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Research Report

The influence of emotional words on sentence processing: Electrophysiological and behavioral evidence

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ABSTRACT

Whereas most previous studies on emotion in language have focussed on single words, we investigated the influence of the emotional valence of a word on the syntactic and semantic processes unfolding during sentence comprehension, by means of event-related brain potentials (ERP). Experiment 1 assessed how positive, negative, and neutral adjectives that could be either syntactically correct or incorrect (violation of number agreement) modulate syntax-sensitive ERP components. The amplitude of the left anterior negativity (LAN) to morphosyntactic violations increased in negative and decreased in positive words in comparison to neutral words. In Experiment 2, the same sentences were presented but positive, negative, and neutral adjectives could be either semantically correct or anomalous given the sentence context. The N400 to semantic anomalies was not significantly affected by the valence of the violating word. However, positive words in a sentence seemed to influence semantic correctness decisions, also triggering an apparent N400 reduction irrespective of the correctness value of the word. Later linguistic processes, as reflected in the P600 component, were unaffected in either experiment. Overall, our results indicate that emotional valence in a word impacts the syntactic and semantic processing of sentences, with differential effects as a function of valence and domain.

1. Introduction

Human verbal communication can be a highly emotional experience, including both the expression of emotional states to others and the elicitation of feelings like pleasure, distress, outrage, and many others, depending on several factors. Arguably one of the most important of these factors is the emotional meaning of the words composing the linguistic message. Although the study of emotion has made much progress in many domains, it is in its infancy when language is concerned, particularly with respect to sentence processing. Indeed, reports on the impact of emotional words on the structural processing of sentences seem to be absent in the scientific literature. It is the aim of the present study to contribute to filling this gap by investigating whether and how the emotional valence of words within sentences affects syntactic and semantic processes of sentence comprehension.

1.1. Studying emotional words and sentence comprehension with event-related brain potentials

Both the processing of emotional words and sentence comprehension have often been investigated with event-related potentials (ERPs). However, with a few exceptions (discussed below), emotional language processing has always been studied using words in isolation (for a review, see Citron, 2012). Emotional words often elicit at least two temporally and topographically dissociable ERP components. The first effect is seen in a negative-going difference wave at temporo-occipital electrodes, termed the early posterior negativity (EPN), starting at about 200 ms after stimulus onset for both positive and negative relative to neutral words (Herbert, Junghofer, & Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007; Schacht & Sommer, 2009a, 2009b). Given its resemblance to ERP components elicited by voluntary attention to non-emotional stimuli, the EPN has been suggested to reflect reflex-like attention allocation caused by the high intrinsic relevance of emotional stimuli (Schupp, Junghöfer, Weike, & Hamm, 2003). The second ERP effect is an enhancement of the late positive complex (LPC), typically starting at about 300 ms and lasting for several hundred milliseconds (e.g., Fischler & Bradley, 2006; Kissler, Herbert, Winkler, & Junghofer,

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2009; Schacht & Sommer, 2009b). Although it has been interpreted as reflecting sustained elaborate processing of high-arousal stimuli regardless of their valence (e.g., Dillon, Cooper, Grent-'t-Jong, Woldorff, & LaBar, 2006; Fischler & Bradley, 2006), this is not unequivocal (e.g., Herbert et al., 2008; Kissler et al., 2009).

Studies of sentence processing, on the other hand, have usually yielded different ERP components that seem to honor the distinction between syntactic and semantic processing. In the syntactic domain, the main ERP effects are anterior negativities and posterior positivities. Anterior negativities are typically labeled as LAN (left anterior negativity), between roughly 250 and 550 ms, or ELAN (early LAN), appearing as early as 100–200 ms. Word category violations are the variations most frequently associated with ELAN (e.g., Friederici & Mecklinger, 1996), whereas other grammatical anomalies, including morphosyntactic violations (e.g., Coulson, King, & Kutas, 1998), usually evoke a LAN. Both anterior negativities may reflect highly automatic first-pass parsing processes, the detection of a morphosyntactic mismatch, and/or the inability to assign the incoming word to the current phrase structure (Friederici, 2002). A late positive-going component with a parietal maximum, labeled P600, has typically been considered as a syntax-related ERP fluctuation because it is elicited by syntactic violations (e.g., Osterhout & Holcomb, 1992). However, a P600 also appears in structurally ambiguous or garden path sentences (Frisch, Schlesewsky, Saddy, & Alpermann, 2002). Therefore, it has been suggested that the P600 indicates increased syntactic processing costs due to revisions and reanalyses of structural mismatches, possibly also reflecting subsequent repair processes (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998). Finally, the occasional observation of P600 deflections to semantic violations has also motivated recent alternative accounts, such as the reflection of the activity of a combinatorial system that integrates both semantic and syntactic information (Kuperberg, 2007), or a domain-general monitoring mechanism (Kolk & Chwilla, 2007).

In the semantic domain, the so-called N400 effect is the main finding (Kutas & Hillyard, 1984). The N400 effect is a negative-going component resembling the LAN in latency, usually most pronounced over central and posterior electrode sites (Kutas & Besson, 1999). Typically, this component increases in amplitude with the difficulty of integrating words into their semantic context—be it a sentence or a preceding prime word (Chwilla, Brown, & Hagoort, 1995). Alternatively, the N400 has also been characterized as an index of the access to long-term multimodal lexico-semantic memory, reflecting the efforts of activating long-term memory representations of features associated with a lexical item (Kutas & Federmeier, 2011).

1.2. Emotional words in context

Interestingly, when emotional words have been studied within the context of sentences (Bayer, Sommer, & Schacht, 2010; Holt, Lynn, & Kuperberg, 2009), they have not been found to elicit the EPN, while LPC enhancements have been observed. That the EPN, typically obtained for emotional words in isolation, vanishes when the words are embedded in sentences could be indication that sentence processing and the emotional content of words might interact. Remarkably, this would occur during the time window at which the EPN normally emerges. Furthermore, in the second experiment of Holt et al. (2009), using passive reading, the EPN remained absent whereas a small N400 to negative and positive words was observed instead, interpreted as reflecting a larger engagement of initial semantic analysis for emotional than for non-emotional words embedded in sentences. Similarly, Bayer et al. (2010) found an N400-like ERP effect to emotionally negative words within sentences. A number of studies have found effects of emotional states or mood—induced by pictures, films, or faces—on the subsequent processing of sentences, both at semantic (Federmeier, Kirson, Moreno, & Kutas, 2001) as well as syntactic levels (Vissers et al., 2010). Although these studies support the interplay between emotions and higher-order cognitive processes such as sentence comprehension, they do not address the impact of emotional words on the processing of sentences in which they are embedded. Finally, a number of studies have explored the effects on the N400 when the emotion induced by non-linguistic material contradicts the emotional valence of a single word presented subsequently, finding significant modulations of this component (e.g., Kiefer, Schuch, Schenck, & Fiedler, 2007).

