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# Unpleasant words can affect the detection of morphosyntactic errors: An ERP study on individual differences

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## Abstract

In recent years, several ERP studies have investigated whether the early computation of agreement is permeable to the emotional content of words. Some studies have reported interactive effects of grammaticality and emotionality in the left anterior negativity (LAN) component, while others have failed to replicate these results. Furthermore, novel findings suggest that grammatical processing can elicit different neural patterns across individuals. In this study, we aim to investigate whether the interaction between grammaticality and emotionality is restricted to participants with a specific neural profile. Sixty-one female native speakers of Spanish performed an agreement judgment task in noun phrases composed of a determiner, a noun, and an unpleasant or neutral adjective that could agree or disagree in gender with the preceding noun. Our results support the existence of two different brain profiles: negative and positive dominance (individuals showing either larger LAN or larger P600 amplitudes in ungrammatical stimuli than in grammatical ones, respectively). Interestingly, the neural pattern of these two groups diverged at different points along the time course. Thus, the negative dominance group showed grammaticality effects as early as 200 ms, along with parallel and autonomous processing of grammaticality and emotionality at the LAN/N400 time window. Instead, for the positive dominance group an early interaction was found at around 200 ms, evidencing a grammaticality effect that emerged only for unpleasant words. Our findings confirm the role of individual differences in the interplay between grammar and emotion at the neural level and call for the inclusion of this perspective in studies on syntactic processing.

KEYWORDS

gender agreement, individual ifferences, LAN/N400, P600, unpleasant words

## 1 | INTRODUCTION

How does the human mind process language? In the field of psycholinguistics, many studies have tried to define the timeline and neural basis of language processing, aiming to depict how the extremely complex and automatic processing of written and spoken language works. One of the central pillars of this line of research has been the historical debate between modular and interactive models of linguistic processing. Classical serial models, such as the Syntactic Encapsulation Hypothesis, postulate a modular processing routine in which syntactic information takes priority (Fodor, 1983). Under this view, grammatical processing would take place first and would not be modulated by other sources of information (e.g., semantic or pragmatic) until later stages of language processing (Frazier & Clifton, 1996). In contrast, interactive models have proposed that, under certain circumstances, other sources of information apart from syntactic ones can be processed and interact from early on during sentence processing (Marslen-Wilson & Tyler, 1980). The development of brain activity measurement tools such as electroencephalography (EEG) and methods such as event-related potentials (ERPs) has provided us with new sources of evidence to prove or dismiss the different assumptions of these two views and, therefore, has led to new and updated models. For example, Hagoort (2003) proposed the Memory, Unification, and Control (MUC) model of language based on findings indicating that as soon as semantic information is available, it is used for the purpose of interpretation. According to this model, extra-syntactic information could be processed first under certain circumstances, thus challenging the strict classical syntax-first views of linguistic processing. Nonetheless, there is evidence for fine-grained millisecond delays between early cortical activations in language processing that interactive or parallel models cannot explain (Pulvermüller et al., 2009). Rather than looking for evidence of a fully modular or interactive model of linguistic processing, recent studies have been exploring to what extent different extra-syntactic variables can interfere with the assumed modularity of syntactic processes. In this work, we will approach this debate from the interplay between grammar and emotion.

Many ERP studies have used agreement errors, or mismatches, to study the timeline of linguistic processing (e.g., *The roses$_{pl}$ is$_{sg}$ in the garden; see Osterhout & Holcomb, 1992). Processing agreement dependencies necessarily involves syntactic parsing operations, and these operations are fundamental for language understanding. Processing sentences containing errors is generally known to be costlier than processing correct utterances, and this cost is often reflected in a specific neural signature. While results from previous literature on this topic are diverse, there are two main ERP components that have been understood to reflect morphosyntactic processing: the left anterior negativity (LAN) and the P600 component.

Considering the time course of syntactic processing, the first component to arise would be the LAN, a negative wave, between 300 and 450 ms after stimulus onset. This component has been specifically conceptualized as an index of early and highly automatic morphosyntactic processes. Thus, increased LAN amplitudes are commonly interpreted as a reflection of the cost associated with the early detection of morphosyntactic errors (Münte et al., 1997; see Molinaro et al., 2011 for a review). Note here that LAN shares the same time window as N400, another negative component with a similar latency (peaking at around 400 ms post-stimulus onset; Kutas & Federmeier, 2009, 2011; Kutas & Hillyard, 1980). While LAN is usually found to be restricted to or stronger over left frontal areas (Barber & Carreiras, 2005; Gunter et al., 2000; Hagoort & Brown, 1999; for bilateral LAN effects, see however Hinojosa et al., 2003; Kaan, 2002; Leinonen et al., 2008), N400 usually presents a centro-parietal distribution (Molinaro et al., 2011). Importantly, there is evidence that N400 reflects access to lexico-semantic information, its prediction and integration, not necessarily related to morphosyntactic processing per se (Kutas & Federmeier, 2011; Nour Eddine et al., 2024).

In a later time window, modulations on the P600 component have been elicited by syntactic and semantic violations as well as by structurally ambiguous or garden-path sentences (Friederici, 2004; Hagoort et al., 1993). The P600 is a positive wave peaking at around 600 ms post-stimulus onset which is typically localized at parietal sites (although centered and frontal P600 effects have also been reported; e.g., Friederici et al., 2002). Due to the heterogeneity of the conditions in which P600 effects have been elicited, larger P600 amplitudes are commonly interpreted in terms of increased processing costs in a late and more general stage of sentence reanalysis (Molinaro et al., 2011). Nonetheless, the functional interpretation of this component is still being questioned by new research. For example, recent studies on semantic processing have found P600 amplitudes to reflect continuous integrative effort (Aurnhammer et al., 2023).

Most studies on agreement dependencies that contain errors have reported what is commonly called the biphasic pattern: increased LAN amplitudes followed by larger P600 effects (Molinaro et al., 2011). This neural signature is thought to reflect two subsequent stages in language processing: an early, preferential, and rather automatic processing of morphosyntactic information, followed by a later reanalysis and integration of information in a general or unspecific sense (Friederici, 1995; Molinaro et al., 2011). This pattern would align with modular views of linguistic processing which predict that the impact of lexico-semantic and pragmatic information would be generally restricted to later time windows. Nonetheless, ERP evidence on semantic processing suggests that this kind of information can be processed earlier (in the N400 component), sharing a similar time window as the processing of morphosyntactic information (reflected in LAN). Some authors have argued that the existence of qualitatively distinct ERP effects in semantic and syntactic processing points toward a neural distinction between semantic and syntactic binding operations, indicating that these two levels of language processing are domain-specific (Hagoort, 2003). However, for this domain specificity to support modular claims, these levels of processing should be encapsulated (i.e., they must operate autonomously, without interaction). Thus, even if both kinds of information can be processed in parallel, lexico-semantic information would never be thought to interfere with agreement computations.

To further investigate this issue, some authors have raised the following hypothesis: if the emotional connotation of words—a lexico-semantic property of language—can affect the processing of morphosyntactic computations—as agreement—it would mean that the morphosyntactic operation is not formally encapsulated (Fraga, 2020). Several studies carried out in Spanish have reported the typical biphasic pattern in the context of agreement errors (i.e., increased LAN and P600 amplitudes for the mismatch condition), and crucially, they have also found differences in the LAN effects depending on the emotionality of the word containing the grammatical error (Hinojosa et al., 2014; Jiménez-Ortega et al., 2017, 2021; Martín-Loeches et al., 2012; Poch et al., 2022). Evidence from studies using number and person agreement mismatches supports the existence of two kinds of interactive effects. Martín-Loeches et al. (2012) reported a grammaticality effect in the LAN component (i.e., increased amplitudes for the mismatch condition) that was larger for unpleasant adjectives than for neutral ones. According to the authors, the presence of unpleasant words increased the cost of processing morphosyntactic errors, pointing to an early interaction between syntax and emotion. Two studies where the presentation of the emotional word was subliminal (Jiménez-Ortega et al., 2017, 2021) and a recent one using person agreement computations (Poch et al., 2022) found that the topographic distribution of the grammaticality effect varied between neutral and emotional words. While agreement errors in neutral words elicited the typical LAN effect, these errors led to more central or less left anterior specific components in emotional words (Jiménez-Ortega et al., 2017; Jiménez-Ortega et al., 2021; Poch et al., 2022, respectively). The authors interpreted these differences in the localization of the effects as evidence for the influence of emotional information in early stages of syntactic processing. As for gender agreement processing, Hinojosa et al. (2014) carried out a study using neutral and unpleasant adjectives embedded in noun phrases (NPs; Determiner + Noun + Adjective). As expected, gender agreement errors elicited increased LAN amplitudes in neutral adjectives, yet this effect vanished when the adjectives were unpleasant. The authors interpreted these results as evidence of a facilitatory effect of unpleasant words on morphosyntactic processing. Differences in the linguistic unit (long sentences, clauses, or NPs), the feature under study (gender, number, or person), the nature of the task used (overt or subliminal presentation of the emotional words), or differences in the specific manipulation of the emotional parameters (i.e., valence and arousal levels) could have been the cause for the discrepancies in these results (Fraga, 2020). In fact, a series of studies that used the same linguistic unit (long sentences: Determiner + Noun + Adjective + Verb + Direct object…), task (gender agreement), and materials failed to replicate previously attested emotional effects on morphosyntactic processing (Díaz-Lago et al., 2015; Fraga et al., 2017; Padrón et al., 2020). In all these studies, gender agreement violations elicited the typical biphasic pattern (LAN and P600 grammaticality effects). However, none of them reported significant differences in the grammaticality effect across neutral and pleasant or unpleasant words, either in LAN or P600.

