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Research report

Effects of reader's facial expression on syntactic processing: A brain potential study

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HIGHLIGHTS

- The aim was to investigate the effects of reader's facial expression (control, frown, smile and non-smile) on morphosyntactic processing.
- All conditions triggered an N400 component instead of LAN component, probably as a result of a different processing style.
- Frown condition triggered a larger N400 component. Unconscious emotional induction may be in the base of these effects.
- However, it is not utterly guaranteed that the facial expressions conditions actually induced emotions.
- Effects might also appear as a result of muscular contraction and effort produced by the facial expressions.

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ABSTRACT

Embodied views of language support that facial sensorimotor information can modulate language comprehension. The aim of this study is to test whether the syntactic processing of simple sentences, as measured with event-related brain potentials (ERP), could be affected by reader's facial expressions. Participants performed a correctness decision task using sentences that could be either correct (50%) or contain a morphosyntactic disagreement (either in gender or number), while making one of four facial expressions: participants either (a) posed no facial expression ("control" condition) (b) brought their eyebrows together, making the ends of two golf tees touch ("frown" condition), (c) held a pencil with their teeth ("smile" condition), or (d) held the pencil using their lips ("non-smile" condition). In all conditions the customary left anterior negativities did not appear. In contrast, an N400-like component emerged, which was larger for the "frown" condition and reduced in the "smile" and "non-smile" conditions. These results can be interpreted as the consequence of either an unconscious emotion induction or an interplay between the motor and the language systems subsequent to the effort needed to hold the facial expression.

1. Introduction

There is substantial evidence that emotions interact with cognitive processing (e.g.Ashby et al., 1999; Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012; Mitchell and Phillips, 2007; Pessoa, 2008; Vissers et al., 2010). Recent studies have demonstrated that emotional material may impact syntactic processing, (Hinojosa et al., 2014; Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012; Verhees et al., 2015; Vissers et al., 2010) even when unconsciously perceived (Jiménez-Ortega et al., 2017).

Recent theories of embodied emotions suggest that feedback from both facial expressions and body posture may elicit emotional experiences. According to the *facial feedback hypothesis*, the facial expression of an emotion feeds back to activate and/or regulates the emotional experience (for a review of this ground-breaking work see (Adelmann and Zajonc, 1989). Imitation of facial expressions is associated with

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both physiological and neural activation of the amygdala and other limbic areas (Carr et al., 2003; Hennenlotter et al., 2009; Lee et al., 2013). Remarkably, these effects are observed even when participants are unaware of the emotional meaning of their own facial expression (Arminjon et al., 2015; Soussignan, 2002; Wiswede et al., 2009). In a pioneering study, Strack et al. (1988) asked participants to hold a pen either between their teeth, to facilitate smiling, or their lips, to inhibit smiling. Participants rated cartoons more positively in the facilitation condition. This finding has been strongly questioned, as recent replication attempts failed to find any support for the effect (Acosta et al., 2016). However, unlike the original study, in the replication study participants were video recorded. A more recent work, which conducted the study with and without recording the participants, concluded that "feeling observed" may eliminate the facial-feedback effect (Noah et al., 2018). Furthermore, by using event related potentials (ERP), Wiswede et al. (2009) observed that inducing a smiling facial expression (holding a chop-stick parallel to the teeth instead of perpendicular to the teeth) increased well-being and reduced error-related negativity (ERN) and error detection. Another suitable way to manipulate facial expressions without awareness is by instructing participants to bring together the ends of two golf tees attached to the inner part of their eyebrows, thus producing the facial expression of a frown (congruent with the feeling of a negative emotion) and increasing feeling of sadness or anger while contracting the corrugator (Larsen et al., 1992). Altogether, there is evidence supporting that facial expressions can indeed trigger unconscious emotions, although it is currently a matter of debate (Acosta et al., 2016; Noah et al., 2018).

Interestingly, language processing is also affected by facial feedback. Congruence between language and bodily expressions of emotions facilitates comprehension processing, while incongruence worsens comprehension (Niedenthal, 2007). Moreover, Havas et al. (2007) demonstrated that by holding a pen in the mouth to produce either a smile (holding the pen using one's teeth) or a pout/inhibiting smile (holding the pen using one's lips), language comprehension was facilitated when the induced emotion by the facial expression and the content of the sentence were congruent. In addition, reading speed of emotional content was reduced in participants injected with botulin toxin in the muscles used to frown, which impaired facial expression (Havas et al., 2010). Recently, it was demonstrated that both early and late ERP syntactic components were affected by motor sequences, which probably share common resources in the human brain (Casado et al., 2018). These findings demonstrate that peripheral feedback and actions play a role in language processing, supporting the embodied views of cognition and language that claim that the motor system and the linguistic processor share neural resources (Fisher and Zwaan, 2008; Glenberg et al., 2005; Glenberg, 2015; Willems and Hagoort, 2007). In this line, facial expression might impact language processing even in the absence of emotional induction.