The latter findings further reinforce the assumption that the emotional content of a word is actually part of its lexico-semantic information (cf. Palazova, Mantwill, Sommer, & Schacht, 2011). Accordingly, it should be able to modulate the lexical access or semantic integration processes of the word, as could be reflected in the N400. In the same line, several neuroimaging studies reveal that the semantic content of words may tap into limbic structures (for a review, see Binder, Desai, Graves, & Conant, 2009). Accordingly, it appears plausible that the emotional content of a word might affect the N400 modulations typically elicited by semantic sentential violations. To explore this possibility is one of the aims of the present study.

On the other hand, if the emotional content of a word is part of its lexico-semantic information, whether it might also affect syntactic processing depends upon our assumptions on the interplay between semantic and syntactic information during sentence comprehension. In this regard, strongly modular models assume that informationally encapsulated and at least partly sequential processes construct distinct syntactic and semantic representations (e.g., Ferreira & Clifton, 1986). In contrast, fully interactive models suggest that syntactic and semantic constraints interact directly and simultaneously with each other at the message-level representation of the input (e.g., McClelland, John, & Taraban, 1989). Intermediate proposals also exist, differing in the degree of independence and prevalence ascribed to semantic and syntactic information (e.g., Kim & Osterhout, 2005).

A large body of evidence from ERPs supports a syntactocentric view, in which syntactic information prevails over and affects semantic processing, with no influence in the opposite direction (e.g., Friederici, 2004). In these studies, double violations—containing both syntactic and semantic anomalies simultaneously—usually yield a LAN and a P600, the N400 being either absent or importantly modulated—for example, boosted—by the syntactic violation (Hagoort, 2003). However, several studies have also reported an inversion of the direction of these effects, demonstrating that at least under certain circumstances semantic information may prevail and modulate syntactic processing (e.g., Martín-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006). The appearance of emotional words within a sentence could actually be one of these situations in which semantics prevails, given their presumed capacity to prompt early attentional resources, as reflected in the EPN. The present study also explores this possibility.

1.3. The present study

None of the previous studies reviewed above has investigated the effects of the emotional content of a word on the structural processing of a sentence in which it is embedded, neither in the syntactic nor the semantic domain. The present study was designed to fill this gap. To this aim, participants had to read sentences containing emotional words that were either correct or represented either a syntactic or a semantic violation. Our main interest was to explore whether the characteristic ERP modulations due to either type of sentential anomaly (i.e., LAN, N400, and P600) are affected by the presence of an emotional content in the word embodying the violation.

Two experiments were designed to pursue these objectives. The first one assessed how adjectives of positive, negative, or neutral valence that could be either syntactically correct or incorrect (by violating number agreement between the adjective and its noun) modulate the ERP components elicited by the syntactic anomalies. In the second experiment, we presented very similar sentences, but positive, negative, or neutral adjectives could either be semantically correct or anomalous given the corresponding noun in order to assess how the valence of adjectives modulate the ERP components elicited by semantic anomalies.

Assuming that emotion-related knowledge has a specific organization within the brain and is segregated and prioritized with respect to non-emotional information (Innes-Ker & Niedenthal, 2002), it can be predicted that encountering an emotional word could lead to increased semantic processing difficulty and, thus, to a boost of the N400 to both semantically correct and anomalous words. For semantically anomalous words, N400 enhancement may add to the normal modulations of this component to semantic violations. On the other hand, priority and increased difficulty of semantic processing of emotional words could also lead to increased difficulty of syntactic processing and LAN boosting. Indeed, the first customary effects of the emotional content of words—EPN—largely overlap in time with both the N400 and the LAN. The P600, reflecting subsequent structural sentence analyses, might plausibly be concerned as well, as this component roughly coincides in time and topography with the LPC reported to emotionally valenced words.

Emotion-related ERP modulations—the LPC and the EPN—have been observed to isolated words but seem to vanish or disappear when the word is embedded into a sentence, particularly the EPN (Bayer et al., 2010; Holt et al., 2009). This does not necessarily imply that also the processes reflected in these components disappear; it is only that they are hardly visible under these circumstances. The specific features of our experimental procedures, in which the main task of the participants consists of plausibility judgments about the correctness of sentences, allow us to predict a noticeable reduction of these components in our results.

2. Experiment 1: syntactic processing

2.1. Material and methods

2.1.1. Participants

Twenty-two native Spanish speakers (12 females) with ages ranging from 19 to 41 (M=25.7 years) participated in the study. All had normal or corrected-to-normal vision and were right-handed, with average handedness scores (Oldfield, 1971) of +83.6%, ranging from +30 to +100. Participants reported no history of neurological or psychiatric complaints. All volunteers gave their informed consent to participate in the study and received reimbursal. The experiment was performed in accordance with the Declaration of Helsinki and had been approved by the ethics committee of the Complutense University of Madrid.

2.1.2. Stimuli

The language material consisted of 360 Spanish sentences. All experimental sentences followed the same structure: [Det]-[N]-[Adj]-[V] (determiner-noun-adjective-verb). The adjective was the critical word. From the 360 experimental sentences, 120 each had emotionally positive, negative, or neutral adjectives. A sample of 23 participants who did not participate in the ERP experiment rated all the adjectives as emotionally positive, negative, or neutral using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994), ranging from 1 (highly unpleasant) to 9 (highly pleasant). Another sample of 30 subjects rated arousal using the same procedure, adapted for arousal-ratings. All adjectives matched across emotional category in length, frequency of use, and concreteness (LEXESP; Sebastián, 2000). A third sample of 21 participants scored cloze probabilities for the critical adjectives in the sentences. Table 1 summarizes this information and shows that cloze probability values were very low. This is the consequence of both words being positioned in the middle of short sentences (in line with, e.g., Martin-Loeches et al., 2009) and of the strong constraints imposed by valence, arousal, frequency, length, and concreteness values (along the lines of Holt et al., 2009). Therefore, our critical words were unpredictable but rated as plausible by our participants (see below). Further, the highly standard N400 modulation by semantic violations in our neutral trials in Experiment 2 confirms the validity of our materials. A second set of sentences was constructed by pluralizing the singular adjectives and vice versa, yielding the 360 experimental sentences in their syntactically anomalous version. Table 2 displays examples of the sentences used in Experiments 1 and 2.

Two experimental blocks were constructed. In each block, we included the whole set of 360 sentences, 120 each with positive, negative, and neutral adjectives. Each of the three valence groups contained 60 syntactically correct and 60 incorrect sentences. The sentences used in one block in their correct version, were in the incorrect one in the other block, and vice versa. Each sentence (whether correct or incorrect) was presented to a given participant only once. In addition to the experimental sentences, we included 120 filler sentences; half of them did not contain an adjective (short filler sentences), whereas the other half included a complement after the verb (long filler sentences). Within the set of filler sentences, half included a syntactic anomaly and half were correct. Each participant was presented with only one of the two blocks. The presentation of the sentences within a block was randomized.

2.1.3. Procedure

At the beginning of each session, participants were informed about the experimental task and presented with a training block followed by the experimental

Table 1
Means (SDs) of valence, arousal, length, frequency of use, concreteness, and cloze probability of the adjectives used in Experiments 1 and 2.

