Affective neurolinguistics: towards a framework for reconciling language and emotion

Hinojosa JA [1,2, 3*], Moreno EM [1], Ferré P [4]

[1] Instituto Pluridisciplinar, Universidad Complutense de Madrid, Madrid, Spain.

[2] Facultad de Psicología, Universidad Complutense de Madrid, Madrid, Spain.

[3] Facultad de Lenguas y Educación, Universidad de Nebrija, Madrid, Spain

[4] Universitat Rovira i Virgili, Department of Psychology and CRAMC, Tarragona, Spain.

*Correspondence:

José A Hinojosa

Universidad Complutense de Madrid

Instituto Pluridisciplinar

Paseo Juan XXIII, 1

Madrid, 28040, Spain

hinojosa@.ucm.es

Tel.: +34 91 394 32 61; Fax: +34 91 394 32 64

This paper is dedicated to the memory of our wonderful colleague, Prof. Albert Costa, who encouraged us to pursue this review and who recently passed away.

Abstract

Standard neurocognitive models of language processing have tended to obviate the need for incorporating emotion processes, while affective neuroscience theories have typically been concerned with the way in which people communicate their emotions, and have often simply not addressed linguistic issues. Here, we summarize evidence from temporal and spatial brain imaging studies that have investigated emotion effects on lexical, semantic and morphosyntactic aspects of language during the comprehension of single words and sentences. The evidence reviewed suggests that emotion is represented in the brain as a set of semantic features in a distributed sensory, motor, language and affective network. Also, emotion interacts with a number of lexical, semantic and syntactic features in different brain regions and timings. This is in line with the proposals of interactive neurocognitive models of language processing, which assume the interplay between different representational levels during on-line language comprehension.

Keywords: Neurolinguistics; Emotion; Neuroimaging; Lexical; Semantics; Syntax

Introduction

In everyday conversations people use language to communicate their feelings or to denote objects, traits and actions that might be dangerous, harmful or pleasant. Given that emotion and language are basic constituents of human experience, it is not surprising that considerable effort has been devoted to the characterization of the neural systems underlying both the linguistic and the affective processes. Strikingly, little is known about the way in which emotional experiences and events are conceptualized and lexicalized in the brain, since the research traditions in neurolinguistics and affective neuroscience have, with a few exceptions, largely ignored each other. There are several possible reasons for this divorce, mainly related to differences in theoretical frameworks and research interests (Jensen, 2014; Majid, 2012; J. J. A. van Berkum, in press-a, in press-b).

On the one hand, neurocognitive affective studies have been concerned principally with the processing of pictorial and facial stimuli, given the biological relevance of these stimuli to human beings. Studies using linguistic stimuli with emotional content are less frequent, which might be related to the indirect symbolic nature of language in signaling emotion. Most of these investigations have been framed within dimensional models that define the affective experience in terms of continuous variations on two main dimensions (Russell, 1980): emotional valence (pleasant or unpleasant) and emotional arousal (low or high degrees of activation). From this perspective, studies using emotional words as stimuli have focused on questions such as exploring the interaction between valence and arousal or disentangling the effects of these variables (e.g., Citron, 2012; Citron, Gray, Critchley, Weekes, & Ferstl, 2014; Delaney-Busch, Wilkie, & Kuperberg, 2016; Espuny et al., 2018; Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009; Recio, Conrad, Hansen, & Jacobs, 2014), contrasting the processing of emotional words, pictures and faces (Bayer & Schacht, 2014; Fruhholz, Jellinghaus, & Herrmann, 2011; Hinojosa, Carretie, Valcarcel, Mendez-Bertolo, & Pozo, 2009; Kensinger & Schacter, 2006; Schacht & Sommer, 2009a; Tempel et al., 2013), or examining task effects to characterize the automatic vs. controlled nature of emotional processes (Flaisch et al., 2015; Hinojosa, Mendez-Bertolo, & Pozo, 2010; Kissler, Herbert, Winkler, & Junghofer, 2009; Schacht & Sommer, 2009b). In addition, few studies using emotional words have sought to test predictions from discrete emotion models (e.g., Briesemeister, Kuchinke, & Jacobs, 2011a, 2011b, 2014; Ferre, Haro, & Hinojosa, 2018; Silva, Montant, Ponz, & Ziegler, 2012), which are those that assume a limited number of discrete emotions (e.g., happiness, anger, sadness, disgust or fear) with characteristic patterns of cognitive appraisals or behavioral action tendencies (Ekman, 1992). Finally, some studies have investigated the predictions of constructionist views of emotion (Brooks et al., 2017), which assume that conceptual knowledge associated with emotional words shapes the perception of specific emotions in a given context (Barrett, Lindquist, & Gendron, 2007). Nonetheless, these theoretical proposals and the aforementioned studies have also examined questions of general interest for affective neuroscience, such as the differences in the processing of words and facial expressions, or the role of language in emotional regulation (Bayer & Schacht, 2014; Cole, Armstrong, & Pemberton, 2010), with little focus on topics of relevance for neurolinguistic theories.