The objective of the present study is to explore the impact of facial expression on syntax processing. A useful approach to this endeavor is the use of syntactic-related ERP components, i.e. anterior negativities (ANs) and P600 (or late positive component). ANs appear between 300 and 500 ms after the stimulus onset and are usually triggered by grammatical anomalies, such as morphosyntactic violations (Bocker et al., 1999; Magne et al., 2016). They reflect automatic first-parsing processes, morphosyntactic mismatches detection, the processing of unusual grammatical structures, the inability to assign the incoming word to the current phrase structure, and/or some aspects of working memory operations (King and Kutas, 1995; Makuuchi et al., 2009; Martin-Loeches et al., 2005; Molinaro et al., 2015; Weckerly and Kutas, 1999). They are often called LAN (left anterior negativity) because of their customary left side distribution, though fronto-central distributions are not rare (e.g. Barber and Carreiras, 2003; Jiménez-Ortega et al., 2017; Mancini et al., 2011; Molinaro et al., 2008; Wicha et al., 2004).

The P600 component to syntactic anomalies, in contrast, appears between 600 and 900 ms after the onset of the anomaly over central-parietal electrodes (Friederici et al., 2004). This may reflect the costs of repair and revision of structural mismatches and meaning integration.

Evidence reveals that both AN and P600 components are affected by emotional information (words, paragraphs and film clips) (Espuny et al., 2018b; Fraga et al., 2017; Hinojosa et al., 2014; Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012; Vissers et al., 2007). Overall, the directions of the effects are nevertheless not straightforward: the amplitude of these components can increase or decrease occasionally –but not always- as a function of several factors, such as emotional valence or the position of the emotional information relative to the target sentence or word (preceding or during its occurrence). Interestingly, in relation to the aims of the present article, unconscious emotional words embedded in a sentence also modulate syntactic processing, both at early and late stages (Jiménez-Ortega et al., 2017).

Altogether, emotional information seems to impact language comprehension, including syntax, while the facial expression of emotions seems to feed back to activate emotional experiences. To test whether the reader's facial expressions affected language comprehension, a group of participants were instructed to judge sentences' correctness, where the sentence could be either correct (50%) or contain morphosyntactic disagreements (in gender or number), while posing four different facial expressions that, according to previous literature, are able to activate an unconscious emotional experience: control (no facial expression), frown (bringing together the ends of two golf tees attached to their eyebrows), smile (holding the pen using their teeth), non-smile (holding the pen using their lips). Specifically, we explored the possibility that facial expressions can affect syntactic processing, as measured by ANs and P600 components of the ERP.

In sum, ERP modulations by facial expression can be expected in syntactic components to morphosyntactic anomalies. This could be the case even in absence of emotional induction, circumstance in which the direction of the results cannot be predicted due to the fact that previously reported effects of motor actions on syntactic processing are relate to motor sequences, largely differing from posing a facial expression. On the other hand, emotions induced by face expression might instead be in place. In this case, specific predictions are again challenging, as reviewed above. Overall, if both frown and smile conditions are able to generate unconscious emotional experiences, syntactic components modulations are expected in these situations relative to control and non-smile conditions.

2. Results

2.1. Behavioural data

The total error rate for the sentence correctness decision task was 9.4%. The behavioural ANOVA analyses (including Correctness and Facial Expression factors) revealed a significant effect of Correctness ($F(1,23) = 5.66$, $p < .05$, $\eta^2p = .19$, $\pi = 0.62$)). The error rate for incorrect sentences ($Ms = 13.9$, $Sd = 6$) was larger than for correct sentences ($Ms = 3.8$, $Sd = 3.2$). However, neither the Facial Expression factor nor the Facial Expression by Correctness interaction yielded significant effects ($F(3,69) = 0.67$, $p > .1$, $\eta^2p = .03$, $\pi = 0.12$; $F(3,69) = 0.98$, $p > .1$, $\eta^2p = .04$, $\pi = 0.26$, respectively)

Reaction times did not show significant difference for Correctness ($F(1,23) = 2.65$, $p > .1$), Facial expression or Facial expression by Correctness interactions yielded significant effects (All $Fs < 2.65$, $ps > 0.1$).

2.2. ERP data

2.2.1. Cluster analyses

During the early time segment (0–500 ms), the cluster-based permutation analysis revealed a significant centro-posterior cluster for Facial expression by Correctness interaction between 392 and 500 ms involving up to 20 electrodes, with larger F values at CP6 and P6 at around 470 ms. This effect exhibits the timing and topography typical of an N400-like component to syntactic anomalies, as later confirmed by time windows analyses. A cluster analyses comparing Correctness within each facial expression revealed a similar pattern of significances for the frown condition at central-posterior electrodes and only at CP3 and CP1 for the neutral. A weaker significant fronto-central cluster was also observed for the main effect of Correctness between 200 and 400 ms, while non-significant effects were observed for *Facial* expression *alone* at this time window.