	Valence*	Arousal*	Length	Frequency	Concreteness	Cloze *p*.
Positive	7.18 (.69)	3.25 (.60)	2.97 (.65)	63.17 (96.3)	4.14 (1.2)	.014 (.02)
Negative	3.03 (.81)	3.27 (.68)	2.97 (.76)	59.82 (96.3)	4.60 (.8)	.013 (.01)
Neutral	5.11 (.55)	2.33 (.51)	2.82 (.50)	63.18 (123)	4.75 (.9)	.015 (.02)

Differences between means were significant (all $ps < .01$) for those marked with an *

Table 2
Example sentences used in the two experiments.

	Correct sentences	Syntactically incorrect sentences (Experiment 1)	Semantically incorrect sentences (Experiment 2)
Positive	La hermana <u>querida</u> acude (“*The <u>loved</u> sister arrives*”)	La hermana <u>queridas</u> acude (“*The <u>loved</u>*[a] *sister arrives*”)	La hermana <u>gratuita</u> acude (“*The <u>gratuitous</u> sister arrives*”)
Negative	La chica <u>fea</u> baila (“*The <u>ugly</u> girl dances*”)	La chica <u>feas</u> baila (“*The <u>ugly</u>*[a] *girl dances*”)	La chica <u>cuadrada</u> baila (“*The <u>square</u> girl dances*”)
Neutral	El espejo <u>ovalado</u> refleja (“*The <u>oval</u> mirror reflects*”)	El espejo <u>ovalados</u> refleja (“*The <u>oval</u>*[a] *mirror reflects*”)	El espejo <u>cocido</u> refleja (“*The <u>cooked</u> mirror reflects*”)

[a] Syntactic violations in these examples are made by using a plural adjective with a singular noun.

task. Participants were required to categorize each sentence as correct or incorrect by pressing one of two buttons with the index fingers. Thus, for the participants the experiment was simply a sentence correctness judgement task, with no indication about the emotional factor of the study. The assignment of correctness to the responding hand was counterbalanced.

All sentences began with a cross in the middle of the screen for 500 ms, and were presented word-by-word for 300 ms each, with a stimulus onset asynchrony (SOA) of 600 ms. One second after the offset of the last word (black screen), a question mark appeared for one second. During this interval participants had to indicate the correctness of the just-presented sentence by pressing the corresponding button. The first word of each sentence began with a capital letter and the last word was presented together with a period at the end. All stimuli were presented in the center of a computer monitor in white on a black background, controlled by Presentation® Software. Participant's eyes were about 65 cm from the monitor. All words were presented with visual angles around .8° in height and .8–4° in width.

Participants were seated in a comfortable chair in an electrically shielded chamber. They were required to avoid movements and eye blinks during the reading of the sentences. The experimental session lasted about 40 min, plus electrode preparation.

2.1.4. Electrophysiological recording and analysis

EEG was recorded from 27 channels; electrodes were mounted in an electrode cap (EasyCap), placed at Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FC4, FT7, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CP4, TP8, P7, P3, Pz, P4, P8, O1, and O2. The impedance of all electrodes was kept below 5 KΩ. Raw data were sampled at 250 Hz and recorded with a band-pass from .01 to 40 Hz. Bipolar vertical and horizontal EOGs were recorded to monitor eye movements and blinks. During recording all EEG electrodes were referenced to the left mastoid; offline they were re-referenced to the average of the right and left mastoids.

The EEG data was analyzed with Brain Vision® Analyzer Software. Raw data were filtered off-line with a band-pass from .01 to 30 Hz. The continuous EEG was segmented into 1-s epochs, starting 200 ms before onset of the adjectives. Ocular correction was applied following the algorithm of Gratton, Coles, and Donchin (1983), and a semi-automatic mode for artefact rejection was implemented to eliminate remaining epochs with artefacts from the data. Additionally, incorrectly classified stimuli (correct sentences judged as incorrect and vice versa) were also excluded from the averages. The final mean rejection rate was 33.4%. Separate average ERPs were calculated for epochs containing adjectives in the experimental sentences as a function of whether they were syntactically correct or not and of positive, negative, or neutral valence. Comparisons by means of repeated measures ANOVAs involved main effects of sentence correctness, main effects of emotional valence, as well as their interaction.

2.2. Results

2.2.1. Performance

Regarding the sentence correctness judgment, the results were as follows: correct sentences were judged as correct in 83.5%, 84.7%, and 82.2% of cases, for neutral, positive, and negative adjectives, respectively. These relatively low values are probably a consequence of the brevity of the sentences employed, as was the case in our previous studies with similar materials (Martín-Loeches et al., 2006, 2009). Incorrect sentences were classified as incorrect in 92.2%, 91.9%, and 91.5% of cases, for neutral, positive, and negative adjectives, respectively. The difference between correct classifications of correct and incorrect sentences (M=83.51% vs. 91.92%) was highly significant (F(1,21)=16.127, p=.001). This effect is in line with previous studies (e.g., Martín-Loeches et al., 2006). No significant main effect of emotion or interaction of emotion and correctness were obtained in the percentage of correct judgements, indicating that the emotional valence of the violating adjectives did not impact final correctness judgements of the participants in this syntactic condition. Given the delay of the established response period—relative to the occurrence of violations—reaction times should be considered uninformative, and indeed no differences appeared in this variable.

2.2.2. Left anterior negativity

Fig. 1 shows the ERP modulations by the syntactic correctness of the adjectives, separately for neutral, positive, and negative adjectives. Fig. 2 displays the same results as difference waves. The neutral condition when contrasting incorrect with correct adjectives clearly exhibits a left anterior negativity (LAN), starting at about 200 ms after stimulus onset and peaking around 400 ms, with a maximum over the left frontal electrodes. Interestingly,

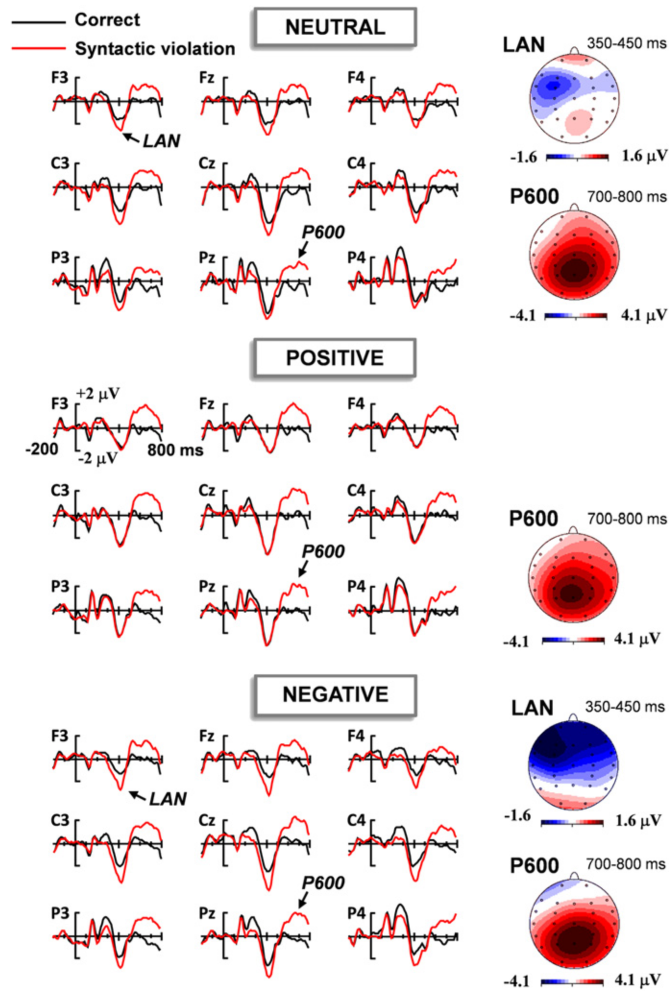

Fig. 1. ERPs to syntactically correct and incorrect adjectives of neutral, positive, and negative emotional valence. *Left*: ERP waveforms at selected electrodes. *Right*: difference maps (incorrect minus correct) of the LAN (absent for positive adjectives) and P600 effects.