On top of the above, recent studies have observed systematic variability in the ERPs elicited by agreement anomalies (Tanner, 2019; Tanner & Van Hell, 2014). By computing a Response Dominance Index (RDI), these authors found that brain responses can vary in a continuum from negative to positive effects, with some people preferentially showing LAN-like grammaticality effects (people with a negative dominance profile), others preferentially showing the effect in the P600 component (people with a positive dominance profile), and only a few showing the classical biphasic pattern. Moreover, these authors also suggest that, when individual differences are considered, the early negativity is no longer left-lateralized, but presents the common distribution of a N400. These results question the so-long assumed functional interpretation of these ERP components and introduce a new perspective in terms of how to characterize the interplay between grammar and emotion. Ultimately, accepting the existence of these two dominance profiles goes against a universal conceptualization of grammatical processing as happening in two successive stages: detection of the error (reflected in the LAN component) and reanalysis (reflected in the P600 component). While the interest on the study of individual differences in cognitive processes is not new (e.g., Coulson & Kutas, 2001; King & Kutas, 1995; Osterhout, 1997), the studies that have directly explored the variables which may explain these differences in the brain patterns of participants are scarce and the evidence is non-conclusive. On one hand, some studies have found that differences in linguistic proficiency and working memory capacity may be related to a trade-off between N400 and P600 effects across individuals. According to this evidence, P600 amplitudes are positively correlated with both participant's proficiency in a second language (L2; e.g., Tanner et al., 2013) and working memory capacity (Kim et al., 2018; Nakano et al., 2010), while N400 amplitudes seem to be negatively correlated instead. On the other hand, several studies have failed to replicate these results, despite finding evidence for individual variability in the dominance of LAN/N400 and P600 effects (Ciaccio et al., 2023; Tanner, 2019; Tanner & Van Hell, 2014)[1].

To our knowledge, two recent studies on the interplay between gender agreement and emotion have considered these individual differences in their analyses, this time selecting NPs composed of a determiner, a noun, and an adjective—the critical word. One of these studies used unpleasant and neutral words and the other used pleasant and neutral words (Fraga et al., 2021; Padrón et al., 2023, respectively). Neutral NPs were kept identical between the two studies, and both pleasant and unpleasant adjectives had moderate levels of arousal to ensure direct comparisons with prior studies. Critically, evidence for the two dominance ERP profiles in gender agreement processing was found in both studies. Results revealed a lack of interaction between grammaticality and emotionality in pleasant stimuli irrespective of the dominance profile of the participants (Padrón et al., 2023). Nonetheless, the authors found a significant interaction in LAN for unpleasant words (Fraga et al., 2021). Interestingly, not only different grammaticality effects but also different emotionality effects were found between the two different profiles. Namely, the effects of word emotionality were restricted to participants with a positive dominance profile when processing unpleasant words (Fraga et al., 2021). These participants showed (a) increased N400 amplitudes for the unpleasant condition relative to the neutral one and (b) an interaction between grammaticality and emotionality: While no differences were found between grammatically correct and incorrect trials when adjectives were unpleasant, an inversed LAN effect arose for neutral adjectives (increased amplitudes in the match condition). These unexpected results might be interpreted in terms of a detrimental effect on agreement processing caused by the presence of unpleasant stimuli, in line with prior evidence (Constantine et al., 2001; Pratto & John, 1991; Zsidó et al., 2023). Additionally, Fraga et al. (2021) found that unpleasant words captured the participants' attention very early, evoking larger N100 amplitudes than neutral words. Interestingly, the grammaticality of the NPs also affected N100 amplitudes. However, this happened exclusively for those participants with a positive dominance profile. Padrón et al. (2023) also found evidence for early grammaticality effects (larger amplitudes in the mismatch condition than in the match condition) starting around 130 ms after stimulus onset in the negative dominance group and interpreted these results as an N100. Although early effects of emotionality and grammaticality have been reported by several studies (for early effects of emotionality, see Hinojosa et al., 2020; for early effects of grammaticality, see Foucart & Frenck-Mestre, 2011; Hasting & Kotz, 2008; Leikin & Breznitz, 1999; Pulvermüller & Shtyrov, 2003), they have been overlooked by many others since they are usually small, short-lived, and focal, and seem to be more sensitive to variance in stimulus parameters, what can explain the inconsistent results (Pulvermüller et al., 2009). Nonetheless, there is evidence for fine-grained millisecond delays between brain correlates of phonological, lexical, and semantic information around 100 and 200 ms. According to Pulvermüller et al. (2009), these results indicate that the access to phonological, lexical, and semantic word features along with semantic and syntactic context integration and parsing occurs early on and almost simultaneously. Therefore, later components, such as the LAN, N400, and P600, might reflect a second step in lexical, semantic, and syntactic information processing or even indicate specific linguistic or non-linguistic post-comprehension processes. This idea could potentially explain why some individuals show grammaticality effects in the LAN and not in P600, while others show the opposite pattern, highlighting the need to extend the study of these individual differences beyond the typical LAN and P600 time windows.

In sum, although some studies have shown evidence for an interaction between emotional and grammatical processing, opposing results can also be found in the available literature. As already stated, differences in the materials used (linguistic unit, arousal, etc.) could account for the disparity in the results. In fact, several studies have demonstrated that the level of arousal

[1]As mentioned above, these authors found that individuals' brain responses varied in a continuum from negative to positive effects (LAN/N400—P600) when processing morphological violations in their native language. However, no evidence for a correlation between the two dominance profiles and either proficiency or working memory capacity was found. According to Tanner (2019), the correlation between working memory capacity and differences in language processing may be limited to studies in which the tasks used to measure the former involved reading and therefore were inherently related to language skills.

affects unpleasant and pleasant words differently and that unpleasant words are processed differently depending on their arousal level (Bayer et al., 2012; Recio et al., 2014; Vieitez et al., 2021). High arousal unpleasant words have been found to yield facilitatory effects in single-word processing studies in comparison with neutral ones with lower levels of arousal (e.g., Herbert et al., 2008; Kissler et al., 2009), while unpleasant words with lower levels of arousal have been found to elicit the opposite effect (Vieitez et al., 2021; see Citron, 2012 for a review). This could be an explanation for the differences between Hinojosa et al.'s (2014) and Fraga et al.'s (2021) results, as the former used unpleasant words with high levels of arousal (6.89 in a 1–9 scale), while the later used unpleasant words with moderate levels of arousal (5.85 in a 1–9 scale). Also, the new evidence on individual differences discussed above suggests that distinct brain profiles emerge in grammatical processing and that the influence of emotional information in syntactic processing may be restricted to one of these profiles, showing neural differences in both grammatical and emotional processing also in very early components such as N100. All in all, the question of whether the early computation of agreement is permeable to outer sources of information, such as the emotional content of words, is still up for debate.

In this study, we aim to shed light on this open question. Our specific aims are three: (1) to investigate whether an interaction between grammatical and emotional processing can be found in the LAN component for high arousal unpleasant words; (2) to analyze whether such interactive effects are common for all individuals or rather restricted to participants with a specific dominance profile; and (3) to explore the temporal and spatial distribution of both the grammaticality and emotionality effects and their interaction beyond the LAN and the P600 components. With these objectives in mind, we designed a gender agreement task using Spanish NPs composed of a determiner, a noun, and an adjective (the critical word) that could be either neutral or unpleasant. Importantly, neutral adjectives in the present study were the same ones as in Fraga et al. (2021), but unpleasant adjectives had high—rather than moderate—levels of arousal. Thus, our materials are highly similar to those of Hinojosa et al. (2014). Furthermore, we calculated the RDI (Tanner & Van Hell, 2014) to examine possible individual differences in grammatical processing and used cluster analyses to explore the temporal and spatial distribution of both the grammaticality and emotionality effects.

Briefly said, should we find the classical grammatical effect in the LAN wave for neutral words together with a cancellation of the LAN effect for unpleasant words, Hinojosa et al.'s (2014) results would have been replicated, and our results would extend prior evidence on the interplay between grammar and emotion. Nonetheless, we hypothesize that if grammaticality and emotionality do interact in the early stages of language processing, this interaction would only arise for those participants with a positive dominance profile, as in Fraga et al. (2021). In the light of previous data, we also expect to find differences in grammatical and emotional effects emerging between 100 and 250 ms across the two dominance profiles.

## 2 | METHOD

### 2.1 | Participants

Sixty-one female students from the University of Santiago de Compostela between 19 and 23 years old (mean age = 19.93, SD = 0.94) participated in this experiment. All of them were native speakers of Spanish with no history of neurological or cognitive disorders and with normal or corrected-to-normal vision. All volunteers were right-handed as assessed with the Spanish version of the Edinburgh Handedness Inventory (Oldfield, 1971). They provided informed consent to participate in the study, and they were rewarded with course credits. The study was approved by the Ethics Committee of the University of Santiago de Compostela (USC-29/2021).

Data from seven participants were excluded due to excessive artifacts in the EEG register ($N = 5$) and an excessive error rate in the behavioral task ($N = 2$), as will be explained later. Thus, the final sample consisted of 54 participants.

