantic Congruency in black (incongruous minus congruous) and Gender Agreement in red (mismatch minus match) for a 1000ms recording epoch. Sixteen representative electrodes are shown; scalp locations are marked with × on the electrode array in the lower right corner.

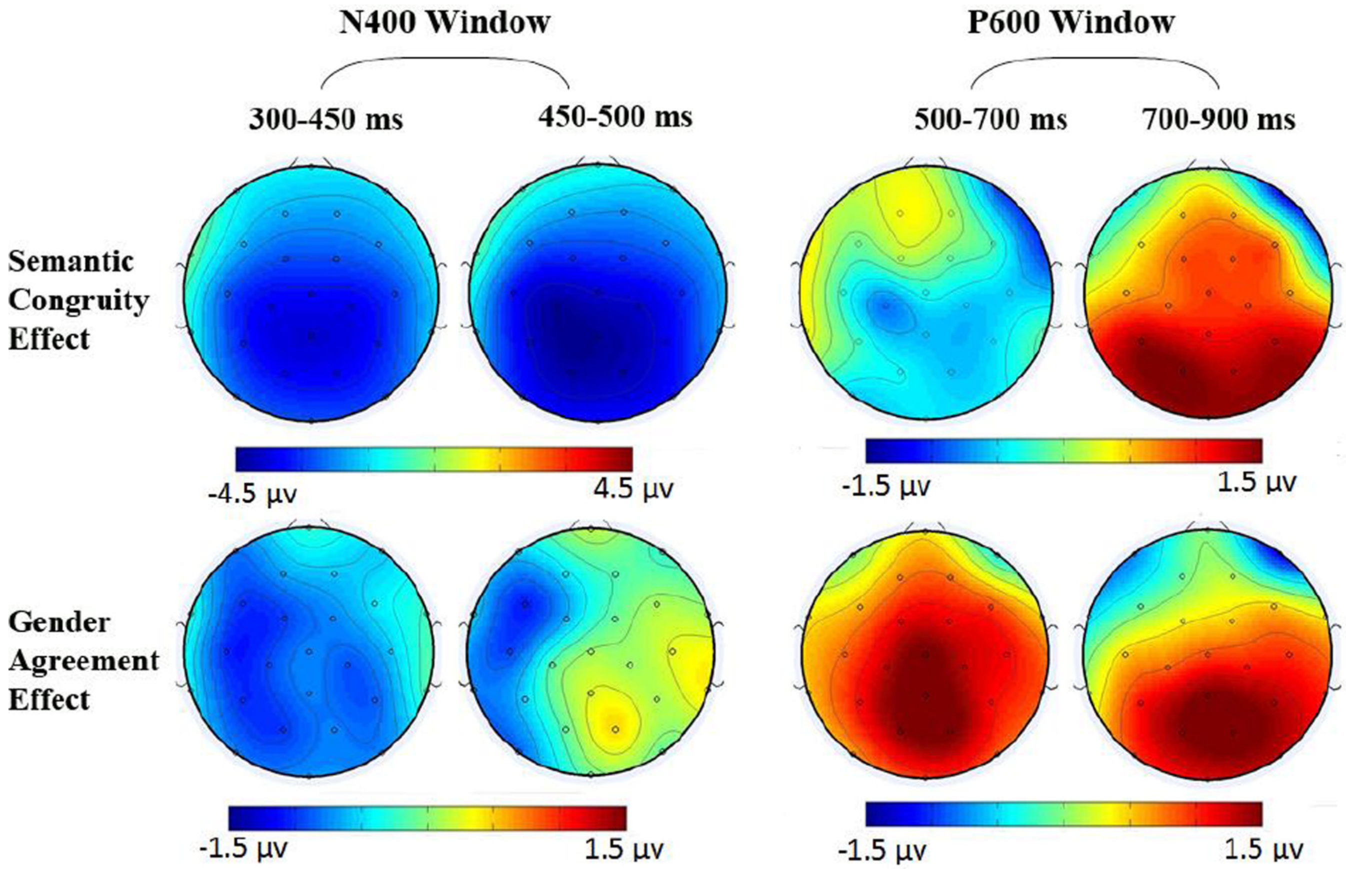

Figure 3. Scalp distribution of main effects

Isovoltage distribution maps in microvolts from difference ERPs across the measurement windows: row 1, main effect of Semantic Congruity (semantically incongruous minus congruous conditions); row 2, main effect of Gender Agreement (gender mismatch minus match conditions). Note that the Semantic Congruity N400 effect is plotted on a broader scale than the other effects.