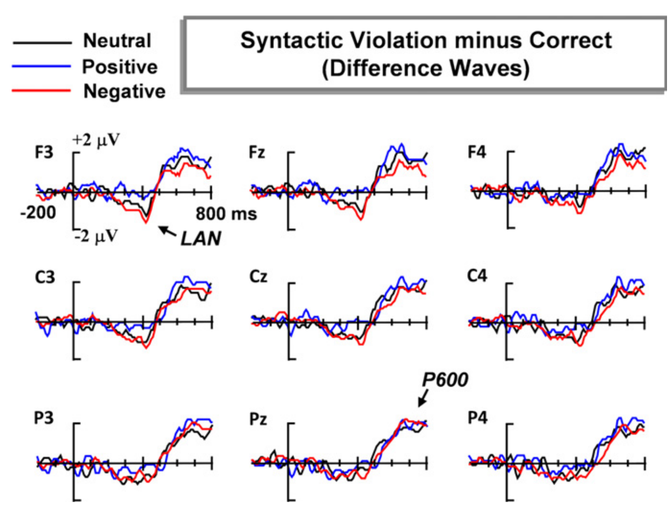

Fig. 2. Difference waves (syntactically incorrect minus incorrect adjectives) for neutral, positive, and negative emotional valence. Same results as in Fig. 1, expressed as difference waves.

however, no LAN appears for positive incorrect adjectives when compared to positive correct adjectives. In turn, and also of the highest interest, negative incorrect adjectives display a LAN that is notably larger than for the neutral adjectives, with the typical left-frontal maximum but spreading also to right frontal electrodes. Repeated-measures ANOVA for mean ERP amplitudes in the time window from 350 to 450 ms, where the LAN was maximal, substantiated this impression, revealing significant interactions of correctness by electrode ($F(26,546)=3.017$, $p=.020$) and correctness by emotion ($F(2,42)=5.167$, $p=.01$), as well as a trend for the interaction correctness by emotion by electrode ($F(52,1092)=2.06$, $p=.06$). Post-hoc analyses were performed using a region of interest (ROI) comprising the electrodes F7, F3, FT7, and FC3. Main effects of correctness were analyzed for each type of valence, which were significant for neutral ($F(1,21)=4.21$, $p=.045$) and negative ($F(1,21)=16.55$, $p=.001$), but not for positive ($F(1,21)=5.24$, $p>.1$) adjectives, confirming a LAN to syntactic violations only in neutral and negative words. As a LAN to positive adjectives could not be observed, we tested next for differences in LAN amplitudes between negative and neutral trials. Significant interactions of correctness by emotion were obtained for the pairwise post-hoc ANOVA comparing negative versus neutral ($F(1,21)=7.33$, $p=.013$), supporting a LAN amplitude increase in the negative adjectives. Overall, it appears that the LAN is boosted when the syntactically violating adjective is, in addition, an emotionally negative word. In contrast, positive adjectives were not able to elicit a measureable LAN.

2.2.3. P600

The P600 appeared robust and similar in both topography and amplitude for neutral, positive, and negative adjectives. This was supported by strong effects of correctness, both in isolation as well as in interaction with electrode in the 600–700 ms ($F(1,21)=34.51$, $p=.0001$, and $F(26,546)=14.43$, $p=.0001$, respectively) and 700–800 ms ($F(1,21)=32.22$, $p=.0001$, and $F(26,546)=19.06$, $p=.0001$) time windows. Subtle differences in amplitude between emotional and neutral words were not statistically supported, as neither the correctness by emotion nor the correctness by emotion by electrode interactions yielded significant results (600–700 ms window: $F(2,42)=.08$ for emotion; $F(52,1092)=1.8$ for emotion by electrode; 700–800 ms window: $F(2,42)=.12$ for emotion; $F(52,1092)=1.7$ for emotion by electrode; all $ps>.1$). Accordingly, the P600 to syntactic violations does not appear to be significantly affected by the emotional valence of the violating word.

2.2.4. Standard emotion effects

Fig. 3 shows the ERP modulations by neutral, positive, and negative valence of the adjectives in correct trials. In this experiment, the results corresponding to main effects of emotion or of emotion by electrode did not reveal significant effects in a thorough exploration of the whole epoch using consecutive 100-ms windows from 0 to 800 ms ($Fs(2,42)$ between .8 and 2.4 for emotion; $Fs(52,1092)$ between .2 and 1.3 for emotion by electrode; all $ps>.1$). In the time segments typically corresponding to the EPN (200–400 ms), no systematic modulations could be appreciated. Unsupported statistically, a very small LPC-like fluctuation along the 500–600 and 600–700 ms windows could be observed, comparable for either emotional valence.

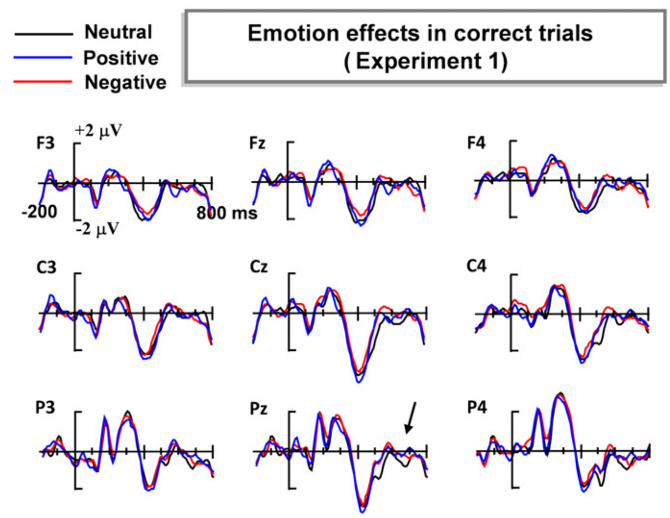

Fig. 3. Effects of emotional valence in Experiment 1 (syntactic processing) for correct trials. ERP modulations as a function of emotional valence for correct trials. No unambiguous effects could be observed, with the exception of an LPC-like fluctuation at later time ranges (arrow), which was statistically non-significant.