### 2.2 | Materials

The experimental materials consisted of a set of 128 Spanish NPs with the structure "Determiner + Noun + Adjective" (see Table 1). The adjective was always the critical word, and it could either agree or disagree in gender with the preceding noun (match and mismatch conditions, respectively). All nouns were animate entities neutral in valence, while the emotionality of the adjectives was manipulated. Thus, 64 neutral nouns and 64 adjectives (32 neutral and 32 unpleasant) were selected to generate the four experimental conditions: 32 neutral grammatically correct NPs (neutral match condition), 32 neutral grammatically incorrect NPs (neutral mismatch condition), 32 unpleasant grammatically correct NPs (unpleasant match condition), and 32 unpleasant grammatically incorrect NPs (unpleasant mismatch condition). The

**TABLE 1** Examples of match and mismatch NPs with unpleasant and neutral adjectives.

| | Match | Mismatch |
|---|---|---|
| Unpleasant | | |
| Feminine | La abogada$_{(fem)}$ violenta$_{(fem)}$ | La abogada$_{(fem)}$ violento$_{(masc)}$ |
| | *The violent*$_{(fem)}$ *lawyer*$_{(fem)}$ | *The violent*$_{(fem)}$ *lawyer*$_{(masc)}$ |
| Masculine | El abogado$_{(masc)}$ violento$_{(masc)}$ | El abogado$_{(masc)}$ violenta$_{(fem)}$ |
| | *The violent*$_{(masc)}$ *lawyer*$_{(masc)}$ | *The violent*$_{(masc)}$ *lawyer*$_{(fem)}$ |
| Neutral | | |
| Feminine | La abogada$_{(fem)}$ meticulosa$_{(fem)}$ | La abogada$_{(fem)}$ meticuloso$_{(masc)}$ |
| | *The meticulous*$_{(fem)}$ *lawyer*$_{(fem)}$ | *The meticulous*$_{(fem)}$ *lawyer*$_{(fem)}$ |
| Masculine | El abogado$_{(masc)}$ meticuloso$_{(masc)}$ | El abogado$_{(masc)}$ meticulosa$_{(fem)}$ |
| | *The meticulous*$_{(masc)}$ *lawyer*$_{(masc)}$ | *The meticulous*$_{(masc)}$ *lawyer*$_{(masc)}$ |

neutral nouns and adjectives used in this study were identical to those employed in two previous studies (Fraga et al., 2021; Padrón et al., 2023). All nouns and adjectives had a masculine and a feminine form and were suffixed with the canonical marker from its correspondent gender in Spanish ("-o" for masculine and "-a" for feminine; e.g., "*violento*$_{masc}$"/"*violenta*$_{fem}$" [violent]). Valence and arousal ratings for the neutral and unpleasant adjectives were obtained from the Spanish database by Stadthagen-Gonzalez et al. (2017) using the emoFinder web tool (Fraga et al., 2018). Values for other lexical variables, such as the number of letters, number of syllables, frequency of use, and concreteness, were sourced from the EsPal web tool (Duchon et al., 2013)[2].

Additionally, we conducted an online survey to collect the valence, arousal, and concreteness values of several adjectives that were not available in the aforementioned databases for some of their masculine or feminine forms. Fifty volunteers, aged between 18 and 30 years (19 men, 31 women; M = 26, SD = 3.8), took part in this survey. None of them participated in the ERP experiment. Each participant rated 67 words distributed in two different lists. The subjective ratings were obtained by employing the self-assessment manikin (SAM; Bradley & Lang, 1994). A 9-point Likert scale was used for the dimensions of valence and arousal (9 being highly pleasant and highly arousing, respectively), and a 7-point Likert scale was used for concreteness (7 being highly concrete).

Table 2 shows the mean values and standard deviations for neutral and unpleasant adjectives in their masculine and feminine forms across several measures. Importantly, neutral adjectives had intermediate levels of valence (M = 5.33) and arousal (M = 5.21), while unpleasant adjectives scored low in valence (M = 2.52), but high in arousal (M = 6.89). A 2 (Emotionality: neutral, unpleasant) × 2 (Gender: masculine, feminine) analysis of variance (ANOVA) was performed for each variable (see Table 2). These analyses confirmed that neutral and unpleasant adjectives differed in valence and arousal, while no main effects of Gender were found for these two variables. As for the frequency of use, both a main effect of Gender, $F(1,62) = 5.75$, $p = .02$, and an interaction between Emotionality and Gender, $F(1,62) = 538$, $p = .02$, were obtained. Post-hoc analyses showed that unpleasant masculine adjectives were more frequent than unpleasant feminine ones ($p < .01$), while no statistical differences were observed among the other conditions ($p_s > .05$). No other main effects or interactions were found to be statistically significant. Thus, all adjectives were matched across Emotionality and Gender concerning length (number of letters and number of syllables) and concreteness.

To control for the predictability of the adjectives in the NPs, a new sample of 41 volunteers (M = 19.90 years old, SD = 1.24) completed one of two versions of a cloze probability questionnaire (with 64 NPs each). Participants were asked to write the word that they thought was most likely to follow each NP (Determiner + Noun). None of the adjectives used in the experimental NPs were predicted by the participants, guaranteeing that the critical adjectives could not be predicted based on the preceding nouns (0% values).

Additionally, we incorporated 112 filler NPs that followed the same structure as the experimental NPs (Determiner + Noun + Adjective). Fillers were identical to the ones used in Fraga et al. (2021) and Padrón et al. (2023)[3]. Like experimental NPs, fillers could be ei-

[2]The experimental materials used in this investigation are available as Supplementary Materials.

[3]A set of 38 NPs contained adjectives with a neutral suffix that is applied indistinctly in Spanish to both masculine and feminine gender nouns (e.g., "-e"; "elegante" [elegant]); 37 NPs contained nouns with opaque gender, that is, nouns without any explicit morphological mark (e.g., "actriz", [actress]); and 37 NPs contained irregular nouns (e.g., "cura" [priest], a masculine noun, ends with the morpheme "-a" that is commonly indicative of a feminine form). These types of fillers were included to avoid participants employing a superficial strategy to perform the task (e.g., by attending only to the similar endings "-o/-o" or "-a/-a" for nouns and adjectives).

**TABLE 2** Mean and standard deviation values for neutral and unpleasant adjectives in valence, arousal, number of letters, number of syllables, frequency, and concreteness.

| | Valence | Arousal | Letters | Syllables | Frequency | Concreteness |
|---|---|---|---|---|---|---|
| Unpleasant | | | | | | |
| Feminine | 2.54 (0.52) | 6.76 (0.45) | 8.19 (1.67) | 3.75 (0.80) | 0.61 (0.44) | 4.40 (0.83) |
| Masculine | 2.51 (0.54) | 7.02 (0.39) | 8.19 (1.67) | 3.72 (0.84) | 0.74 (0.42) | 4.50 (0.70) |
| Neutral | | | | | | |
| Feminine | 5.29 (0.87) | 5.20 (0.77) | 8.00 (1.81) | 3.53 (0.88) | 0.62 (0.53) | 4.13 (0.62) |
| Masculine | 5.38 (0.82) | 5.22 (0.99) | 8.00 (1.81) | 3.53 (0.88) | 0.62 (0.44) | 4.33 (0.92) |
| ANOVA | | | | | | |
| Emotion | $F=299.15$* | $F=117.78$* | $F=0.00$[ns] | $F=0.00$[ns] | $F=0.24$[ns] | $F=1.66$[ns] |
| Gender | $F=0.19$[ns] | $F=2.91$[ns] | $F=0.00$[ns] | $F=0.00$[ns] | $F=5.72$** | $F=1.79$[ns] |
| Emotion × Gender | $F=0.78$[ns] | $F=2.19$[ns] | $F=0.00$[ns] | $F=0.00$[ns] | $F=5.38$** | $F=0.25$[ns] |

*Note*: Valence and arousal were measured in scales ranging from 1 to 9 (1 = highly unpleasant, 9 = highly pleasant; and 1 = highly calming, 9 = highly arousing, respectively). Concreteness was measured in a 1–7 scale (1 = highly abstract, 7 = highly concrete). As for the ANOVA results, df = 1.62.

Abbreviation: ns, non-significant.

*$p < .01$. **$p < .05$.

ther grammatically correct or incorrect and they could contain neutral or unpleasant adjectives.

The whole set of 240 NPs was divided into four experimental lists using a Latin-square design, ensuring that each list included a distinct version of each NP to prevent repetition effects (see Table 1 for details). The NPs were pseudo-randomized such that no more than four NPs of the same condition could be presented successively.

## 2.3 | Procedure

The experiment was run in an isolated and dimly lit room. NPs were presented word by word at the center of a PC monitor situated about 65 cm from the participant's eyes. A chin rest was employed to prevent head movements and to keep the distance between participants' eyes and the screen constant. Words were displayed in black lowercase letters (except for the first word of each phrase, which began with a capital letter) using a 30-point Chicago font on a gray background.

During the EEG recording, participants performed a grammaticality judgment task. They were instructed to press one of two keyboard keys ("M" and "N") with their right-hand middle or index finger to indicate whether the phrase was grammatically correct or incorrect. The assignment of the correct and incorrect keys was counterbalanced across participants. Each trial began with a fixation cross that appeared in the center of the screen for 1000 ms. After a following blank-screen interval of 100 ms, each word was presented in the center of the screen for 300 ms followed by a 300 ms inter-stimulus interval. One hundred milliseconds after the final word, three question marks appeared on the screen, indicating that participants should answer by pressing the appropriate key. The question marks remained on the screen for 2500 ms or until a response was recorded. The inter-trial interval was 500 ms. Participants completed a training block consisting of six NPs (all of them were different from the experimental NPs) before the beginning of the experimental trials. Furthermore, participants had the option to rest for a few minutes after completing 50% of the main task. Once they had finished the grammaticality judgment task, participants were asked to fill out an online questionnaire, where ratings from valence, arousal, and plausibility were collected for all the experimental NPs (in their correct form). A 9-point Likert scale (SAM; Bradley & Lang, 1994) was used for valence and arousal ratings, and a 5-point Likert scale was used for plausibility (1 being low plausibility and 5 being high plausibility). In total, each session lasted approximately 1 h and 30 min.