During the late segment (500–900 ms), the cluster-based permutation analysis did not reveal any significant effect either for Facial expression or for the interaction *F*ace expression by Correctness. A main effect of Correctness appeared between 600 and 900 ms, maximal between 600 and 700 ms. It showed a spread topography involving up to 40 electrodes at early phases from frontal to parietal electrodes consistent with an early P600, and a lesser spread topography at around 800 ms. Therefore, both distribution and timing resembled a P600 component.

2.2.2. Time-window analyses

Overall, taking into account both cluster analyses and visual inspection of the ERP (Fig. 1), the data revealed a mainly central-posterior negativity between 400 and 500 ms for grammatical violations in all Facial Expression conditions resembling an N400 component, larger in the frown condition, hardly visible in the smile and non-smile conditions, while of intermediate amplitude in the neutral condition. In turn, a P600 component was detected between 600 and 800 ms, which was apparently similar across conditions.

The visually observed central-posterior negativity around 400–500 ms was statistically supported by the main ANOVA for that time window, which revealed a significant Correctness effect ($F(1,23) = 9.01, p < .01, \eta^2p = .28, \pi = 0.96$). A Correctness by Facial Expression interaction ($F(3,69) = 2.89, p < .05, \eta^2p = .11, \pi = 0.64$) supported the differences in amplitude between conditions suggested by visual inspection. Subsequent comparisons of the component amplitude (Incorrect minus Correct conditions) between facial expressions showed significant differences between frown and non-smile, and between frown and smile conditions ($F(1,23) = 8.92, p < .05, \eta^2p = .28, \pi = 0.82$; $F(1,23) = 8.6, p < .05, \eta^2p = .27, \pi = 0.8$, respectively). All other post hoc analyses were not significant (all $Fs < 2.6; ps > 0.1$). In line with visual inspection, statistics seems therefore to support an intermediate position of the control condition. In the 600–800 time window, significant differences were observed for Correctness ($F(1,23) = 4.06, p < .05, \eta^2p = .15, \pi = .49$), whereas Correctness did not significantly interact with the other factors (all $Fs < 3.2; ps > 0.1$), supporting that facial expressions did not differentially affect this component.

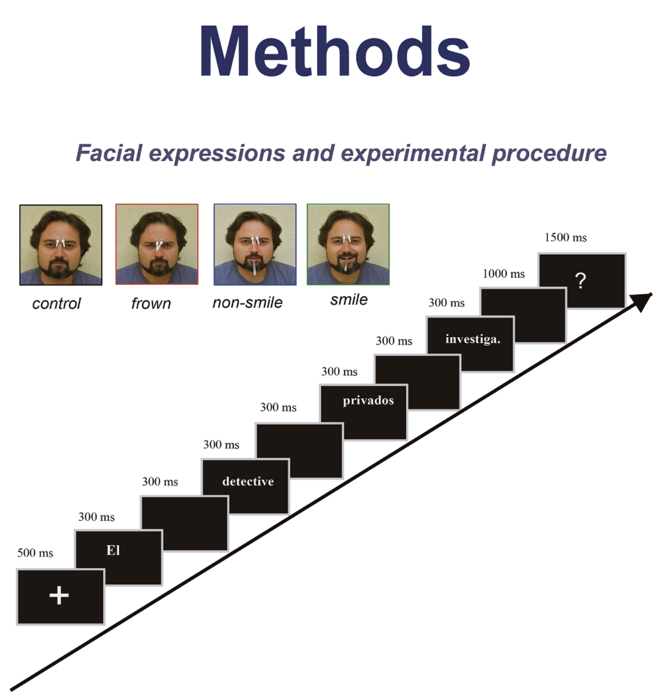

Fig. 1. Schematic representation of the stimulation procedure. To induce facial expressions, participants either (a) posed no facial expression ("control" condition), (b) brought the ends of the golf tees together ("frown" condition), (c) held a pencil with their teeth ("smile" condition), or (d) held the pencil using their lips ("non-smile" condition).

3. Discussion

The main goal of this study was to explore whether syntax processing can be affected by the participant's facial expression. To this aim, the participants' task was to judge the correctness of sentences based on morphosyntactic cues, while making four types of facial expressions.