On the other hand, following the proposals made in psycholinguistic models (Grainger & Jacobs, 1996; Mcclelland & Rumelhart, 1981; D. Norris, 2013), neurocognitive studies of language processing have focused on the neural bases of orthographic, phonological, lexical, syntactic, and semantic processes (Carreiras, Armstrong, Perea, & Frost, 2014; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001;

Dien, 2009; Hauk, Davis, Ford, Pulvermuller, & Marslen-Wilson, 2006; Mcclelland & Rumelhart, 1981; Price, 2012), with marginal interest in the effects of emotion on these processing levels. Such indifference might be due in part to the fact that neurolinguistic research has largely been influenced by generative linguistics (Chomsky, 1986) and modular conceptions of the language processing system (J. A. Fodor, 1983; J. A. B. Fodor, A.; & Garrett, F.M., 1974). This view assumes encapsulated processing for different linguistic levels of representation that do not interact with each other or with other cognitive domains. Over recent years, however, evidence has grown that suggests interactive and cascaded processing, in which distinct linguistic representations are processed serially but in interaction with each other via feedback mechanisms (Allen, Smith, Lien, Kaut, & Canfield, 2009; Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Coltheart et al., 2001; Grainger & Holcomb, 2009).

It is within such an interactive approach to language processing that the field of affective neurolinguistics has built bridges between language and emotion, by characterizing the brain signatures underlying the engagement of the emotional features of words at several levels of linguistic operations. As we shall show below, researchers here are mainly concerned with the use of neuroimaging methodologies to address questions such as the conceptualization and encoding of emotional information in the lexicon, the functional locus of emotion effects, or the interaction between emotional features and operations involved in the building of syntactic structures during sentence processing. Although a comprehensive theoretical framework to explain results from studies in affective neurolinguistics is still lacking, novel proposals are emerging for an affective perspective on language processing. In this sense, the Affective Language Comprehension model (ALC; J. J. A. van Berkum, in press-a; J. J. A. van Berkum, in press-b) assumes that the comprehension of emotional language involves psycholinguistic, pragmatic and emotional aspects. Accordingly, in order to parse and understand affective utterances, phonological, orthographic, syntactic and conceptual representations of the linguistic signs are activated. In a further step, the interpretation of the communicative move can only be successfully achieved by taking into account the emotional state of the addressee, as well as contextual aspects partially based on pragmatic cues such as referential, social and communicative intentions.