## 2.4 | EEG recording and preprocessing

Scalp voltages were collected using a *QuickAmp* recording system from 32 electrodes mounted on an elastic cap (Electro-Cap International, Inc.) in the standard 10/20 positions. The vertical electrooculogram (VEOG) was monitored to detect artifacts using two electrodes positioned below and above the left eye orbital region. Electrode impedances were kept below 5 kΩ, and continuous signal recording was conducted with a band-pass filter set at 0.01–30 Hz and a sampling rate of 500 Hz. Throughout the data recording process, the average of signals from all electrodes served as the online reference.

The EEG data analysis was conducted using Brain Vision Analyzer® 2.3 software (Brain Products, Germany). Raw data were re-referenced off-line to the average of the left and right earlobes, and a band-pass filter with a range of 0.1–30 Hz (24 dB/oct.) was applied. To remove ocular artifacts, the Gratton et al. (1983) computation method was employed. The continuous EEG recording was segmented into 1100 ms epochs, starting 200 ms before the critical adjective onset. Only segments with correct responses were selected for further analysis. During data preprocessing, trials with voltage values exceeding ±80 μV in any channel were automatically excluded from further analysis. Baseline correction was applied using the mean amplitude of the 200 ms prior to stimulus onset. Subsequently, grand average ERPs were calculated for each participant at every electrode within each experimental condition (i.e., neutral match, neutral mismatch, unpleasant match, and unpleasant mismatch). A minimum of 20 trials (out of 32) were required for averaging in each condition. Data from seven participants were excluded because they did not meet this criterion. After the artifact rejection procedure, the average number of trials per condition was 28.52 (SD = 3.21) for neutral match, 28.57 (SD = 3.36) for neutral mismatch, 28.85 (SD = 3.47) for unpleasant match, and 28.70 (SD = 3.65) for unpleasant mismatch. There were no significant differences among these conditions, as indicated by *Fs* (1,53) <1.4.

## 2.5 | Data analysis

### 2.5.1 | Estimation of the Response Dominance Index

To account for individual differences in participants' ERP patterns (Fraga et al., 2021; Padrón et al., 2023; Tanner, 2019; Tanner & Van Hell, 2014), we calculated the effect size of the LAN and P600 components individually (see Figure 1a). Specific brain electrodes and time windows in which these effects are most robust were selected for each component. For the LAN component, we computed the difference between the match and mismatch conditions over the mean activity at left-anterior electrodes (F3, F7, C3A, and C7A) in the 300–450 ms time window. As for the P600 component, we computed the difference between the mismatch and match conditions over the mean activity at centro-parietal electrodes (CZ, PZA, and PZ) in the 500–900 ms time window. Then, we calculated each individual's RDI, which provides a measurement of the relative predominance of negative effects over positive effects regardless of their magnitude. The RDI (see formula below) was calculated by fitting the individual's least square distance from the equal effect size lines using perpendicular offsets. This index provides valuable interpretations based on its values. A positive RDI indicates a relative predominance of positivity, with a greater presence of P600 effects in participants' ERP responses. An RDI near zero suggests a balanced presence of LAN and P600 effects, and a negative RDI indicates a relative predominance of negativity, with a stronger influence of LAN effects in the ERP responses (see Figure 1a).

$$\mathrm{RDI} = \left(\mathrm{P600_{mismatch}} - \mathrm{P600_{match}}\right) - \left(\mathrm{LAN_{match}} - \mathrm{LAN_{mismatch}}\right) / \sqrt{2}.$$

Similar to previous studies, participants exhibited a continuous distribution of RDI values, spanning from negative dominance (i.e., more LAN effects) to positive dominance (i.e., more P600 effects). With the aim of exploring the time course of these individual differences, we grouped the sample of participants based on their dominance profile: participants who exhibited a negative dominance profile ($N = 28$) and participants who exhibited a positive dominance profile ($N = 26$; see Figure 1b). These two groups constituted the two levels of the factor Dominance.

### 2.5.2 | ERP analysis

To examine the time course of the experimental effects of Grammaticality and Emotionality, ERP differences between condition pairs were assessed across the whole scalp and over the entire epoch of interest (0–900 ms), following a nonparametric cluster-based random permutation analysis approach (Maris & Oostenveld, 2007)[4]. In this analysis, the statistical significance of the difference between conditions is evaluated at the cluster level, following a randomization procedure. First, a t test is computed in every spatio-temporal pair (for each electrode and time-point). The cluster statistic is calculated as the sum of all the adjacent significant temporospatial univariate statistic values (dependent sample test). That is, the significant values that are close in time and space are summed to compute the cluster statistic. Then, the significance of the cluster statistic is assessed by comparing its value with the null distribution obtained through a randomization procedure that computes the cluster statistic 10,000 times while shuffling the data labels (i.e., randomly assigning data points to each

[4]Following open science practices, the raw data can be found at https://osf.io/evyxg/.

PSYCHOPHYSIOLOGY



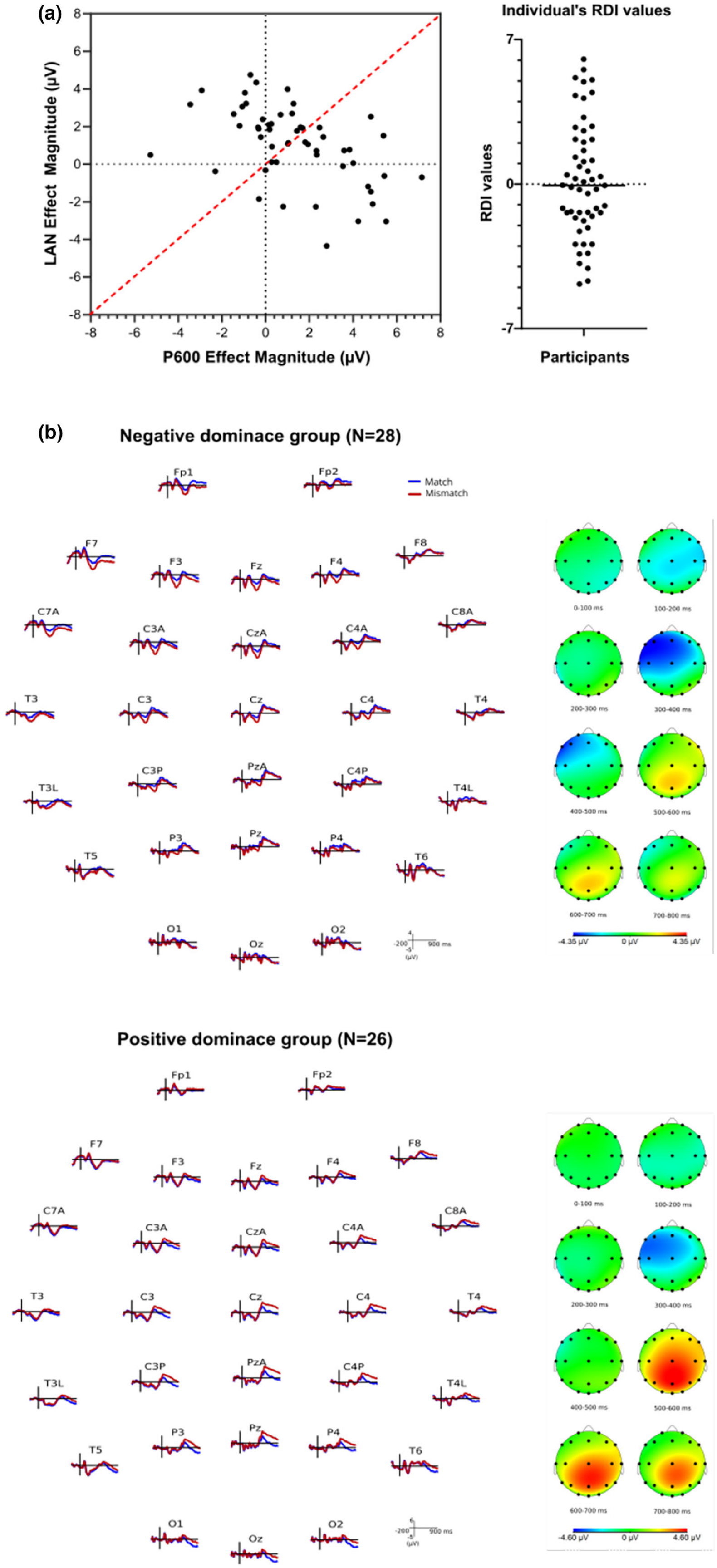


**FIGURE 1** Distribution of participants according to their RDI and ERP waveforms for the grammaticality effect in the two dominance groups. (a) Left: Scatterplot showing the distribution of LAN effect amplitudes (match minus mismatch; y axis) and P600 effect amplitudes (mismatch minus match; x axis) averaged over the mean activity at left anterior electrodes (F7, F3, C7A, and C3A) and centro-parietal electrodes (CZ, PZA, and PZ) for LAN and P600, respectively. Each dot shows data from a single participant. The dashed red line represents equal LAN and P600 magnitudes. Participants above/to the left of the red dashed line show a negative dominance brain profile, and participants below/to the right of the dashed line show a positive dominance brain profile. Right: Violin plot showing the distribution of RDI values across participants. More negative RDI values represent a negative dominance profile, while more positive values represent a positive dominance profile; values closer to zero show a biphasic profile. (b) Grand mean averaged ERPs for the whole scalp are shown for match (blue line) and mismatch (red line) conditions for each dominance group.

condition). The cluster is considered statistically significant when it is found to be above the 95th percentile of the null distribution. This procedure solves the multiple comparison problem intrinsic to parametrical statistical procedures. Additionally, since the analysis is not restricted to predetermined temporo-spatial windows, a cluster-based approach allows for an unbiased exploration of the whole timeframe.