2.3. Discussion

Our main results in this experiment support a significant modulation of the LAN to syntax violations by the presence of emotional information in the word, which has several notable implications. First, the emotional lexico-semantic information of the adjectives was already processed and classified (i.e., the specific valence was identified) within the time the LAN was elicited, as shown by the differential effects of valence on this component. This effect cannot be interpreted as the consequence of a coinciding EPN-like fluctuation, normally peaking at about the time window of the LAN. In consonance with previous studies using emotional words in sentences (Bayer et al., 2010; Holt et al., 2009), this component did not seem to emerge. But even if it had emerged, its typical temporo-occipital distribution prevents such a conclusion. The specific processes reflected by this component, therefore, would be somewhat independent of the effects observed on syntactic processes. Actually, both the EPN and LPC might be relatively unstable and/or not very salient when the emotional word is embedded into a sentence, and indeed none of them could be unambiguously observed here. This reasoning is extended in Section 4.

A second implication of our results is that emotional words seem to conform to one of those situations in which a syntactocentric view of sentence processing might not be applicable, since the morphosyntactic processes reflected in the LAN have been significantly affected by the emotional valence of the syntactically anomalous word. On one hand, it seems that a negative emotional meaning in a word promptly summons attentional resources, conveying in turn larger processing costs in the co-occurring syntactic operations as reflected in LAN increase. This might constitute a case example for the "negativity bias" reported in several studies with emotional pictures or facial expressions, by virtue of which negative information exhibits processing preference and consumes more resources than positive or neutral information, probably due to the preferential survival value of negative information (Carretié, Albert, López-Martín, & Tapia, 2009).

On the other hand, positive words also modulated the LAN relative to neutral words to the point of abolishing this component. In consonance with the interpretation of the modulations for negative words, this might be indication of a facilitation of the syntactic analyses reflected by the LAN. However, no available model of attention would assume that positive valence of words captured less attention than neutral words. Facilitating effects of positive words could instead be understood in the light of the proposal by Isen (1987) (see also Ashby, Isen, & Turken, 1999) that positive material is more strongly interconnected in the semantic system, to the point that positive words would even compose a separate semantic category. Hence, access to positive representations might facilitate semantic processing and the integration of the word in the sentence model. This possibility is problematic, however, since it is difficult for psycholinguistic models to embrace that the processing of semantic meaning could facilitate the detection of our morphosyntactic anomalies.

Alternatively, in our view, these data seem compatible with studies reporting that positive emotional states increase the use of heuristic strategies, less computationally demanding than algorithmic strategies (e.g., Blanchette & Richards, 2010). If this were the case, it is possible that positive words within a sentence are not syntactically parsed in a first-pass in the same way as neutral or negative words but with other, less algorithmic strategies—syntax is often considered as strictly algorithmic, e.g., Friederici and Weissenborn (2007). This second interpretation is not in terms of processing difficulties, but on induced changes in processing strategies. Possibly, the lexico-semantic emotional information contained in a word might not be powerful enough as to elicit emotional states, particularly considering the short time intervals used here. However, at the cognitive level at least part of the strategies elicited by positive emotional states might be triggered when a positive word appears in a sentence. This line of reasoning would be consistent with embodied frameworks of semantic memory (e.g., Glenberg, Havas, Becker, & Rinck, 2005), according to which decoding the meaning of emotional words would lead to rapid activation of emotional processing networks within the brain (see Holt et al., 2009, for a similar interpretation). Indeed, this claim is also supported by reports that the lexico-semantic content of words seems to tap into limbic structures (Binder et al., 2009).

3. Experiment 2: semantic processing

3.1. Materials and methods

3.1.1. Participants

Twenty-two native Spanish speakers (17 females) with ages ranging from 18 to 35 (M=22.4 years) participated in the study. All had normal or corrected-to-normal vision and were right-handed, with average handedness scores (Oldfield, 1971) of +71.3%, ranging from +44 to +100. Participants reported no history of neurological or psychiatric complaints. All volunteers gave their informed consent to participate in the study and received reimbursal. The experiment was performed in accordance with the Declaration of Helsinki and approved by the ethics committee of the Complutense University of Madrid.

3.1.2. Stimuli and procedure

A second set of incorrect sentences was constructed from the set of 360 correct sentences used in Experiment 1. To build this set we randomly exchanged the adjectives between the sentences of the correct list in order to obtain 360 semantically incongruent sentences. As a result, all semantically incorrect words exhibited a cloze probability of zero according to the scores by the same raters as in Experiment 1. Two experimental blocks were constructed with these sentences, following the same procedures described in the previous experiment. In the present experiment, the filler sentences were the same as in Experiment 1 but semantic violations were used instead of syntactic ones.

3.1.3. Electrophysiological recording and analysis

We followed the same procedures as described for Experiment 1. The final mean rejection rate after considering performance results and artefact rejection was 39.73%. This relatively high rate is not rare in the literature (for a recent example, see Stroud & Phillips, 2012) and is mainly the consequence of increased judgement errors in the emotionally positive adjectives (see results). Separate average ERPs were calculated for epochs containing adjectives in the experimental sentences as a function of whether they were semantically correct or not and of positive, negative, or neutral valence. As in the previous experiment, comparisons involved main effects of sentence correctness, main effects of emotional valence, and their interaction.

3.2. Results

3.2.1. Performance

Correct sentences were judged as correct in 80.6%, 83.1%, and 80.6% of the cases with neutral, positive, and negative adjectives, respectively. Incorrect sentences were classified as such in 81.8%, 67.6%, and 77.7% of the cases with neutral, positive, and negative adjectives, respectively. Although on average correct sentences were classified better than incorrect ones (M=81.46% vs. 75.73%), correctness as main effect was not significant ($F(1,21)=1.08$, $p>.1$); however, a significant main effect of emotion ($F(2,42)=14.09$, $p=.0001$) and of the interaction of emotion and correctness ($F(2,42)=33.2$, $p=.0001$) were obtained. Bonferroni-corrected post-hoc analyses revealed that correctness affected performance only for positive adjectives ($F(1,21)=1.15$, $p<.05$), where classification of incorrect sentences was worse than for correct sentences. Finally, and similar to the previous experiment, no effects were observed in reaction times.