Here we aim to review the neuroscientific literature on the interface between language and emotion to examine whether affective neurolinguistics might indeed be a fruitful avenue for future research into the interface between language and emotion. To limit the scope of this review we will focus on the effects of emotional information on the comprehension of visually presented single words, sentences and texts. The processing of affective speech has been characterized less thoroughly and indeed studied less often, and when it has been addressed, the focus has mainly been on the integration of verbal and non-verbal linguistic aspects (e.g., prosody: Beaucousin et al., 2007; Ferstl, Rinck, & von Cramon, 2005; S. A. Kotz, Kalberlah, Bahlmann, Friederici, & Haynes, 2013; S. P. Kotz, S., 2011; Kryuchkova, Tucker, Wurm, & Baayen, 2012; Wegrzyn, Herbert, Ethofer, Flaisch, & Kissler, 2017). Also, although some attempts have been made to explore the neural bases of emotion effects on language production (Cato et al., 2004; Hinojosa, Mendez-Bertolo, Carretie, & Pozo, 2010), these studies are very scarce and do not allow for firm conclusions to be established. We also excluded studies on the effects of affective mood on language processing (Chwilla, Virgillito, & Vissers, 2011; Egidi & Caramazza, 2014; Federmeier, Kirson, Moreno, & Kutas, 2001; Hinojosa et al., 2017; J. J. Van Berkum, De Goede, Van Alphen, Mulder, & Kerstholt, 2013; Vissers et al., 2010). Finally, we focused on studies framed within a dimensional view of emotions, that is, those that controlled or manipulated the valence and/or arousal dimensions of emotional features. Thus, we did not consider the results of those few studies that used words belonging to discrete emotions as stimuli, since their main aim was to compare the claims made by dimensional and discrete models of emotion and not to examine the interaction between emotional and linguistic features (Briesemeister et al., 2011, 2014). The goal of this review is twofold. First, to identify the locus of emotional effects during single word processing, by highlighting the interactions between emotional features and lexico-semantic variables and examining the way in which emotional features are represented. Second, to show that the emotional features of words modulate combinatorial operations associated with prediction and integration processes involved in the syntactic and semantic processing of sentences.

Effects of emotion on the processing of isolated words

Behavioral studies have consistently reported effects of emotional features such as valence or arousal on the processing of words presented in isolation (e.g., Kousta, Vinson, & Vigliocco, 2009; Kuperman, Estes, Brysbaert, & Warriner, 2014; Rodriguez-Ferreiro & Davies, 2018; Vinson, Ponari, & Vigliocco, 2014; Warriner, Kuperman, & Brysbaert, 2013). In brief, results from these studies are rather mixed, with some research finding a processing advantage for positive over neutral words (e.g., Kuperman et al., 2014), this also extending to negative words in other studies (e.g., Kousta et al., 2009; Larsen, Mercer, Balota, & Strube, 2008; Vinson et al., 2014). Similarly, an interaction between arousal and valence was reported in some studies whereas a lack of such interaction has also been observed (see Citron, Weekes, & Ferstl, 2014, for an overview). Once emotion effects on word processing have been firmly established, researchers in the field of affective neurolinguistics have been concerned with two important issues. One fundamental question has been to explore the neural correlates of emotion effects on the different levels of representation involved in visual word processing, with the aim of establishing their functional localization (see Palazova, 2014). Another relevant issue has been to examine how emotional word features are represented in the brain. In the following sections, we will review single word studies with a focus on these two aspects.