Regarding behavioural results, error rates revealed that it was more difficult to identify incorrect sentences compared to correct ones. This is in contradiction with previous studies using similar sentences (Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012), but is in line with others (Jiménez-Ortega et al., 2017). In the latter study, participants were also unaware of the possible emotional induction. That is, in both studies unconscious emotional information was present. Our result suggests that facial expressions, regardless of the induced emotion, might increase error detection difficulty. To test this hypothesis, error rates were compared between Espuny et al. (2018a) study and the present one, since both of then used almost the same sentences, while in the former the participants did not pose facial expressions. The Correctness (2) by Study (2) mixed ANOVA revealed a significant interaction ($F(1,45) = 11.42, p < .01, \eta^2p = .21, \pi = 0.91$). That is, even though sentences were the same, error detection was significantly harder in this study probably as a result of facial expression pose. This result is in line with studies claiming that mimicry seems to play an important role in language comprehension (Chwilla et al., 2007; Davis et al., 2015; Davis et al., 2017; Havas et al., 2007). In particular, it has been observed that facial muscle blocking impairs language comprehension (Davis et al., 2017), and that facial motor resonance and skin conductance are smaller when understanding one's second language compared to one's native language (Baumeister et al., 2017). Reaction times (RT), however, did not yield significant differences. RT differences are found when comparing congruent emotional content versus incongruent emotional one (Havas et al., 2010). Given the neutral valence of our sentences, incongruences between face expressions and sentences might not exist, which could explain the lack of significances. It is also possible that the long lag between the critical words and response time, customary of many EEG studies to avoid artifacts, was long enough as to reduce any difference in this regard.

Regarding the electrophysiological results, both cluster and time window analyses revealed that the main effects of facial expressions on morphosyntactic processing seemed to be limited to earlier fluctuations, around 400 to 500 ms after the onset of the critical word. All conditions triggered a central negativity that could be interpreted as an N400, normally considered as an index of semantic processing (Kutas and Federmeier, 2011). Of interest, most of the sentences used in this study were previously used (Espuny et al., 2018a; Jiménez-Ortega et al., 2014; Jiménez-Ortega et al., 2017), and triggered a standard LAN component, at least for the control condition. An N400 component to syntactic violations, however, is not an uncommon finding (e.g. Barber & Carreiras, 2003; Jiménez-Ortega et al., 2017; Mancini et al., 2011; Molinaro et al., 2008; Wicha et al., 2004). The emergence of an N400 to morphosyntactic violations is probably reflecting the use of alternative strategies to solve these anomalies (Bornkessel-Schlesewsky et al., 2011). According to Molinaro et al (2011, 2015) the N400 component was therefore more likely to appear to morphosyntactic information the more often strategies based on lexico-semantic information processing were tapped. The larger the lexico-semantic requirements for the syntactic agreement processing, the more N400-like the distribution of the negativity (Molinaro et al., 2015, Molinaro et al., 2011; Bornkessel-Schlesewsky et al., 2011). In the same line, an N400 component instead of an AN has been also reported for positive unconscious adjectives embedded in a sentence containing a syntactic anomaly (Jiménez-Ortega et al., 2017). Unconscious emotions induced by facial expression might engage areas involved in semantics due to its meaningful nature, thus resulting in a N400 instead of an AN. In the present experiment three quarters of the sentences were presented while making a facial expression, which seems to have induced an overall solving strategy that engages the semantic networks that ultimately trigger an N400-like component. It should be noticed, nonetheless, that the N400 component to morphosyntactic anomalies is more sensitive to different linguistic properties than the semantic N400 (Molinaro et al., 2011). Therefore, the functional interpretation of the N400 to morphosyntactic anomalies might be similar to the LAN component in some respects. Accordingly, the change in the processing strategy triggered by the facial expressions could be the result of a more heuristic-like or associative processing style, proper of lexico-semantic operations, instead of the pure algorithmic and rule-based strategy, typically expected for morphosyntactic violations (Martin-Loeches et al., 2009). The recruitment of additional non-syntactic information -facial expressions in the present case- indicates that rule-based computations of agreement dependencies are not blind to non-syntactic information, as mirrored by the N400-like component distribution to syntactic anomalies.

Interestingly, the frown condition triggered a larger N400 in comparison to the smile and non-smile conditions. No significant differences were observed either between the frown and control conditions, or when comparing the control with the smile and non-smile conditions. Therefore, the data seem to point out that the neutral condition is in between frown and both smile and non-smile conditions, which behave similarly.

The observed facial expression effect on syntax can be discussed in light of two alternative and/or complementary hypotheses: emotional facial feedback hypothesis and embodiment theories proposing relationships between motor and syntax systems.

3.1. *Emotional facial feedback hypothesis*

Although this possibility should be considered with caution, unconscious frowning mainly increases feelings of anger (Marzoli et al., 2013). In this line, an N400 increase has been observed for negative mood in response to incongruent words (Pinheiro et al, 2013), which has been related to differences in cognitive flexibility between affective states. Furthermore, N400 modulations have been also observed in anger prosody and anger styles (Chronaki et al., 2012; Stewart et al., 2010). Our results therefore seem to follow those in which fluctuations to morphosyntactic anomalies are boosted for negative language compared to a neutral one during sentence comprehension, either before the target sentence or within it (Espuny et al., 2018a; Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012).