3.2.2. N400

Fig. 4 summarizes the main ERP results of this experiment, showing ERP modulations of the semantic correctness of the adjectives, separately for neutral, positive, and negative adjectives. Fig. 5 displays the same results as difference waves. Prior to the main analyses, we checked whether the small drifts apparent at the very beginning of the epoch—particularly at electrodes F3,

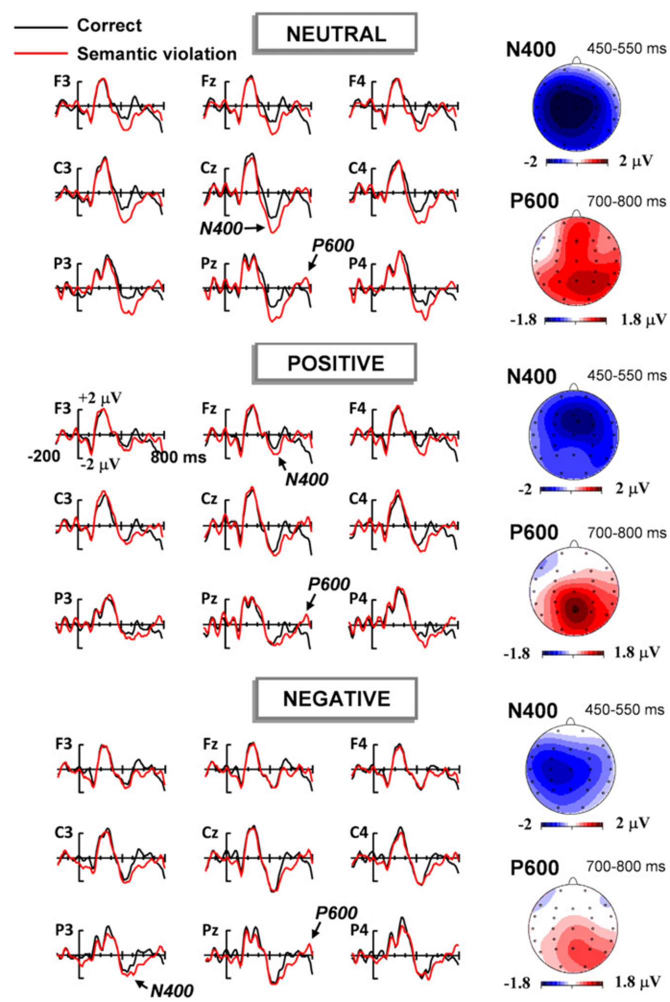

Fig. 4. ERPs to semantically correct and incorrect adjectives of neutral, positive, and negative emotional valence. *Left*: ERP waveforms at selected electrodes. *Right*: difference maps (incorrect minus correct) of the N400 and P600 effects.

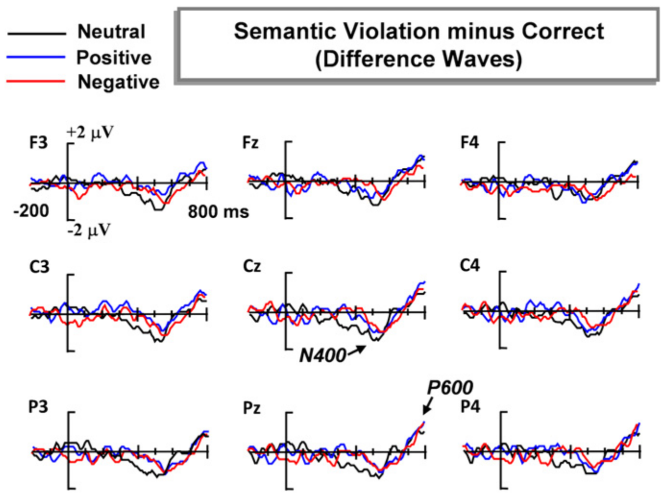

Fig. 5. Difference waves (semantically incorrect minus incorrect adjectives) for neutral, positive, and negative emotional valence. Same results as in Fig. 4, expressed as difference waves.

C3, and P3 for the negative adjectives—might impact subsequent components by assessing the strength of these fluctuations. Two ANOVAs in the 0–50 and 50–100 ms windows with the same factors as used for experimental purposes revealed no significant main effects or interactions (*Fs* between .2 and 1.7, $ps > .1$). Therefore, these early fluctuations can be considered inconsequential.

The neutral condition clearly exhibits a typical centro-parietal N400, starting at about 300 ms after stimulus onset and peaking around 500 ms when contrasting semantically incorrect with correct adjectives. Interestingly, however, the N400 also appeared when the violating adjectives were emotional, though subtle modulations of topography and amplitude seem to be present as well. Whereas positive adjectives yielded an N400 with a more frontal distribution, a reduction of the N400 amplitude appeared for negative adjectives.

Main effects of correctness were found in the time window selected to analyze the N400, 450–550 ms ($F(1,21)=28.9$, $p=.0001$). However, no significant effects were found for the remaining interactions: correctness by electrode ($F(26,546)<1$), correctness by emotion ($F(2,42)<1$), and electrode by correctness by emotion ($F(52,1092)=1.31$, $p>.1$). In post-hoc analyses, significant main effects of correctness were obtained at each type of valence: neutral ($F(1,21)=30.7$, $p=.0001$), positive ($F(1,21)=7.66$, $p=.011$), and negative ($F(1,21)=11.3$, $p=.003$) These results confirm that an N400, or at least a negativity due to semantic violations, was obtained in each case. However, the apparent differences in amplitude and topography across the categories of word valence were statistically unsupported. The differences between valences, nevertheless, might be more conspicuous at earlier segments, during the development of the N400, as is particularly apparent in the difference waves in Fig. 5. Accordingly, we performed ANOVAs in two preceding time windows, 300–400 and 400–500 ms. These analyses only yielded significant main effects of correctness ($F(1,21)=5.81$ and 20.07, respectively, $p=.003$ and .0001, respectively). A trend for an interaction of electrode, correctness, and emotion ($F(52,1092)=2.0$, $p=.09$) was found in the 400–500 ms window. Finally, an ANOVA was performed using the peak amplitudes in the interval between 400 and 600 ms. Results only yielded significant effects of correctness ($F(1,21)=25.01$, $p<.0001$) and of correctness by electrode ($F(26,546)=2.76$, $p=.05$). Overall, it seems that the emotional valence of adjectives did not significantly modulate the N400, neither in amplitude nor in topography.

3.2.3. P600

A small P600 component appeared at the very end of the epoch in this semantic condition, in consonance with previous reports (e.g., Martín-Loeches et al., 2006). Repeated-measures ANOVAs for mean ERP amplitudes in the time windows 600–700 and 700–800 ms revealed significant effects only in the latter window for correctness ($F(1,21)=9.2$, $p=.011$) and correctness by electrode ($F(26,546)=4.4$, $p=.002$). No effect of emotion, neither alone nor in interaction with other factors, could be found at these time windows. Thus, as in Experiment 1, the P600 was not affected by the emotional valence of the violating word.

3.2.4. Standard emotion effects

Fig. 6 shows the ERP modulations by the neutral, positive, and negative valence of the adjectives in correct trials. In a thorough exploration of emotion effects of the whole epoch using 100-ms wide consecutive windows from 0 to 800 ms, main effects of emotion and of emotion by electrode reached significance in the windows 300–400 and 400–500 ms ($Fs(2,42)=4.6$ and 3.4, respectively, both $ps<.05$). The other windows did not exhibit significant main effects of emotion (*Fs* (2,42) between .6 and 2.6; $p>.1$) or interactions of emotion and electrode (*Fs* (52,1092) between 0,6 and 1.2; $p>.1$). The observed main effect of emotion consisted in a parieto-central positivity in positive adjectives when compared to neutral and negative adjectives, as can be seen also in Fig. 7 with ERPs collapsed across correctness. The relative instability and/or small salience of the EPN and LPC components, particularly in sentential contexts, as commented in Experiment 1, might also explain their absence in this second experiment.