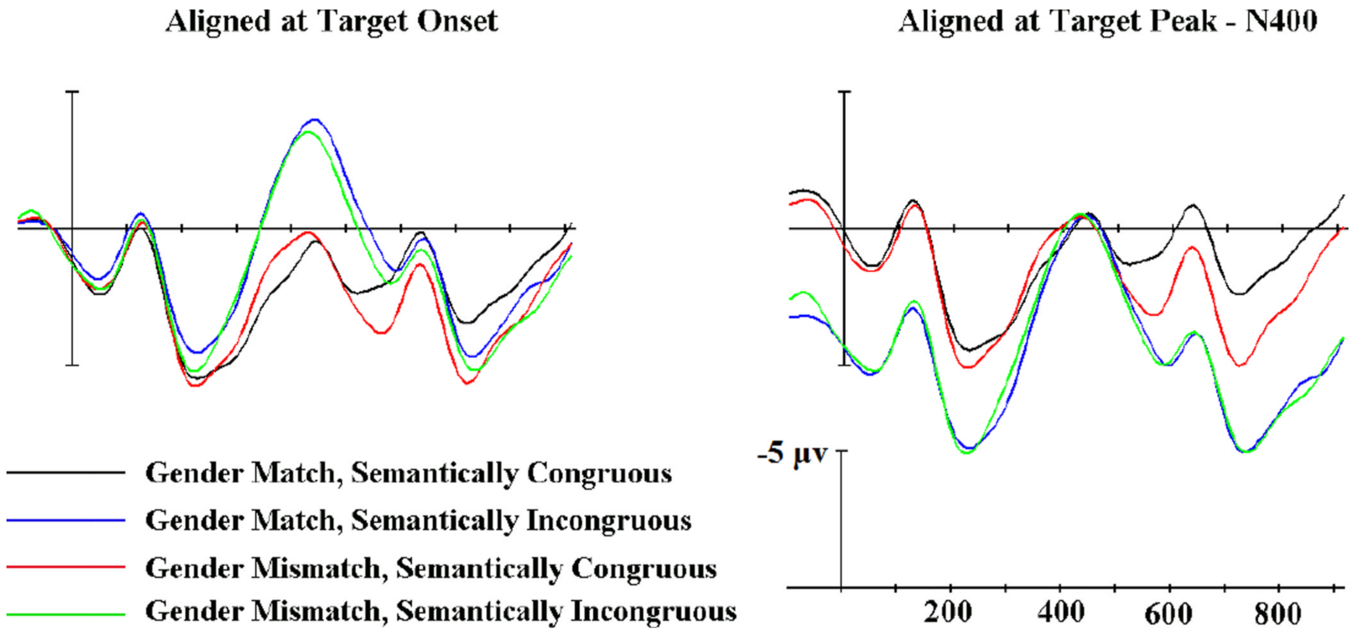

Figure 4. Comparison between 2 baseline measures

Grand average ERPs for all 4 conditions at electrode MiPa (middle parietal) are plotted relative to 2 baselines for illustration purposes. On the left, 1 second of data is plotted relative to a 100ms prestimulus baseline. On the right, the same data is plotted using the peak of the N400 as the baseline (equivalent to a peak-to-peak measurement from the N400 to the LPC).

Table 1

Sample Stimuli

Three example sentences showing the possible article-noun combinations (in **bold**) that created 4 conditions for each sentence: Semantically Congruent and Gender Matching/ Semantically Congruent and Gender Mismatching/ Semantically Incongruent and Gender Matching/ Semantically Incongruent and Gender Mismatching. Note that the target adjective is post nominal in Spanish.

Example	English Gloss
Aunque perdieron, el entrenador intentó mostrar una actitud positiva /positivo /griega /griego ante sus jugadores.	Although they lost, the coach tried to show a_{fem} $attitude_{fem}$ $positive_{fem}$ / $positive_{masc}$ /$greek_{fem}$ /$greek_{masc}$ in front of his players.
En una monarquía el rey tiene el poder ***absoluto /absoluta / vacío /vacía*** *sobre los ciudadanos*.	In a monarchy the king has the_{masc} $power_{masc}$ $absolute_{masc}$ /$absolute_{fem}$ / $empty_{masc}$ /$empty_{fem}$ over the citizens.
En la cena sirvieron las galletas en una charola ***plateada / plateado /obvia /obvio*** *y muy bonita*.	At the dinner they served the cookies on a_{fem} $tray_{fem}$ $silver_{fem}$ /$silver_{masc}$ / $obvious_{fem}$ /$obvious_{masc}$ and very pretty.