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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 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 450 ms 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.

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 and Clifton, 1986; Frazier, 1987), while others have argued that all information is used as soon as and whenever possible (e.g., Tyler and 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 et al., 1996, 2004), others have argued that they can interact from early on (e.g., Hagoort, 2003; Wicha et al., 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 potential (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 and 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.

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

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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 400 ms after stimulus onset (Kutas and 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 and 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 and Federmeier, 2011; Niedeggen et al., 2003; Salillas and Wicha, 2012; Sitnikova et al., 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 600 ms after stimulus onset over posterior electrodes, and was thought to reflect processes specific to syntax (Hagoort et al., 1993; Osterhout and Holcomb, 1992). However, there is accumulating evidence that the LPC reflects general cognitive processes related to language comprehension (e.g., Coulson et al., 1998; Friederici and Weissenborn, 2007; for a review, Kuperberg, 2007). Finally, the LAN is a negativity that occurs between 300 and 450 ms after stimulus onset. The name reflects its typical scalp distribution over left anterior recording sites, though some have observed a bilateral (Hagoort et al., 2003) or more widespread distribution of a LAN-like effect (Molinaro et al., 2011; Münte et al., 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 and Kutas, 1993). There is also some debate over whether the LAN is a separate component from the N400 (Service et al., 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 — $table_{fem}$/car_{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} $table_{fem}$ $long_{fem}$'; *el carro largo* 'the_{masc} car_{masc} $long_{masc}$'). Speakers of languages like Spanish are very sensitive to these morphological cues during comprehension (Barber and Carreiras, 2003; Bates et al., 1995; Van Berkum et al., 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, 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 et al., 2003a,b). 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 and Holcomb, 1992; Vos et al., 2001; Wicha et al., 2003a), it is not specific to agreement processes (Coulson et al., 1998; Friederici et al., 1993; Gunter et al., 1997; Hahne and Friederici, 1999; Neville et al., 1991), nor is it specific to syntactic processes (Coulson and Kutas, 2001; Hoeks et al., 2004; Kim and Osterhout, 2005; Kolk et al., 2003; Kuperberg, 2007; Kuperberg et al., 2006; Münte et al., 1998; Stroud and Phillips, 2012; Van Herten et al., 2005), or even to linguistic stimuli (Patel et al., 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 and Carreiras, 2005; Hagoort et al., 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 and Weissenborn, 2007), the LAN has been less reliably observed than the LPC in response to morphosyntactic violations during sentence comprehension (e.g., Bañón et al., 2012; Barber and Carreiras, 2005; Hahne and Friederici, 1999; Koester et al., 2007; Morris and Holcomb, 2005; Rösler et al., 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} $piano_{masc}$; *faro alto*/*alta* — $lighthouse_{masc}$ $tall_{masc}$/$tall_{fem}$). 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 and 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