Nonetheless, this approach inherently limits us to making 1 versus 1 comparisons (e.g., grammatical vs. ungrammatical; unpleasant vs. neutral). Since we aim to investigate whether individual differences can modulate the interaction between grammatical and emotional processing, addressing the effects of this complex interaction using only a cluster-based approach would be difficult. Additionally, most prior studies on agreement and emotional processing have used ANOVAs to explore well-known ERP components in specific time windows and regions. Thus, to further explore whether the results obtained in the cluster-based analyses correspond to specific ERP components, we carried out this type of analysis as well. Based on the electrodes that showed the stronger effects in the cluster-based analyses and following relevant literature on agreement and emotional language processing, we selected specific time windows and ROIs for each component. Electrodes were grouped into six regions of interest (ROIs): left anterior (LA; F3, F7, C3A, and C7A), central anterior (CA; Fz, CZA, and CZ), right anterior (RA; F4, F8, C4A, and C8A), left posterior (LP; T3L, C3P, T5, and P3), central posterior (CP; PZA, and PZ), and right posterior (RP; T4L, C4P, T6, and P4). Then, mean amplitude voltage values for each one of the selected time windows were analyzed using repeated-measures ANOVAs with Grammaticality (match and mismatch), Emotionality (neutral and unpleasant), and Region (when necessary; LA, CA, RA, LP, CP, or RP) as within-participant factors. The between-participants factor Dominance (negative and positive profile) was included to explore whether any of these effects were modulated by the dominance profile of the participants. The Greenhouse–Geisser correction was applied to adjust the degrees of freedom when necessary. For all ANOVAs carried out in this study, the partial n-square ($\eta_p^2$) was reported for significant effects. Statistical analyses were carried out using the software JASP (Version 0.16.3).

#### 2.5.3 | Behavioral data

Participants' performance during the grammaticality task was analyzed by conducting two 2 (Dominance profile: negative, positive profile) × 2 (Grammaticality: match, mismatch) × 2 (Emotionality: neutral, unpleasant) repeated-measures ANOVAs, one for mean reaction times (RTs; only correct responses) and another one for the percentages of correct responses (i.e., hits). To perform the statistical analyses, reaction times were log-transformed to reduce non-normality.

#### 2.5.4 | Subjective ratings

As for the analysis of the subjective ratings, a 2 (Dominance profile: negative, positive profile) × 2 (Emotionality: neutral, unpleasant) × 2 (Gender: masculine, feminine) repeated-measures ANOVA was conducted for each variable of interest (valence, arousal, and plausibility).

## 3 | RESULTS

### 3.1 | Behavioral results

Participants were quite accurate when performing grammaticality judgments (neutral match: 82.96%; neutral mismatch: 81.22%; unpleasant match: 81.90%; and unpleasant mismatch: 81.32%). This happened irrespectively of the Grammaticality and the Emotionality status of the NPs, $Fs\,(1, 51) < 1.5$.

Regarding the RTs, the Dominance × Grammaticality × Emotionality repeated-measures ANOVA showed a main effect of Emotionality, $F(1,51) = 9.17$, $p = .004$, $\eta_p^2 = .15$, $\theta = 1$. Participants' responses were faster to NPs with unpleasant adjectives (M = 425 ms; SD = 122) than to NPs with neutral adjectives (M = 449 ms; SD = 120). No other main effects or interactions were significant.

### 3.2 | Subjective ratings

The statistical analyses of subjective ratings showed a main effect of Emotionality for valence, $F(1,51) = 293.90$, $p < .001$, $\eta_p^2 = .85$, $\theta = 1$; arousal, $F(1,51) = 170.05$, $p < .001$, $\eta_p^2 = .77$, $\theta = 1$; and plausibility ratings, $F(1,51) = 4.70$, $p = .03$, $\eta_p^2 = .08$, $\theta = .99$. Unpleasant NPs were rated as more unpleasant, arousing, and less plausible than neutral NPs. Moreover, a main effect of Gender was found for valence, $F(1,51) = 7.74$, $p = .008$, $\eta_p^2 = .13$, $\theta = 1$, and plausibility ratings, $F(1,51) = 6.21$, $p = .02$, $\eta_p^2 = .11$, $\theta = .99$, showing that NPs with feminine adjectives were rated as less unpleasant and plausible than their masculine counterparts. The main effect of Dominance was not significant, and this factor did not interact with either Emotionality or Gender, indicating that there were no differences in the subjective assessment of the NPs based on the dominance profile of the participants.

### 3.3 | ERP results

#### 3.3.1 | Overall analyses

The cluster-based analysis performed for the entire sample revealed significant Grammaticality effects in two clusters (see Figure 2). For the first cluster, amplitudes were more negative in the mismatch condition than in the match condition between 296 and 446 ms. This effect was widely distributed on the scalp (Fp1, F7, F3, Fz, F4, C7A, C3A, CzA, C4A, C8A, T3, C3, Cz, C4, T4, T3L, C3P, PzA, C4P, T4L, T5, P3, Pz, P4, and T6) and had a left frontal maximum. The *p*-value associated with the cluster, calculated by a randomization procedure, was .005. The second significant cluster revealed more positive amplitudes in the mismatch condition compared to the match condition in several centro-parietal electrodes (F8, CzA, C4A, C8A, C3, Cz, C4, T4, C3P, PzA, C4P, T4L, T5, P3, Pz, P4, T6, O1, Oz, and O2) between 602 and 898 ms, with a *p*-value of .0015.

As regards Emotionality, the cluster permutation test revealed a significant effect in a cluster between 468 and 566 ms in centro-parietal electrodes (Fz, F4, CzA, C4A, C3, Cz, C4, C3P, PzA, C4P, P3, Pz, P4, O1, Oz, and O2), with more negative amplitudes in the neutral condition compared to the unpleasant one (see Figure 2). The *p*-value associated with the cluster, calculated by a randomization procedure, was .024.

Considering its temporal distribution and left frontal maximum, the first cluster seems to correspond to a LAN component (e.g., Molinaro et al., 2008; Münte et al., 1997; see Figure 2). Thus, a Dominance × Grammaticality × Emotionality repeated-measures ANOVA

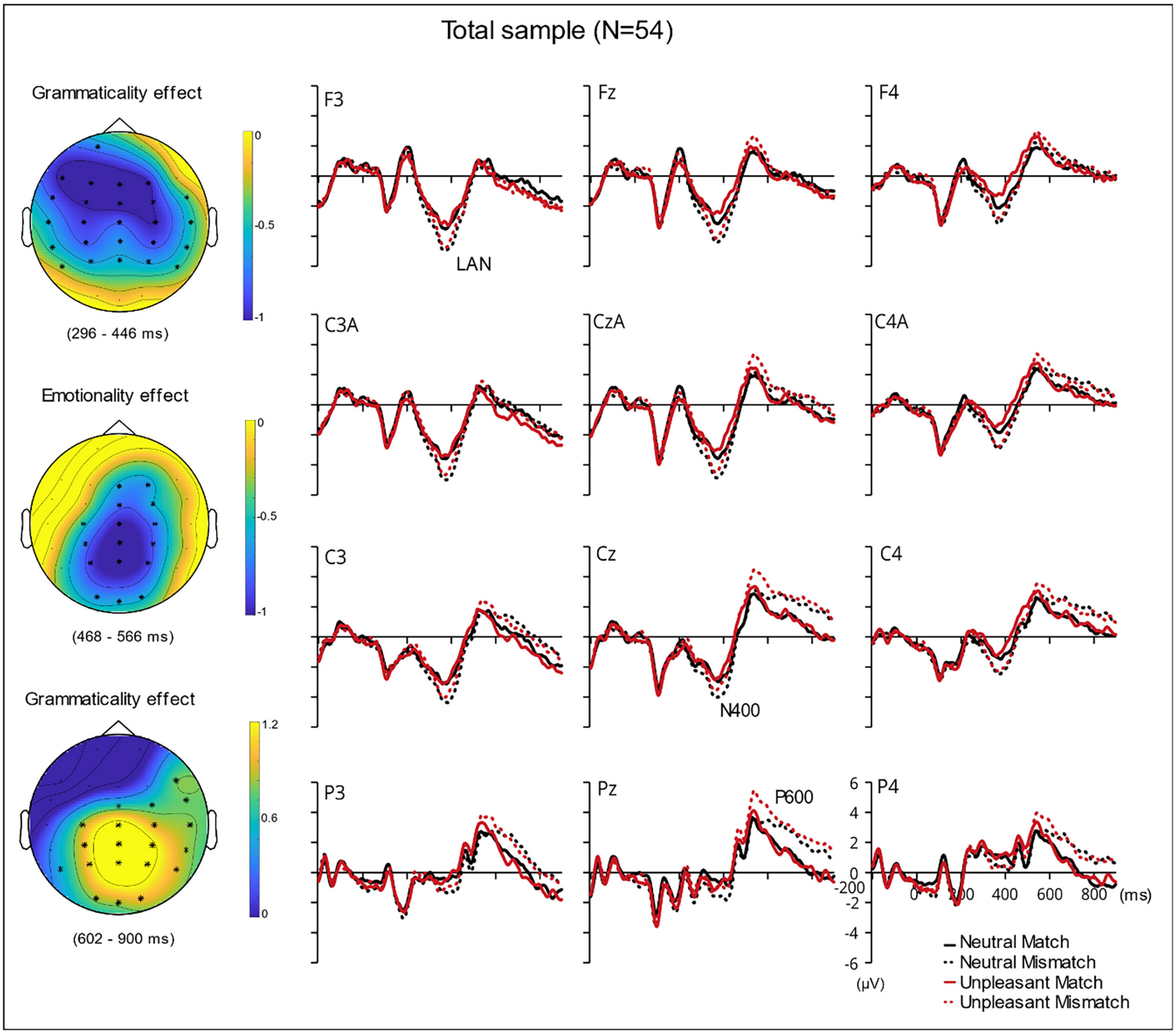


**FIGURE 2** Grammaticality and Emotionality effects for the total sample of participants. Left: Topography maps of the difference between match and mismatch conditions, as well as between neutral and emotional conditions, averaged across specific time windows where Grammatical and Emotional main effects were significant. The asterisks in bold represent the significant electrodes that form part of each of the depicted clusters. Right: Grand mean averaged ERPs from 12 representative electrodes for match (solid line) and mismatch (dashed line) conditions as a function of neutral (black) and unpleasant (red) conditions for the total sample ($N = 54$).