3.3. Discussion

Performance data suggest a prominent effect of positive valence, by virtue of which a higher number of incorrect—and to some extent also correct—sentences were classified as correct. This result could be a secondary consequence of the random reallocation of the adjectives to different sentences, a procedure used here to control for important psycholinguistic variables such as frequency of use or concreteness while revoking plausibility and holding cloze probability at zero. The procedure is often used

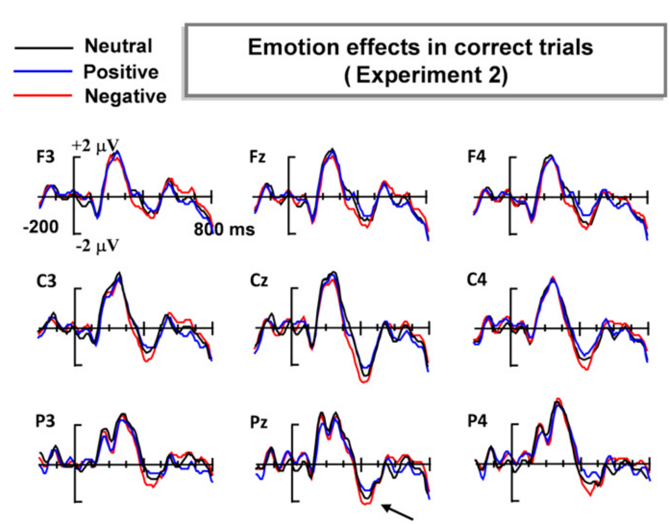

Fig. 6. Effects of emotional valence in Experiment 2 (semantic processing) for correct trials. ERP modulations as a function of emotional valence for correct trials. No differential effects were observed, with the exception of a parieto-central positivity resulting from the positive minus neutral- and negative-trials. This effect can be better seen in Fig. 7.

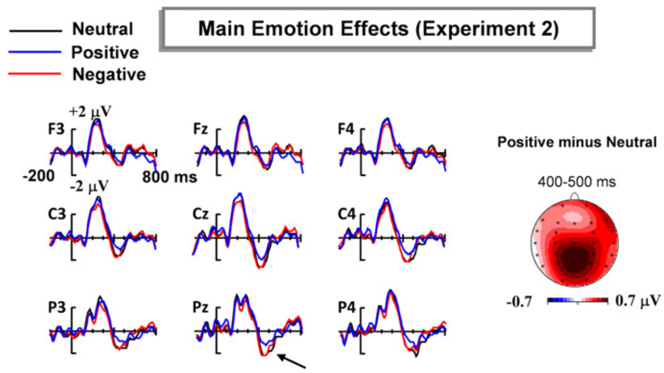

Fig. 7. Effects of emotional valence in experiment 2 (semantic processing). The parieto-central positivity resulting from the positive minus neutral words comparison, interpreted as a possible reduction of the N400 component in positive adjectives. The data collapse both correct and incorrect trials.

in the literature, as it reliably elicits standard N400 effects (e.g., Chwilla, Virgillito, & Vissers, 2011), but the randomization process could have resulted in assigning a relatively larger amount of positive words to sentences in which they might become acceptable. However, if this were the case one might expect equivalent countereffects in the classification rates for neutral and negative adjectives—as they come from the sentences in which positive adjectives were originally acceptable; but this was not the case.

In our opinion, our data can be better explained, in line with the proposal by Isen (1987) outlined above, by a facilitated semantic processing of positive words due to their strong interconnections in the semantic system. In the present experiment, this effect would have been detrimental for performance, biasing responses towards "correct" classifications even for semantically incongruent sentences. This result parallels studies showing reduced error rates and reaction times to emotionally positive words, particularly in semantic decision tasks (e.g., Schacht & Sommer, 2009a). In the present task, where semantic violations are the main feature, this facilitating effect seemed to affect overall correctness judgments, at variance with what we observed in the previous experiment endorsing syntactic anomalies. Emotional information seems therefore to affect semantic judgments but not syntactic ones, harmonizing with the more heuristic character of the semantic system, as compared to the syntactic one (Townsend & Bever, 2001).

The modulations of the N400 to sentential semantic violations appeared unaffected by the presence of concurring emotional information in the violating word. Although slight modulations, particularly of topography, could be observed as a function of the emotional valence, these were not robust enough as to be supported statistically. Variability in the N400 topography is nevertheless not exceptional (Kutas & Federmeier, 2011), and different topographies of the N400 have been shown to be functionally identical to standard centro-parietal N400s (e.g., Voss & Federmeier, 2011).

The emotional effect to positive words (Fig. 7) deserves consideration. It did not resemble the EPN, to which these time windows roughly correspond, rather resembling an LPC instead. However, the LPC usually peaks at about 500 ms, or later, and lasts for several hundred milliseconds (Citron, 2012), typically present for both positive and negative words, even when differing in amplitude (Kissler et al., 2009). Our effect, in contrast, peaked earlier, was relatively restricted in its time-course, and was elicited only by positive words. It is our opinion that this positivity might be better interpreted as an overall reduction of the N400 to all positive adjectives, whether semantically correct or not. Indeed, the N400 component is evoked by every content word regardless of its correctness value (Kutas & Federmeier, 2011), and the result would be in consonance with previous studies reporting an N400 reduction for positive words (Herbert et al., 2008). Again, this interpretation would be in line with the proposal by Isen (1987) of facilitated semantic processing for positive words (cf. Palazova et al., 2011) and in consonance with the performance results obtained in this second experiment, as discussed above.

4. General discussion

The general purpose of the two experiments reported here was to explore the effects of the emotional words on syntactic and semantic processes involved in sentence comprehension. Given the capacity of emotional words to prompt early attentional resources, approximately coinciding in time with earlier ERP indices of syntactic and semantic processing during sentence comprehension (LAN and N400, respectively), we expected that the latter might be affected. Our results showed a LAN increase for syntactically incorrect and emotionally negative words together with a decrease for positive words. On the other hand, the N400 to sentential semantic violations was not noticeably affected as a function of the emotional valence of the violating word. Interestingly, however, a centro-parietal positivity, interpreted as a possible N400 decrease, could be found for emotionally positive words in the semantic experiment irrespective of their sentential correctness. Subsequent linguistic processes, as reflected in the P600, were unaffected in either experiment. Effects on performance were observed for positive words in the semantic condition, where more semantically anomalous sentences were considered as acceptable. The results of the present experiments convey several implications and contribute to a better understanding of how emotional meaning of words in a sentence may modulate the processing of its structure as it unfolds over time.