Even though smile and non-smile facial expressions are often interpreted, respectively, as positive and negative emotional generators, or as positive and control (Davis et al., 2015; Havas et al., 2007), both triggered a reduced early syntactic component compared to the frown and control conditions, while we did not find significant differences between them. The fact that the N400 was reduced in these conditions would indicate that holding a pen either between one's lips (non-smile condition) or with one's teeth (smile condition) seems to be alike, equally affecting language comprehension. However, an unconscious emotional induction cannot be entirely discarded. Similar early syntactic modulations have been reported for negative and positive emotions when arousal levels are equated for positive and negative linguistic information preceding sentences containing morphosyntactic anomalies (Espuny et al., 2018a; Jiménez-Ortega et al., 2012). Therefore, according to these data and assuming unconscious emotional inductions were produced by facial expressions with different valences (positive vs negative) but comparable arousal levels (as could be the case for smile and non-smile conditions), similar modulations could be expected.

3.2. *Embodiment hypothesis on motor and syntax overlap*

An alternative or complementary explanation might be that frowning might rather impair facial mimicry instead of producing an emotion resulting in the N400-like syntactic component, in line with recent results questioning the emotional facial feedback effect (Acosta et al., 2016). Skilled readers may present more successful subvocalization of language (Buchweitz et al., 2009), while it has been reported that motor areas involved in speech production are activated during language comprehension (Pulvermuller et al., 2006; Wilson et al., 2004). In a recent study in line with our results, an N400 instead of a LAN component was observed to syntactic anomalies when a previous motor sequence structure matched with the subsequent sentence structure which contained an agreement anomaly (Casado et al., 2020). The frown condition, which was maintained during the whole presentation block, was probably more effortful and demanding than other facial expressions (as stated by some participants at the end of the experiment), thus largely affecting facial muscles and probably impairing facial subvocalization. In turn, this might result in a larger N400-like component as a consequence of increased difficulties to detect the morphosyntactic anomalies.

The fact that the N400 was reduced for both smile and non-smile facial expressions might be also explained by a muscular stimulation rather than by an unconscious emotional induction, in line with embodied theories posing an overlap between language and motor systems (Casado et al., 2018, 2020; Glenberg et al., 2005; Niedenthal, 2007; Willems and Hagoort, 2007). It might also happen for both conditions that the motor areas involved in language comprehension are pre-activated (Pulvermuller et al., 2006; Wilson et al., 2004), resulting in a facilitation as mirrored by the N400 reduction. In contrast, as discussed above, the larger effort and demands of the frown condition might result in an impairment. In any event, given that facial expressions seem to affect early syntactic processing regardless of whether this can be attributed to effective unconscious emotional induction, our findings add to growing evidence in which syntactic computations appear affected by extra-linguistic factors, such as emotions or actions (e.g. Casado et al., 2018; Espuny et al., 2018b; Fraga et al., 2017; Hinojosa et al., 2014; Jiménez-Ortega et al., 2012; Jiménez-Ortega et al., 2017; Martin-Loeches et al., 2012; Vissers et al., 2007), thus conflicting with classical syntactic models (Fodor, 1983; Friederici, 2002; Hauser et al., 2002; Ullman, 2001).

Facial expressions did not seem to modulate the P600 component, which was similar for all conditions. Modulations for both the LAN and P600 components to syntactic anomalies have been observed for emotions and actions (e.g. Casado et al., 2018; Casado et al., 2020; Jiménez-Ortega et al., 2017; Verhees et al., 2015; Vissers et al., 2010). However, the result is not unexpected since other studies have observed LAN modulations but not P600 modulations by extralinguistic information (Hinojosa et al., 2014; Martin-Loeches et al., 2012; Verhees et al., 2015).

In conclusion, facial expression seems to impact language processing. Unconscious emotional induction may be in the base of these effects. However, it is not utterly guaranteed that the facial expressions posed during the experimental conditions actually induced emotions. The observed effects might alternatively appear as a result of muscular contraction and effort produced by the facial expressions thus supporting an interplay between the motor systems and syntactic comprehension. To disentangle which of both explanations (emotional induction or muscular contraction and effort) could hold, further research is needed in which both factors can be isolated and manipulated independently. For instance, one in which the facial expression of the participant and the possible emotional induction by that expression (as triggered by -e.g.- the picture of that expression in another person while the participant poses no facial expression) were directly compared in a within-subject design. Another valuable research would take into account that the main result is observed for the frown condition and thus conducting a study in people who have the corrugator paralyzed due to botulinum toxin while they observe pictures of angry people or just frowning (e.g., erasing the golf tees using software) might also contribute to clarify the present finding.