was performed in the LA region for the 300–450 ms time window. This analysis revealed a main effect of Grammaticality, $F(1,52) = 23.73$, $p < .001$, $\eta_p^2 = .31$, $\theta = 1$, with ungrammatical NPs evoking larger LAN amplitudes than grammatical ones, as well as a significant interaction between Dominance and Grammaticality, $F(1,52) = 47.73$, $p < .001$, $\eta_p^2 = .48$, $\theta = 1$. No other main effects or interactions were significant (all $F_s < 1.2$). The second cluster, while widely distributed on the scalp, seems to have the common temporal and spatial distribution of the P600 component (Hinojosa et al., 2014; Osterhout & Holcomb, 1992; see Figure 2). Thus, a Dominance × Grammaticality × Emotionality repeated-measures ANOVA was performed in the CP region for the 600–900 ms time window. A main effect of Grammaticality was obtained, $F(1,52) = 41.26$, $p < .001$, $\eta_p^2 = .44$, $\theta = 1$, with ungrammatical NPs evoking larger P600 amplitudes than grammatical ones. Additionally, the interaction between Dominance and Grammaticality was significant, $F(1,52) = 48.62$, $p < .001$, $\eta_p^2 = .48$, $\theta = 1$. No other main effects or interactions were significant (all $F_s < 1$).

As for the emotional cluster, its temporal and spatial distribution could correspond to a late N400 component (Kutas & Hillyard, 1980, 1984; Kutas & Federmeier, 2011; see Figure 2). Therefore, a Dominance × Grammaticality × Emotionality × Region repeated-measures ANOVA was performed in the central regions (CA and CP) for the 450–550 ms time window. This analysis revealed a significant main effect of Emotionality, $F(1,52) = 12.42$, $p < .001$, $\eta_p^2 = .19$, $\theta = 1$. Reduced N400 amplitudes were registered for unpleasant adjectives in comparison with neutral ones. Additionally, this analysis revealed a statistically significant interaction between Dominance and Grammaticality, $F(1,52) = 29.39$, $p < .001$, $\eta_p^2 = .36$, $\theta = 1$, and an interaction between Dominance, Grammaticality, Emotionality, and Region, $F(1,52) = 7.82$, $p = .007$, $\eta_p^2 = .13$, $\theta = 1$. No other main effects or interactions were significant (all $F_s < 2$).

In summary, the statistical analyses performed for the total sample showed grammaticality effects in both the LAN and P600 components, with larger amplitudes in mismatch trials than in match trials, and a facilitatory effect of Emotionality in the N400 component, with reduced amplitudes in the unpleasant condition in comparison with the neutral condition. Critically, the Dominance factor interacted with both Grammaticality and Emotionality, pointing to differences in agreement and affective processing between the two groups. Hence, new cluster-based analyses were carried out separately to explore the specific temporal and spatial distribution of these effects for each dominance group.

### 3.3.2 | Negative dominance group

The cluster-based analysis approach revealed a significant effect of Grammaticality in one cluster (see Figure 3a). Amplitudes were more negative in the mismatch condition than in the match condition between 188 and 898 ms. This effect was widely distributed on the scalp (Fp1, Fp2, F7, F3, Fz, F4, C7A, C3A, CzA, C4A, C8A, T3, C3, Cz, C4, T4, T3L, C3P, PzA, C4P, T4L, T5, P3, Pz, P4, T6, O1, Oz, and O2) and had a left frontal maximum. The *p*-value associated with the cluster, calculated by a randomization procedure, was .0001. As regards Emotionality effects, the cluster permutation test revealed a significant effect in a cluster between 472 and 538 ms in centro-parietal electrodes (Fz, F4, CzA, C4A, C3, Cz, C4, C3P, PzA, C4P, P3, Pz, and P4), with more negative amplitudes in the neutral condition compared to the unpleasant one (see Figure 3a). The *p*-value associated with the cluster, calculated by a randomization procedure, was .038.

The first cluster was widely temporally and spatially distributed and therefore seems to be grouping effects reflected in several different components (see Figure 3a). After the visual inspection of the ERP waveforms, it seems that the earliest segment of this cluster could correspond to a P200 component (e.g., Gootjes et al., 2011; Herbert et al., 2006; Sass et al., 2010). A Grammaticality × Emotionality × Region repeated-measures ANOVA was performed for the regions where the effect was the strongest (LA and CA) for the 180–250 ms time window. This analysis revealed a significant main effect of Grammaticality, $F(1,27) = 9.52$, $p = .005$, $\eta_p^2 = .26$, $\theta = 1$, showing that grammatically incorrect NPs evoked lower amplitudes than grammatically correct ones (0.40 μV vs. 1.20 μV, respectively). No other main effects or interactions were significant (all $F_s < 1.5$). From 300 to 450 ms, a Grammaticality × Emotionality repeated-measures ANOVA was performed for the LA region to explore what appeared to be a LAN component. As expected, a robust main effect of Grammaticality arose for the negative dominance group, $F(1,27) = 110.35$, $p < .001$, $\eta_p^2 = .80$, $\theta = 1$, with ungrammatical NPs evoking larger LAN amplitudes (−4.38 μV) than grammatical ones (−2.01 μV). No other main effects or interactions were significant (all $F_s < 1$). Finally, a Grammaticality × Emotionality repeated-measures ANOVA was performed in the CP region for the 500–900 ms time window to explore whether the last segment of this significant cluster corresponded to a P600 component. However, the negative dominance group did not show any significant main effect or interaction in the CP region in this time window (all $Fs < 1.5$).

As for the emotional cluster, a Grammaticality × Emotionality × Region repeated-measures ANOVA was

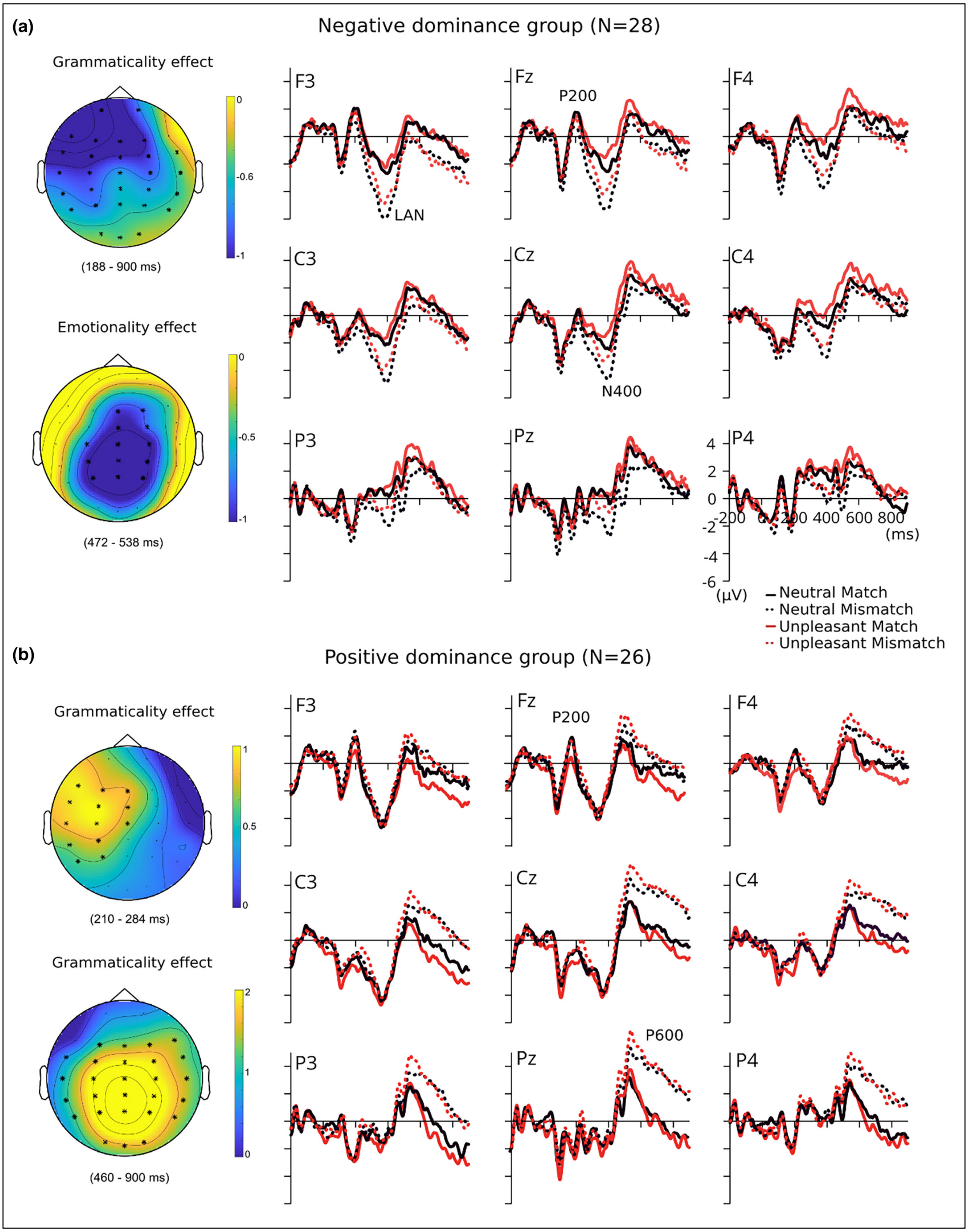


**FIGURE 3** Individual differences: Grammaticality and Emotionality effects. Left: Topography maps of the difference between match and mismatch conditions, as well as between neutral and emotional conditions, averaged across specific time windows where Grammatical and Emotional main effects were significant, for the negative dominance group (a) and the positive dominance group (b). The asterisks in bold represent the significant electrodes that form part of each of the depicted clusters. Right: Grand mean averaged ERPs from nine representative electrodes for match (solid line) and mismatch (dashed line) conditions as a function of neutral (black) and unpleasant (red) conditions for the negative dominance group (a) and the positive dominance group (b).