4.1. Task effects

At variance with most studies using isolated words or words in sentences (e.g., Bayer et al., 2010; Schacht & Sommer, 2009b), we have been able to find effects on ERPs at earlier windows as a function of the emotional valence of the critical word. These effects did not relate to an EPN, however, which was absent in our data, but to effects on the linguistic LAN component. The absence of an EPN was not unexpected, as this is in line with studies using emotional words in sentences (Bayer et al., 2010; Holt et al., 2009). Whereas these studies had not found an EPN, they did find an LPC in subsequent time windows. In contrast, the present study revealed neither EPN nor LPC. Our study differed from previous reports, which could explain these discrepancies. Whereas Bayer and co-workers (Bayer et al., 2010) presented the emotional verbs at sentence-final positions, here correct and incorrect words were emotional adjectives at central positions within the sentences. In contrast to the study reported by Holt et al. (2009), the present tasks required sentence correctness judgments, the critical words varying both in terms of correctness and emotional valence. Strong LPC modulations, including its absence in isolated emotional words, have been reported depending on the task (Carretié, Iglesias, García, & Ballesteros, 1996; Naumann, Maier, Diedrich, Becker, & Bartussek, 1997; Schacht & Sommer, 2009a), suggesting that this component appears to be highly susceptible to experimental manipulations.

Interestingly, task effects seemed to be specific also for our experiments. Indeed, one remarkable result was that the core type of sentential process involved in either experiment (i.e., syntactic, semantic) seemed to determine the nature of main effects of the emotional valence of words during sentence comprehension. These differential effects concern not only linguistic processes involved in sentence comprehension, to be discussed below, but also main effects of emotional valence irrespective of the syntactic or semantic correctness of the word.

In this regard, whereas in the semantic task a reduced centroparietal N400 was elicited by positive words irrespective of their information for sentence structure, in the syntactic task, if anything, an LPC component could be seen irrespective of valence and correctness values, but it was not robust enough as to surpass significance levels. These results seem remarkable considering that the same lexical entries were used as critical words in either experiment (with suffix interchange for the morphosyntactic violations in Experiment 1), and that the sentential contexts preceding these words were also the same, some being interchanged across conditions. It appears, accordingly, that the prevailing type of task performed by the participants determined the type of main ERP modulations related to emotional valence independent of sentence processing. As the emotional valence is part of the lexico-semantic information of a word, it seems consistent that the semantic task has been able to prompt modulations of the semantic N400 component as main emotional effects. This would not have been the case, however, for the syntactic experiment, where the main task belonged to a different domain. Task effects appear therefore critical to explain differences across- and within-studies in the modulations of ERP fluctuations by emotionally valenced words in a sentence, in consonance with previous studies (e.g., Holt et al., 2009).

4.2. Syntactic processing

In Experiment 1 syntactic processes reflected by the LAN have been directly affected by the emotional valence of the critical words, with opposite effects as a function of the concerned valence. Negative words triggered a LAN increase interpreted as reflecting increased difficulties in the syntactic processes related to this component. The effect was explained in terms of attentional resources allocation summoned by the negative valence information of the word. Previous studies have reported that unpleasant words boost more prominent neural response compared to pleasant and neutral words (Carretié et al., 2008; Kanske & Kotz, 2007). Carretié et al. (2008), for instance, found that negative verbal stimuli (insults) capture the attention of the subjects and interfere with their cognitive processes. The increased difficulty of syntactic processes, however, did not noticeably affect final performance results in our experiment.

For the sake of consistency, the LAN decrease observed for positive adjectives should be interpreted as facilitation of syntactic processes, again with no observable effects on behavior. Facilitated processing could be assumed in the frame of the proposal by Isen (1987) that positive material in the semantic system is strongly interconnected. This assumption, however, would imply that semantic information facilitates syntactic processing, which is difficult to reconcile with available psycholinguistic models. As discussed earlier, an alternative explanation might hold if we assume that at least some of the cognitive mechanisms elicited by emotional states might have been initiated by positive words, an assumption based on embodied frameworks of semantic memory. As mentioned, it is possible that positive words within a sentence do not trigger the syntactic processes reflected by the LAN to the same extent than neutral or negative words, biasing instead the use of other types of strategies. Plausibly, the straightforwardness of morphosyntactic violations—particularly in Spanish, where an ending suffix [-s] marks most of plurals—might have been on the base of such a strategy change. This might actually be a case of switching from an algorithmic strategy—syntactic processes—to a rather heuristic one, and appears consistent with evidence that positive emotions increase the preference for heuristic over analytic decision-making strategies (Isen & Means, 1983). The straightforwardness of morphosyntactic violations—at variance with, e.g., semantic violations in the second experiment—might explain why the use of a more heuristic strategy was not detrimental at the performance level.

A relevant finding of the first experiment has been, therefore, the overall impact of emotional information on the syntactic processes reflected in the LAN. This result clearly contrasts with proposals that syntactic processing, particularly in its earlier stages, is encapsulated and largely unaffected by other cognitive operations, syntactic information prevailing in time and affecting semantic processing (Friederici, 2002, 2004). Indeed, our results add to growing evidence conflicting with the dominant syntactocentric view (for a review, see Pulvermüller, Shtyrov, & Hauk, 2009), and are in line with suggestions that under certain circumstances semantic information appears to prevail and modulate syntactic processing (e.g., Martín-Loeches et al., 2006). The present study indicates that the occurrence of emotional words within a sentence might be one of these situations.

4.3. Semantic processing

A main result of the present study has been the apparent insensitivity of the N400 elicited by sentential semantic violations to the emotional valence of the violating word. Interestingly, however, other N400-like modulations appeared to emerge, as is the case of the positivity interpreted as an N400 reduction to positive words regardless of their correctness. Indeed, these fluctuations seemed to coexist with the sentential N400 modulations, without significantly influencing or interacting with them. In consonance with this, Kuperberg (2007) has suggested that the semantic information during sentence processing should be subdivided into associative memory-based semantic relationships on the one hand and semantic–thematic relationships that have implications for sentence structure on the other. Our results would add to these suggestions.

Although emotional effects did not significantly impact semantic sentence processing as typically reflected in the N400 to violations, they apparently did so at later response-decision stages, as reflected in performance. The presence of a positive word seemed to affect the semantic correctness judgment of the sentence in which it was embedded. As discussed earlier, this is possibly a consequence of facilitated semantic processing for positive words (Isen, 1987), entailing higher acceptability rates for semantically incongruent material as well as an apparent reduction of the N400 to both correct and incorrect positive words. An alternative explanation in consonance with our interpretation of the syntactic results, however, could be that some of the mechanisms triggered by long-term emotional states have also been prompted by positive words in the semantic experiment. As already mentioned, positive emotions tend to increase the preference for heuristic strategies (Isen & Means, 1983), facilitating cognitive flexibility and reducing perseverations, by virtue of which subjects may commit more mistakes (Dreisbach & Goschke, 2004; Wiswede, Münte, Krömer, & Rüsseler, 2009). This fits well with increased performance errors as a consequence of judging some semantically anomalous sentences as plausible, as a possible consequence of increased cognitive flexibility.

5. Conclusion

In conclusion, emotional words appeared able to significantly impact the structural processing of the sentence in which they are embedded. This occurred in the syntactic but not in the semantic domain. Whereas syntactic analyses reflected by the LAN appeared hampered for negative words, they seemed diluted for positive words, possibly conveying the use of alternative processing strategies. These effects, however, did not appear notably detrimental for performance. In turn, semantic modulations of emotional valence were observed, but these did not collide with semantic operations related to sentence processing. Nevertheless, they seemed to influence the acceptation rates of semantically anomalous sentences.

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