The locus of emotion effects in language processing

Based on fMRI and ERP data, neurocognitive studies have shown that the processing of linguistic representations involves different brain areas and shows different temporal brain dynamics (Carreiras et al., 2014; Dien, 2009; Hauk et al., 2006; Price, 2012). On these lines, the sublexical processing of orthographic information has been linked to the activation of the visual word form area within the left mid-fusiform gyrus during the first 250 ms (Baker et al., 2007; Dehaene, Cohen, Sigman, & Vinckier, 2005; Schlaggar & McCandliss, 2007). Projections from dorsal and inferior parietal regions – including left angular and supramarginal gyrus – to the posterior portion of the inferior frontal gyrus underlie the processing of phonological features, which takes place between 250 and 350 ms post-stimulus (Carreiras, Vergara, & Barber, 2005; Philipose et al., 2007; Spironelli & Angrilli, 2007; Taylor, Rastle, & Davis, 2013). Finally, lexico-semantic processing between 250 and 300 ms and post-lexical processes at around 400 ms involve the activation of middle and anterior temporal regions (Grainger & Holcomb, 2009; Hauk et al., 2006; Protopapas et al., 2016). However, although most proposals suggest that lexical and semantic processing follow some initial orthographic analysis of the input, there is no consensus on the relative timing of lexical and semantic processing (Hauk et al., 2006) since some studies have reported modulations of lexico-semantic features within the first 200 ms (e.g., Amsel, 2011; Assadollahi & Pulvermuller, 2003; Hauk et al., 2006; Pulvermuller, Shtyrov, & Hauk, 2009; Sereno, Rayner, & Posner, 1998). Hence, semantic effects might appear much earlier than the timing assumed by traditional models of visual word recognition through a feedback mechanism from semantics to orthography (Yap & Seow, 2014).

Research in affective neurolinguistics has tried to establish the locus of emotion effects in language processing (i.e., pre-lexical, lexico-semantic or post-lexical). To this end, two strategies have been followed. The first has focused on comparing the time-course of emotion effects with that expected for language processing stages, and to examine whether the emotional features of words activate brain regions involved in language processing. A second strategy is based on the orthogonal manipulation of emotional content and other lexico-semantic factors. We will now review the main findings of these two lines of research. The terms “emotional content”, “emotional words” or “emotion effects” denote the combined effects of arousal and valence, since most studies do not examine the specific contribution of these two dimensions. Nonetheless, there is both direct and indirect evidence that points to a differential impact of valence and arousal in the processing of emotional words.

The relationship between emotional content and language-processing stages

A number of studies have aimed at identifing the ERP components linked to the processing of the emotional content of words. The aforementioned timing of the processing stages involved in word processing suggests that emotion effects within the first 200 ms would be pre-lexical or lexical. This would indicate that emotional properties are processed before (or in parallel with) the identification of a sequence of graphemes, being part of the lexical representation of words (i.e., the form of the words). In contrast, effects at later time windows would suggest that the effects of emotion are lexico-semantic or post-lexical and might possibly be linked to the retrieval of semantic representations (Kissler, Herbert, Peyk, & Junghofer, 2007).

The results of several ERP studies suggest that at least some aspects of the emotional properties of words are processed in parallel with or prior to accessing the representation of word forms. Accordingly, enhanced amplitudes for emotional relative to neutral words have been observed within 150 ms after word onset using different tasks. These effects include P1 modulations between 80 and 120 ms (lexical decision task, LDT: Bayer, Sommer, & Schacht, 2012; Hofmann et al., 2009; Ortigue et al., 2004; Scott, O'Donnell, Leuthold, & Sereno, 2009) (silent reading: Keuper et al., 2014), N1 modulations around 100 ms (LDT, Scott et al., 2009; silent reading, Kissler & Herbert, 2013) and N170 modulations at around 170 ms (LDT, Yao et al., 2016) (rapid serial visual presentation task, Zhang et al., 2014) (color naming task, Fruhholz et al., 2011). Of note, although most studies found similar modulations for both positive and negative words, these effects were restricted to negative words in some studies (Scott et al., 2009; Yao et al., 2016; Zhang et al., 2018). This negativity bias has been interpreted as reflecting the preferential capture of attention by negative content (i.e., the so-called Automatic Vigilance Hypothesis, Ohman & Mineka, 2001), or an adaptive advantage to initially, rapidly and selectively process negative information (the Appraisal theory, Grandjean & Scherer, 2008; Kissler & Herbert, 2013). However, the results of large-scale regression analyses challenge this view, since they show that this negative bias might be attributed to a failure to control lexico-semantic variables such as age of acquisition, familiarity, concreteness or imageability (Kousta et al., 2009). Also, the fact that the negative words used in several studies are often longer and less frequent (although not significantly so) than neutral and positive words is problematic for this view (Kissler & Herbert, 2013; Larsen, Mercer, & Balota, 2006). Finally, it has also been suggested that negative words have higher standard deviations relative to positive words (some people consider the word *naked* as negative while others consider it to be positive; Larsen, et al., 2008). Thus, it seems that the early processing advantage restricted to negative words in prior studies might reflect a lack of control of variables such as familiarity or age of acquisition.