performed in the central regions (CA and CP) between 450 and 550 ms to explore possible effects in the N400 component (see Figure 3a). This analysis revealed significant main effects of Grammaticality, $F(1,27) = 13.46$, $p < .001$, $\eta_p^2 = .34$, $\theta = 1$, and Emotionality, $F(1,27) = 9.16$, $p = .009$, $\eta_p^2 = .25$, $\theta = 1$. The participants exhibited larger N400 amplitudes in mismatch trials (0.94 μV) than in match trials (2.03 μV). At the same time, reduced N400 amplitudes were registered for unpleasant adjectives (0.94 μV) in comparison with neutral ones (2.07 μV). Additionally, this analysis revealed a statistically significant interaction between Grammaticality, Emotionality, and Region, $F(1,27) = 7.02$, $p = .013$, $\eta_p^2 = .21$, $\theta = 1$, so separate ANOVAs were performed for each Region. Both the main effects of Grammaticality and Emotionality were significant for the CA region, $F(1,27) = 8.55$, $p = .007$, $\eta_p^2 = .24$, $\theta = 1$, $F(1,27) = 8.74$, $p = .006$, $\eta_p^2 = .24$, $\theta = 1$, and the CP region, $F(1,27) = 15.26$, $p < .001$, $\eta_p^2 = .37$, $\theta = 1$, $F(1,27) = 8.45$, $p = .007$, $\eta_p^2 = .24$, $\theta = 1$, respectively, but the Grammaticality × Emotionality interaction did not reach significance in either of the two regions (all $Fs < 1.8$). Thus, the triple interaction seems to have been a consequence of the differential magnitude of the Grammaticality effect in the two regions.

### 3.3.3 | Positive dominance group

The cluster-based analysis approach revealed a significant effect of Grammaticality in two clusters (see Figure 3b). For the first cluster, amplitudes were more positive in the mismatch condition than in the match condition between 210 and 284 ms in fronto-central electrodes (F7, F3, Fz, C7A, C3A, CzA, T3, C3, Cz, T3L, C3P, T5, and P3). The *p*-value associated with the cluster, calculated by a randomization procedure, was .043.

The second significant cluster revealed more positive amplitudes in the mismatch condition compared to the match condition, this time in centro-parietal electrodes (F3, Fz, F4, C7A, C3A, CzA, C4A, C8A, T3, C3, Cz, C4, T4, T3L, C3P, PzA, C4P, T4L, T5, P3, Pz, P4, T6, O1, Oz, and O2) between 460 and 900 ms. The *p*-value associated with the cluster, calculated by a randomization procedure, was .0001.

After the visual inspection of the ERP waveforms, it seems that the first cluster could correspond to a P200 component. A Grammaticality × Emotionality × Region repeated-measures ANOVA was performed for the regions where the effect was the strongest (LA and CA) at the 180–250 ms time window. This analysis revealed a significant main effect of Grammaticality, $F(1,25) = 9.51$, $p = .005$, $\eta_p^2 = .28$, $\theta = 1$. Amplitudes were larger for ungrammatical (0.60 μV) than for grammatical NPs (−0.13 μV). Importantly, the interaction between Grammaticality, Emotionality, and Region reached significance, $F(1,25) = 4.58$, $p = .042$, $\eta_p^2 = .15$, $\theta = .99$. Thus, separate ANOVAs were performed for each Region. In the LA region, only the main effect of Grammaticality was significant, $F(1,25) = 11.01$, $p = .003$, $\eta_p^2 = .31$, $\theta = 1$. In the CA region, both the main effect of Grammaticality, $F(1,25) = 5.50$, $p = .027$, $\eta_p^2 = .18$, $\theta = .99$, and the interaction between Grammaticality and Emotionality were significant, $F(1,25) = 5.48$, $p = .028$, $\eta_p^2 = .18$, $\theta = .99$. Pair-wise comparisons revealed that these participants showed the Grammaticality effect (larger amplitudes for ungrammatical than for grammatical phrases) in NPs that contained an unpleasant adjective, but not in those containing a neutral one ($p = .01$ and $p > .05$, respectively; see Figure 4).

A Grammaticality × Emotionality repeated-measures ANOVA was performed in the CP region for the 500–900 time window to explore whether the second cluster corresponded to a P600 component (see Figure 3b). These

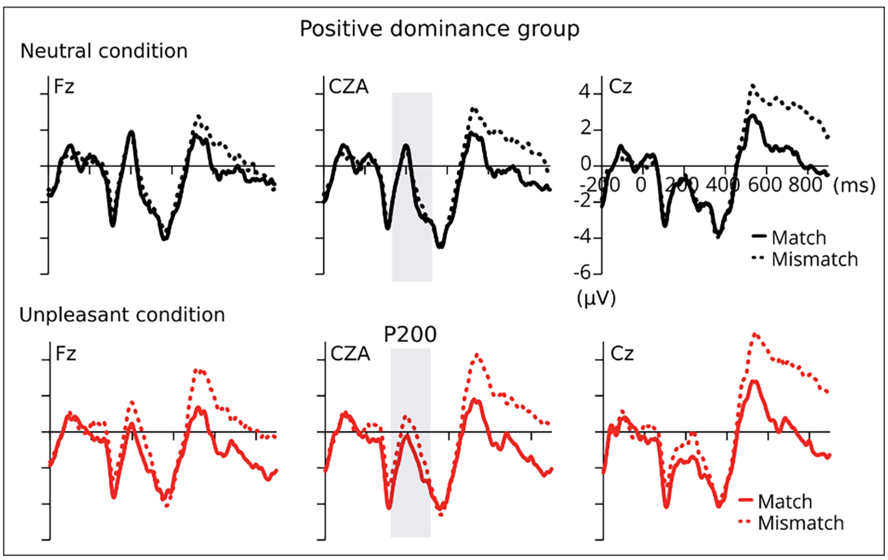


**FIGURE 4** Grammaticality × Emotionality interaction in P200. Grand mean averaged ERPs for match (solid line) and mismatch (dashed line) conditions as a function of neutral (up) and unpleasant (down) conditions in the specific electrodes for CA region for the positive dominance group.

analyses showed a robust main effect of Grammaticality, $F(1,25) = 76.15$, $p < .001$, $\eta_p^2 = .75$, $\theta = 1$ in the expected direction, with larger P600 amplitudes in mismatch trials (3.77 μV) relative to match trials (0.50 μV). No other main effects or interactions were significant in this time window (all $F_s < 1.5$).

## 4 | DISCUSSION

The main aim of the present study was to investigate whether an interaction between grammatical and emotional processing can be found in the LAN component for high arousal unpleasant words, as suggested by prior studies (Hinojosa et al., 2014; for other interactive effects in LAN, see also Jiménez-Ortega et al., 2017; Jiménez-Ortega et al., 2021; Martín-Loeches et al., 2012; Poch et al., 2022) and to confirm whether this interaction is limited to individuals with a positive dominance profile. Additionally, we wanted to explore the time course of grammatical and emotional processing beyond the two ERP components classically associated with morphosyntactic processing (LAN and P600), following prior data revealing neural differences between the two dominance profiles as soon as 100 ms after stimulus onset (Fraga et al., 2021; Padrón et al., 2023). In a nutshell, we found no evidence for an interaction between grammaticality and emotionality in the LAN component (for similar null results, see Díaz-Lago et al., 2015; Fraga et al., 2017; Padrón et al., 2020). Nonetheless, our findings confirm that participants do present different neural profiles when processing the grammaticality of a phrase and that there are differences in how they process emotionality as well. These results will be discussed in detail below.

In this study, when data from all participants were analyzed as a whole, the classical grammaticality effect (larger amplitudes for ungrammatical than for grammatical items) was obtained in the time windows and areas typically associated with the LAN and P600 components. Additionally, an emotionality effect was found, as N400 amplitudes were reduced for unpleasant words in comparison with neutral ones. On their own, these results seem to agree with prior literature, showing the classical biphasic pattern of grammatical processing (e.g., Molinaro et al., 2011) and a facilitatory effect of word emotionality (Kutas & Federmeier, 2011; Trauer et al., 2015). Nonetheless, these studies did not take into consideration the possible role of individual differences in grammatical processing. After calculating the RDI (see Fraga et al., 2021; Tanner, 2019; Tanner & Van Hell, 2014), we confirmed that the effects of grammaticality were dependent on participants' dominance profile. That is, instead of a generalized biphasic pattern, individuals showed the grammaticality effect either in the LAN component (negative dominance profile) or in the P600 component (positive dominance profile), confirming prior evidence on neural differences in number (see Tanner, 2019; Tanner & Van Hell, 2014) and gender agreement processing (Fraga et al., 2021; Padrón et al., 2023). Critically, the emotional effect obtained in N400 was modulated by the dominance pattern of the participants as well, thus pointing to differences in emotional processing across the two groups.