4. Methods

4.1. Participants

Twenty-four native Spanish speakers (8 males, 16 females), whose ages ranged from 19 to 34 (mean = 26.5, SD = 8.4), participated in the experiment. They all gave their informed consent and were reimbursed afterwards. The study was performed according to the Declaration of Helsinki and approved by the ethics committee of the Hospital Clínico Universitario, UCM, Madrid. All participants had normal or corrected-to-normal vision, with no previous history of language difficulties or neural or psychiatric disorders. They were right-handed (mean = 70.5, ranging from 40 to 100), according to the Edinburgh Handedness Inventory.

4.2. Materials

We constructed 360 syntactically-correct sentences in Spanish. The structure of the sentences (i.e. [determiner]-[noun]-[adjective]-[verb]) has been used in previous experiments (Jiménez-Ortega et al., 2012; Martin-Loeches et al., 2012; Jiménez-Ortega et al., 2014) and the whole set of sentences has been used in Espuny et al. (2018a). Each noun, adjective and verb was used only once in the whole set. The adjectives (our critical words, CWs) differed in number and gender and were selected from the Spanish adaptation of the ANEW (Redondo et al., 2007). Adjective valence mean was 5.1 (*SD* = 0.73) and arousal mean was 4.7 (*SD* = 0.8) in 1–9 scales. For each correct sentence an additional version was generated, containing either a gender or a number disagreement between noun and adjective. Altogether, we had 360 correct sentences and their incorrect versions: 180 sentences with a gender disagreement and other 180 sentences with a number disagreement in the adjective (see Table 1 for examples).

To counterbalance stimuli presentation, 8 different counterbalanced sets of sentences were composed in order to equally present all sentences across all experimental conditions. Each set contained a total of 360 sentences, which were later presented while participants made one of the four facial expressions (see below). In this manner, 90 sentences were presented for each facial expression, 45 containing a syntactic anomaly and 45 correct sentences. Therefore, each presentation set of sentences was composed to contain different combinations of sentences and to avoid the repetition of an experimental sentence within a given set. Each complete set was presented to three participants, yielding the total sample of 24 participants considered in the analyses. Therefore, subjects saw a given sentence only once, corresponding to one condition (facial expression/morphosyntactic correctness). In addition, each set contained 120 fillers of a different grammatical structure resulting in 480 sentences per set. Half of the fillers contained noun-adjective agreement violations. Filler sentences could be short (60 sentences: [determiner]-[noun]-[verb]) or long (60 sentences: [determiner]-[noun]-[adjective]-[verb]-[mask]-[complement]), all of them were previously used in Jiménez-Ortega et al (2012).

4.3. Procedure

First, two golf tees were attached to the inner part of the participant's eyebrows. Second, they were instructed to discriminate between correct and incorrect sentences by pressing one of two keys with the index and the middle fingers of the same hand. Both hand and key assignment of correctness were counterbalanced. To induce the different facial expressions subjects either (a) posed no facial expression ("control" condition) (b) held a pencil between their teeth ("smile" condition"), (c) held a pencil using their lips ("non-smile" condition) or (d) brought together the ends of the golf tees ("frown" condition). In conditions (a) and (d), no pencil was held in the mouth, while the golf tees were attached to the participants' eyebrows in all conditions (Fig. 2). Each facial expression was made during a block of 90 sentences and block order was counterbalanced across participants.

The experimenter avoided telling the participants about the correspondence of these facial expressions with emotional feelings. Furthermore, to make participants unaware of the emotions, they were told that the main aim of the experiment was to develop an algorithm to disentangle neural from muscular activity in the EEG recording. To monitor participants' facial expressions, a camera connected to a computer outside the room recorded the participants and they practiced with the experimenter before each block.

The experimental material was presented with the Presentation®

Table 1
Examples of sentences.

Correct sentences	e.g. (a) El Ganado **lanudo** pasta. {The cattle [mas., sing.] **shaggy** [mas., sing.] graze.} (b) El detective **privado** investiga. {The detective [mas., sing.] **private** [mas., sing.] investigates.}
Gender disagreement	e.g. (a) El Ganado **lanuda** pasta. {The cattle [mas., sing.] **shaggy** [fem., sing.] graze.} (b) El detective **privada** investiga. {The detective [mas., sing.] **private** [fem., sing.] investigates.}
Number disagreement	e.g. (a) El Ganado **lanudos** pasta. {The cattle [mas., sing.] **shaggy** [mas., plur.] graze.} (b) El detective **privados** investiga. {The detective [mas., sing.] **private** [mas., plur.] investigates.}

Critical word in bold. Literal translations (noun-adjective inverted order) into English.
Where mas. = masculine, fem. = feminine, sing. = singular, plur. = plural.