Two alternative explanations have been proposed based on either learning or linguistic mechanisms to account for early emotional effects. Several findings indicate that early emotional modulations might be the consequence of associative learning arising from the concurrent exposure of word forms and emotional connotation (Hinojosa et al., 2015; Keuper et al., 2014; Palazova, Mantwill, Sommer, & Schacht, 2011). Accordingly, some studies found that pseudowords that were previously associated with affective valence relative to new pseudowords elicited diminished negative amplitudes between 80 and 120 ms in a LTD task (Fristch & Kuchinke, 2013), as well as enhanced P1 in an old-new recognition task (Bayer, Grass, & Schacht, 2018). In a similar vein, in a LDT study Kuchinke et al. (2014) reported P1 effects for emotional words only when they were presented in a familiar font, which suggests that contextual learning of emotional connotations may involve visual features. Of note, effects in these three studies were restricted to negative words, in that there were no positive stimuli (Fritsch & Kuchinke, 2013; Kuchinke et al., 2014) or they did not show any effect at all (Bayer et al., 2018). Interestingly, the results from a study in which participants had to identify positive, negative and neutral words that were presented as paired with pseudowords on either the left or the right visual fields for 13 ms suggested a neural origin for the P1 emotional effects in bilateral occipital cortices (Ortigue et al., 2004). Activity in these brain areas was linked to the activation of mnemonic templates representing emotional features of words based on learned associations with past experiences. However, the short duration and the lateralization of stimuli presentation might have biased participants to adopt a fast strategy for the processing of linguistic stimuli that does not require a lexico-semantic processing of the words. In fact, two studies that used longer stimuli durations and a centered presentation of the words (Hofmann et al., 2009; Keuper et al., 2014) found that P1 emotional effects were generated in left occipito-temporal areas, including the middle temporal gyrus (MTG) and the fusiform gyrus. Considering that these brain regions have previously been linked to lexico-semantic processing (Price, 2000), the results of these studies argue for an interpretation of P1 emotion effects in terms of speeded lexical access and/or semantic activation. Thus, it seems that the involvement of different brain regions in early effects of emotional content critically depends on the processing demands imposed by the words.

In contrast, effects of emotional features during lexico-semantic processing have been more consistently reported (for reviews see Citron, 2012; Palazova, 2014). Early Posterior Negativity (EPN) shows larger amplitudes for emotional words relative to neutral ones, with an onset at around 200-300 ms (e.g., LTD: Citron, Weekes, & Ferstl, 2013; Palazova et al., 2011; Scott et al., 2009; Schacht & Sommer, 2009b; Xu, Kang, Sword, & Guo, 2017) (silent reading: Kissler et al., 2007; Kissler et al., 2009). The EPN has been located at a lexico-semantic processing stage (Citron, 2012; Kissler, Assadollahi, & Herbert, 2006). It is thought to reflect possibly automatic and task-independent attention allocation to the intrinsically relevant emotional features of words. Current evidence suggests that these processes are arousal-driven, since most studies observed similar EPN amplitude enhancements for positive and negative words relative to neutral words (e.g., Herbert et al., 2008; Kissler et al. 2007; see also Kissler et al., 2006 and Citron, 2012). A different view argues that the EPN could be linked to a general ‘‘emotionality’’ effect in which valence is integrated with arousal during emotion processing (Citron, 2012; (C. J. Norris, Gollan, Berntson, & Cacioppo, 2010 for similar theoretical claims from the evaluative space model). The results from those few studies that orthogonally manipulated valence and arousal show that around the onset of the EPN, arousal preceded valence effects in some studies (Recio et al., 2014) whereas valence was processed earlier than arousal in others (Gianotti et al., 2008). Some authors have proposed that differences in word duration would account for the prevalence of arousal over valence effects and vice-versa, with short stimulus durations favoring earlier arousal effects that would prepare processing resources for a subsequent assessment of valence (Gianotti et al., 2008). However, current evidence challenges this view, since stimulus were presented for longer durations in Recio's et al study (until response, at around 600 ms on average) than in Gianotti´s et al. study (fixed presentation, 450 ms). Besides using different tasks (LTD versus passive reading), an important difference between these studies is that words were assigned to three categories of arousal (high, low and medium) in the former, whereas only high- and low-arousal words were presented to participants in the latter. This suggests that a more fine-grained differentiation in arousal levels of the words might have directed attentional resources to this dimension, resulting in a processing advantage for the arousal over the valence dimension.