When analyzing participants with negative and positive dominance profiles separately, the two groups showed differences in both grammatical and emotional processing along different points of the time course. Participants with a negative dominance profile showed a strong left anterior grammaticality effect that emerged around 200 ms and lasted until around 900 ms. The visual inspection and the analyses carried out suggest that these participants processed grammaticality in P200, a component usually related to attentional processing. Following the typical functional interpretation of P200 effects, participants with a negative dominance profile seem to have devoted more attentional resources to grammatically correct items, in comparison with grammatically incorrect ones. Immediately after, these individuals showed the typical LAN grammaticality effect (i.e., larger amplitudes for grammatically incorrect items than for grammatically correct items). Thus, our results could indicate that participants with this dominance profile allocate their attention preferentially to grammatically correct items, subsequently leading to a costlier morphosyntactic processing of grammatically incorrect items (as reflected in LAN). Interestingly, while this effect had a left frontal maximum, it was registered in almost all the electrodes, and the difference in amplitudes remained until 900 ms after stimulus onset, although no grammaticality effects were found in the topographical area and time window commonly reported for P600. Nonetheless, the grammaticality effect was also registered in central electrodes around 400 ms after stimulus onset, evidencing that agreement processing costs may also be observed in the N400 component (Barber & Carreiras, 2005). Furthermore, high arousal unpleasant adjectives elicited reduced N400 amplitudes in comparison with neutral ones, that is, a facilitatory effect of emotionality (Kutas & Federmeier, 2011; Padrón et al., 2023; Trauer et al., 2015). Critically, these two effects did not interact, revealing a simultaneous yet autonomous processing of grammatical and emotional features in this group. These results suggest an encapsulated processing of grammar and emotion, in line with modular views of linguistic processing (e.g., Frazier & Clifton, 1996).

By contrast, the grammatical processing of participants with a positive dominance profile seems to have been adversely affected by emotionality, with this interactive effect arising earlier than expected (P200). These participants showed a grammaticality effect at around 200 ms in fronto-central electrodes, in that larger amplitudes were observed for the mismatch condition in comparison with the match condition. However, this effect only arose in NPs containing an unpleasant adjective and not in those containing a neutral one. These results suggest that unpleasant ungrammatical stimuli preferentially captured these participants' attention, showing that this early attentional effect of grammaticality can be modulated by emotionality. While evidence on the interactive effects of grammaticality and emotionality was circumscribed to the LAN component (around 300–450 ms) in prior literature (see Fraga et al., 2021; Hinojosa et al., 2014), in the present study this interaction arose in P200, around 100 ms earlier. In Hinojosa et al.'s (2014) study, the cost of processing the agreement error found for neutral NPs vanished when the adjectives were unpleasant (and high in arousal). The authors interpreted the absence of the grammaticality effect in the LAN component as evidence for a facilitated processing of the gender agreement mismatches in unpleasant adjectives. However, this interpretation could be reversed in that grammaticality may have been overlooked in NPs that contained unpleasant adjectives instead[5]. This interpretation would go in line with our findings, evidencing that the presence of unpleasant words can interfere with the detection of morphosyntactic errors, yet only in some individuals (see Fraga et al., 2021). All in all, such effects would favor an interactive view of linguistic processing (e.g., Marslen-Wilson & Tyler, 1980). Additionally, the positive dominance group showed a grammaticality effect in P600, grammatically incorrect stimuli eliciting larger amplitudes than grammatically correct ones. Interestingly, this effect arose earlier than expected, around 450 ms after the stimulus was presented, in line with prior findings on individual differences (see Tanner, 2019).

The analysis of the subjective evaluations showed that, irrespective of their dominance profile, all participants rated the adjectives in a similar manner. This happened for behavioral measures as well, as all participants responded faster when the adjectives were unpleasant than when they were neutral. Similar effects of emotion have been found in previous research, commonly explained by the natural relevance of highly arousing unpleasant stimuli for survival (Pratto & John, 1991; Vogt et al., 2008). Note that, similarly to past studies using the same task, the grammaticality of the NPs did not affect either RTs or accuracy (e.g., Martín-Loeches et al., 2012). Nevertheless, these results should be taken with caution, since participants were asked to wait until a cue was presented to them to give their response, something which could have affected the presence and even the direction of the behavioral effects (see Vieitez et al., 2024).

All in all, this study shows that both groups of participants processed the grammaticality of the NPs and the emotional features of words, albeit in a different manner, ultimately leading to distinct ERP effects. Participants with a negative dominance profile processed grammaticality as early as 200 ms after the stimulus onset and showed a parallel and autonomous processing of grammaticality and emotionality at the LAN/N400 time window. For participants with a positive dominance profile, an interaction between grammaticality and emotionality arose at around 200 ms—in that the grammaticality effect emerged only for unpleasant words—and no further grammaticality effects were found until the P600 component. Interestingly, both groups showed early and opposite effects of grammaticality in P200, an ERP component commonly associated with attention allocation, followed by grammaticality effects in LAN or P600, respectively. These results would support an early access to lexical and semantic word features along with semantic and syntactic context integration and parsing and point to later components like LAN, N400, and P600 as indexes of a second step in lexical, semantic, and syntactic information processing (Pulvermüller et al., 2009). Thus, our results suggest the existence of different attentional strategies that could be linked to the neural dominance pattern of the individuals, further extending our knowledge about the mechanisms underlying the neural differences in morphosyntactic processing. While the relation between these individual differences and variables such as working memory capacity and proficiency have led to inconsistent results (see Tanner, 2019), the literature on the variables that may predict individual variability is expanding constantly. For example, Verhees et al. (2015) found the amplitude of early components and P600 to be modulated by both mood state and attention during agreement processing. A recent study exploring the effects of personality traits on the ERP markers of syntactic processing observed that participants with higher levels of Conscientiousness (those with a propensity to self-control, responsible toward others, and rule-abiding, among other characteristics) tend to show

[5]As the authors state in their paper, "enhanced LAN amplitudes could be interpreted as a reflection of the processing costs associated with the correct (or as we would say, successful) detection of inappropriate gender agreement relations" (Hinojosa et al., 2014; p. 1293). That is, the successful detection of the ungrammaticality of a construction would involve a processing cost that should be reflected in some way in the ERP amplitudes. The absence of these effects could be interpreted as an indicator of a detrimental processing of incorrect agreement relations.

stronger LAN effects and weaker P600 effects than participants with lower levels of Conscientiousness (Jiménez-Ortega et al., 2022). These authors argue that higher levels of Conscientiousness promote the use of rule-based strategies instead of heuristics, what could result in a more efficient processing of syntactic information (as shown by stronger LAN effects). Interestingly, in our study those participants with a negative dominance pattern were the ones that were able to process the emotionality of the NPs without it interfering with grammatical processing. As for N400, the amplitude of the emotional effect in this component has been found to be influenced by Extraversion and Neuroticism personality traits in word recognition tasks (Ku et al., 2020), so the interaction between grammar and emotion may be more intertwined with personality than expected. We consider that future studies should explore the influence that these variables may have on the negative and positive dominance patterns, opening new lines of research that may better explain the differences in morphosyntactic and emotional processing found in the present study. This is relevant since we did not collect measures for either personality traits or working memory capacity, mainly because exploring these variables was beyond the scope of our study. Additionally, it is important to consider that making direct comparisons between our results and those from past studies on the interplay between grammar and emotion is delicate, as grammaticality effects with an earlier onset than the LAN component have not been always explored. Neither Hinojosa et al. (2014) nor Fraga et al. (2021) analyzed the effect of grammaticality in the P200 time window. Furthermore, Hinojosa et al. (2014) did not include individual differences in their analysis. Therefore, the functional interpretation of the early effects registered in this study should be further explored in future research. Finally, all the participants of the present study were women. While most previous studies on this topic also have a sample where the percentage of male participants is very low, it cannot be fully disregarded that this may have contributed to the contrasting results concerning emotionality (for evidence on gender differences in emotional evaluation and processing, see Pinheiro et al., 2017; also, Maquate et al., 2022).

To summarize, while the interpretation of the interactive effects of grammatical and emotional processing is still up for discussion, evidence from past studies and the present one reinforces the idea that for grammaticality and emotionality to interact, unpleasant words are needed (but see Poch et al., 2022 for similar effects in pleasant words). Moreover, our results indicate that such interactive effects only arise in participants with a positive dominance profile (in line with Fraga et al., 2021). For these participants, the presence of unpleasant words seems to have had a detrimental effect on how the other NPs were processed (i.e., those containing neutral adjectives). Interestingly, this happened in an earlier stage of language processing than in prior literature (P200 vs. LAN, respectively). In contrast, participants with a negative dominance profile seem to have processed the grammaticality of the NPs and the emotionality of the adjectives in a parallel and autonomous way, showing not only the typical LAN grammaticality effect but also independent effects of grammar and emotion in N400 amplitudes. Altogether, our results point toward the existence of different processing strategies linked to the neural dominance pattern of the individuals: some being able to successfully process both features independently (negative dominance profile); others being more prone to intertangle grammatical and emotional processing (positive dominance profile).

Although further research is needed to prove the replicability of our results, they raise serious concerns about the universality of a strictly modular syntactic processor, since we have demonstrated that individual differences modulate agreement computations and can be determinant for the interplay between morphosyntactic and affective processing. In light of these findings, perhaps we should assume that autonomous models and interactive models have to coexist in order to reach a comprehensive characterization of linguistic processing in different languages and individuals.

## AUTHOR CONTRIBUTIONS

**Lucia Vieitez:** Formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Isabel Padrón:** Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing – original draft; writing – review and editing. **Marcos Díaz-Lago:** Data curation; formal analysis; writing – review and editing. **Iria de Dios-Flores:** Formal analysis; investigation; writing – review and editing. **Isabel Fraga:** Conceptualization; funding acquisition; methodology; project administration; supervision; writing – review and editing.

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## CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the "OSF data repository" at http://doi.org/10.17605/OSF.IO/EVYXG.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**Data S1.**

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