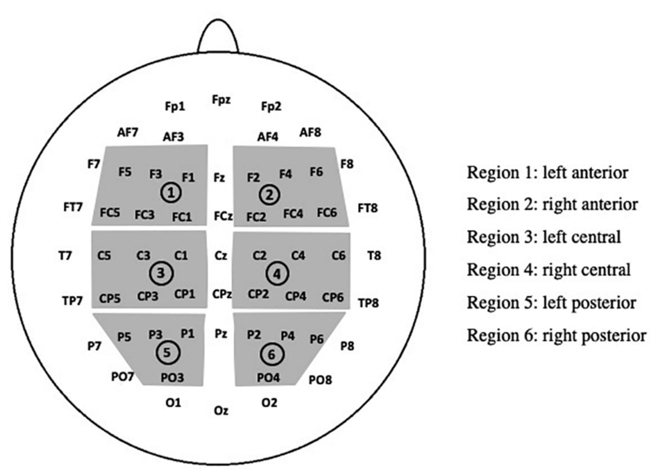

Fig. 2. Scheme of the ROIs used for statistical analyses.

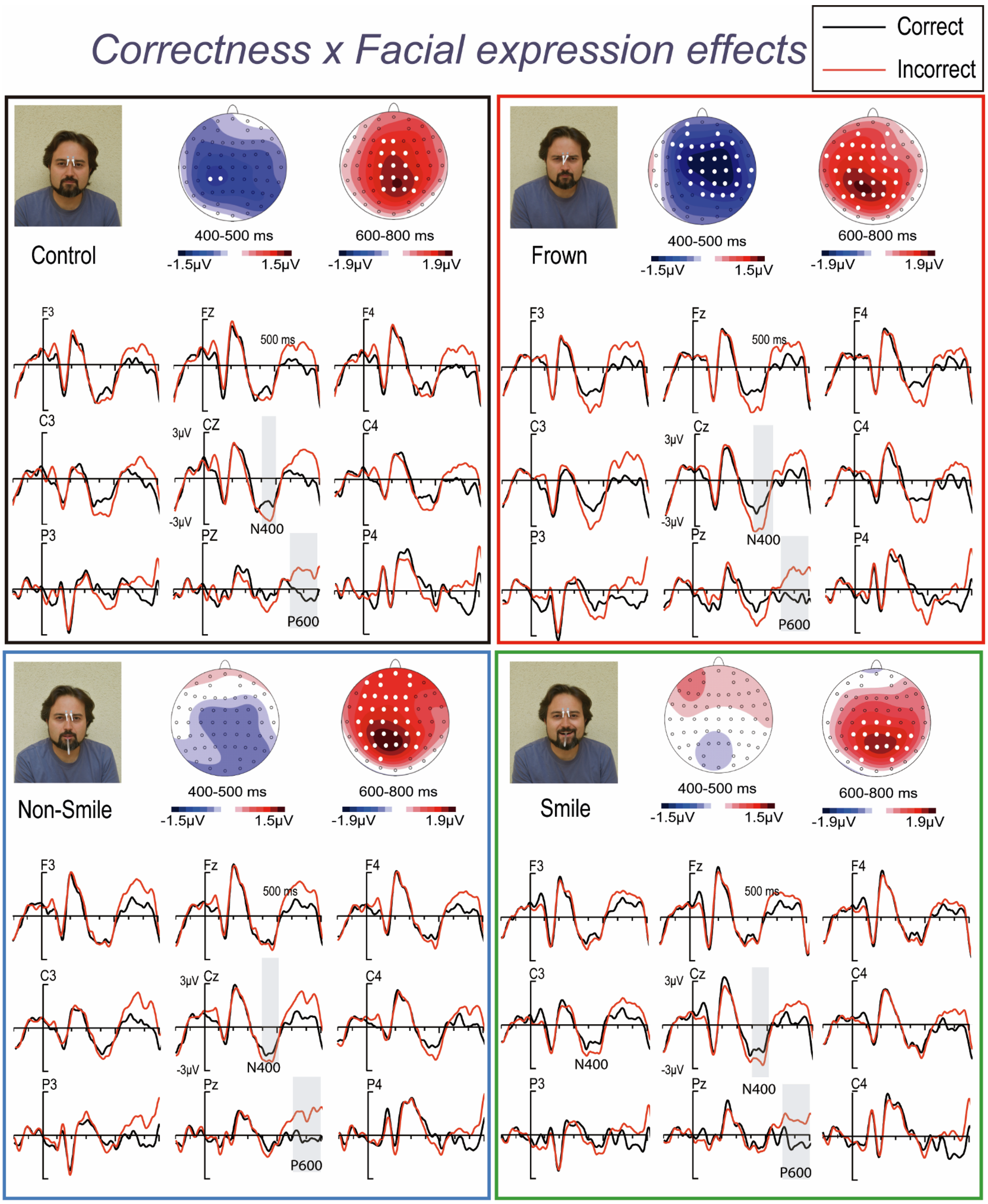

Fig. 3. ERP response to syntactically correct and incorrect critical words, as a function of facial expressions (control, frown, smile, and non-smile). The extent of the clusters appears superimposed (white marks) in the voltage maps.

software. All stimuli were presented in white in the center of a black computer screen. Each trial began with a white cross that lasted 500 ms. Immediately thereafter, a sentence was presented on a word-by-word basis (300 ms each) with a blank screen of 300 ms in between (Fig. 2). That is, the stimulus onset asynchrony (SOA) was of 600 ms. The last word, marked with a period, was followed by a blank screen of 1000 ms. Finally, a question mark appeared for 1500 ms, inviting the participants to respond. Participants' eyes were about 65 cm away from the screen (visual angles around 0.8° to 4° width). They were instructed to blink during the question mark presentation. The experimental session lasted for 60 min. Sentences were randomly presented, and each set included two pauses every 160 sentences.