A second component, the Late Positive Component (LPC), peaks between 500 and 800 ms at centro-parietal electrodes and indexes more elaborated or sustained processing of emotional features (e.g., Carretie et al., 2008; Herbert, Junghofer, & Kissler, 2008; Herbert, Kissler, Junghofer, Peyk, & Rockstroh, 2006; Schacht & Sommer, 2009b). This component is sensitive to the valence dimension (Fischler & Bradley, 2006; Herbert et al., 2006; Hinojosa, Mendez-Bertolo, & Pozo, 2010; Kissler et al., 2009; Schacht & Sommer, 2009b). However, there are some inconsistencies in the direction of these effects, in that some studies found larger LPC amplitudes for positive than negative words (Herbert, Junghöfer, & Kissler, 2008; Kissler, Herbert, Winkler, & Junghöfer, 2009) whereas an opposite pattern was observed in others (Hofmann et al., 2009; Schacht & Sommer, 2009b). Differences in arousal values between the words used in different studies might account in part for opposite valence effects. In this sense, low levels of arousal might facilitate the processing of positive valence through the activation of the approach system, whereas high levels of arousal would activate the withdrawal system, thus favoring the processing of negative valence (Kissler et al., 2006; Robinson, Storbeck, Meier, & Kirkeby, 2004). In line with this view, after standardizing the arousal scores from some studies to a 9-point scale, we observed that arousal values for emotional words in those studies showing enhanced LPC amplitudes for positive scores were lower (e.g., on average, 5.6 in Herbert et al., 2008 and 5.51 in Kissler et al., 2009) than in studies reporting larger LPC amplitudes for negative words (on average, 6.03 in Hofmann et al., 2009 and 6.48 in Schacht and Sommer, 2009b)[1]. The LPC is also modulated by the task demands. Thus, enhanced LPC effects on emotional words have been observed in tasks that involve some degree of lexico-semantic processing, whereas these effects vanished in structural tasks that require rather shallow language processing (Fischler & Bradley, 2006; Hinojosa, Mendez-Bertolo, & Pozo, 2010; Schacht & Sommer, 2009b).