4.3.1. Electroencephalogram (EEG recording and data processing)

The electroencephalogram (EEG) was recorded with a sample rate of 250 Hz and a bandpass of 0.01–100 Hz. Data were recorded from 59 channels using the standard 10/20 system (see Fig. 3), all of them were originally referenced to the left mastoid (M1) and later offline re-referenced to average mastoids (M1-M2). EEG was also filtered offline with a bandpass of 0.1–25 Hz. Eye-related activity was monitored by the recorded activity of bipolar vertical and horizontal electro-oculograms (EOG). Electrode impedance was kept below 5 kΩ. Data was segmented into 1000 ms epochs for each trial starting 200 ms previous to the target onset. Eye-movements and muscular artifacts were identified and corrected using the Independent Component Analysis (ICA, Jung et al., 2000) implemented in Brain Vision Analyzer® (Brain Products). Other artifacts were semi-automatically rejected offline, eliminating epochs exceeding ± 100 µV in any of the channels and removing epochs containing artifacts through visual inspection. On average, 36 correct and artefact-free trials out of 45 per condition were included in the data analyses, with no difference between conditions (all $Fs < 2.5$, $p > .1$).

4.4. Data analysis

Taking into account the advantages and disadvantages of different types of analyses (Brusini et al., 2016, 2017; Fields and Kuperberg, 2019; Groppe et al., 2011a,b), two approaches for data analyses were conducted: factorial cluster-based permutation analyses and time windows analyses based on both previous literature and visual inspection, the latter also guided by consideration of the results of the cluster analyses.

Cluster-based permutation analyses were calculated by using the Factorial Mass Univariate Toolbox (Fields and Kuperberg, 2019), which builds upon and extends the Mass Univariate Toolbox developed by Groppe et al. (2011a). This Matlab® toolbox was specifically chosen because it can be employed with complex factorial designs and it shows good power when a priori time segments are used (Fields and Kuperberg, 2019). In this regard, guided by Brusini et al. (2016, 2017) procedures, we considered two time segments for these analyses: an early one (0–500 ms) to capture the early effects typically described to syntactic anomalies, and a late one (500–900 ms) to detect the late P600 component to syntactic anomalies. Therefore, two Factorial cluster-based permutation analyses were calculated, each with 10,000 iterations and an alpha level of 0.05 involving the factors Correctness (Correct, Incorrect) and Facial Expression (control, frown, smile, non-smile).

For the time windows analyses, statistical analyses of variance (ANOVAs) were performed with the SPSS 22® software. Three brain regions of interest (ROIs) were used: anterior, central and posterior regions (Fig. 3). The main ANOVA included four factors: ROI (three levels: anterior, central, posterior), Hemisphere (right, left), Facial Expression (four levels: control, frown, non-smile, smile) and Correctness (two levels: correct, incorrect). Violations of the sphericity assumption were corrected when necessary by the Greenhouse-Geisser method and reported p-values for post-hoc contrasts were corrected by the Bonferroni method. Guided by both visual inspections and cluster analyses, and also by previous literature, the following windows were initially analysed: 400–500 ms, and 600–700 ms and 700–800 (Fig. 1). However, since the two latest windows resulted in similar statistical results in the time window ANOVA analyses, exclusively a 600 to 800 ms. window was included in the results section for simplicity.

CRediT authorship contribution statement

Laura Jiménez-Ortega: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Funding acquisition. **Esperanza Badaya:** Data curation, Formal analysis. **David Hernández-Gutiérrez:** Data curation, Writing - review & editing. **Marta Silvera:** Data curation, Writing - review & editing. **Javier Espuny:** Conceptualization, Methodology, Data Curation, Writing - review & editing. **José Sánchez Garcia:** Conceptualization, Methodology, Data Curation, Writing - review & editing. **Sabela Fondevila:** Conceptualization, Methodology, Data Curation, Writing - review & editing. **Francisco Muñoz Muñoz:** Conceptualization, Methodology, Data Curation, Writing - review & editing. **Pilar Casado:** Conceptualization, Methodology, Data Curation, Writing - review & editing. **Manuel Martín-Loeches:** Conceptualization, Methodology, Data curation, Formal Analysis, Writing - review & editing, Funding acquisition, Supervision.

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Appendix A. Supplementary data

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