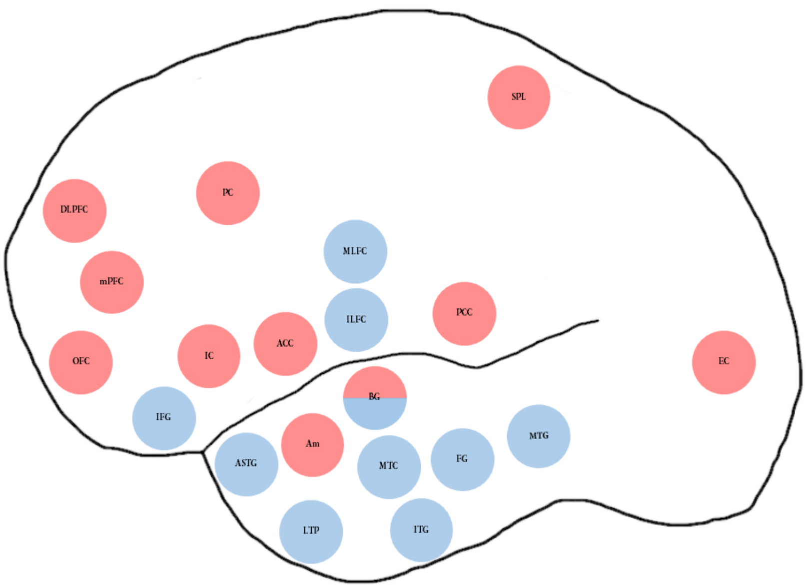
Finally, a third component is worth mentioning: the so-called N400. Some studies found that emotional words, compared to neutral ones, elicited smaller amplitudes in a centro-parietal negativity peaking around 400 ms, (Gootjes, Coppens, Zwaan, Franken, & Van Strien, 2011; Palazova, Sommer, & Schacht, 2013; Sass et al.,

[1] Valence and arousal scores are typically measured through the Self-Assessment Manikin (Bradley & Lang, 1994), which is composed of 9 points accompanied by characters depicting the different anchor points (valence: from extremely negative (1) to extremely positive (9); arousal: from extremely calm (1) to extremely energized (9)). Instead, the studies by Hofmann et al. (2009) and Schacht and Sommer (2009b) used a 7 point scale. Therefore, to allow a direct comparison with the studies by Herbert et al. (2008) and Kissler et al., (2009) we converted ratings from these studies to a 9 point scale.

2010; Zhang et al., 2014). Since larger N400 amplitudes during single word processing indicate increased difficulty in the processing of semantic features (Kutas & Federmeier, 2011), the results of these studies suggest that the processing of emotional features is facilitated at the semantic and post-lexical levels. In line with ERP findings, the results of fMRI and PET studies with explicit (e.g., emotion judgements) and implicit (e.g., LDT; Stroop tasks, silent reading) tasks suggest that emotional words, relative to neutral ones, exhibit increased activation in brain areas associated with different aspects of the processing of lexical and semantic features, including the fusiform gyrus (Herbert et al., 2009; Kensinger & Schacter, 2006; Maddock, Garrett, & Buonocore, 2003), the middle temporal gyrus (Beauregard et al., 1997; Kensinger & Schacter, 2006), the left-temporal pole (Schlochtermeier et al., 2013), the inferior temporal gyrus (Beauregard et al., 1997; Herbert et al., 2009; Kensinger & Schacter, 2006), and the inferior and middle left frontal cortices (Kuchinke et al., 2005; Maddock et al., 2003). Remarkably, in agreement with the neural re-use perspective (Anderson, 2010), the processing of emotional features of words also involves activations in a set of brain regions associated with emotional evaluation and memory that include portions of the prefrontal cortex (i.e., orbital, medial and dorsolateral prefrontal cortices, Herbert et al., 2009; Kensinger & Schacter, 2006; Kuchinke et al., 2005; Lewis, Critchley, Rotshtein, & Dolan, 2007; Straube, Sauer, & Miltner, 2011), the anterior (Beauregard, Benhamou, Laurent, & Chertkow, 1999; Kuchinke et al., 2005; Schlochtermeier et al., 2013) and posterior cingulate cortex (Maddock et al., 2003), the insula (Citron, Gray, et al., 2014; Lewis et al., 2007), the superior parietal lobe (Chen, Lin, Chen, Lu, & Guo, 2015; Herbert et al., 2009), the extra-striate cortex (Beauregard et al., 1997; Herbert et al., 2009) and the amygdala (Hamann & Mao, 2002; Herbert et al., 2009; Isenberg et al., 1999; Kensinger & Schacter, 2006). Thus, the results from fMRI and PET studies reviewed here indicate that the processing of the emotional features of words entails brain regions involved in both lexico-semantic and affective information processing. Figure 1 shows the brain regions that have been shown most consistently to be activated in prior research.

From these studies, a clear pattern in the contribution of valence and arousal to emotional effects cannot be reliably established, since the activation of these brain areas was modulated by either valence (Herbert et al., 2009; Kuchinke et al., 2005) or arousal (Kensinger & Schacter, 2006; Schlochtermeier et al., 2013). However, two fMRI studies explicitly aimed to explore the contribution of valence and arousal dimensions to the processing of emotional words, although they had important methodological differences in terms of stimuli, control for psycholinguistic variables, task demands and the approach followed for analyzing data. In the first of these studies, Lewis et al. (2007) presented positive and negative words with different levels of arousal to participants, who indicated whether each word could be used to describe themselves. The aim of this study was to characterize the functional neuroanatomy supporting the processing of valence and arousal, as well as to test different models of valence (U-shape, linear or independent relationships). Orbitofrontal regions were activated in response to valence. Also, district orbitofrontal activations were observed in association with either negative or positive valence (independent models), as well as with shared activity (U- shaped models). Finally, responses in the amygdala, the insula and the basal ganglia were associated with the processing of arousal (Lewis et al., 2007). By contrast, Citron et al. (2014) used a LDT to orthogonally manipulate the valence and arousal levels of words that were matched in terms of a higher number of linguistic variables, such as word familiarity, age of acquisition and imageability. They found that these dimensions were processed in an interactive way in the insula and extra-striate cortices

(Citron et al., 2014). Despite the crucial methodological differences in these studies, fMRI data indicates that emotional valence and arousal constitute distinct dimensions. Although both dimensions interact in a complex way, valence would seem to have a higher impact in more cognitively demanding processing systems, whereas arousal would impact to a greater extent on perceptual and physiological levels (Citron, 2012; Nicolle & Goell, 2013).



As we have shown, emotional content influences several word processing stages and recruits the activation of brain areas underlying different linguistic and affective processes. Early latency and EPN effects could be particularly suitable candidates for establishing the pre-lexical, lexico-semantic or post-lexical nature of such influences. Unfortunately, the inconsistent modulations found in early effects (e.g., P1, N1) do not allow any firm conclusions to be drawn. Also, data from fMRI studies show activation in brain areas underlying both lexical (e.g., the fusiform gyrus (Herbert et al., 2009; Kensinger & Schacter, 2006; Maddock et al., 2003) and semantic processes (e.g., middle temporal gyrus; (Beauregard et al., 1997; Kensinger & Schacter, 2006). In order to shed light on this question, a different approach has been used, in which the relative onsets for the processing of emotional and lexical features are compared. These studies have focused on lexicality effects (i.e., the comparison between words and pseudowords) and frequency effects (i.e., the comparison between high and low frequency words). Most LDT studies with ERPs reported that emotion effects show a delay onset compared to the onset of the differences between words and pseudowords (Palazova et al., 2011, 2013; Schacht & Sommer, (2009b) or frequency effects (Palazova et al., 2011), indicating that the processing of emotional properties follows lexical processing. Interestingly, the relative timing of lexicality and emotional effects is modulated by grammatical class with differences between noun/adjectives and verbs (Palazova et al., 2011), although some caution is required in interpreting these results, since compared with other studies, a rather small set of 10 words was repeated 4 times. By contrast, in a passive reading study, lexicality effects for emotional words precede those for neutral words, which suggests that emotional features speeded lexical access (Kissler & Herbert, (2013). Also, as we will show later, there is ERP evidence from a LDT indicating that the emotional content interacts with word frequency effects by the time of lexical access (Scott et al., 2009); (see also Scott, O'Donnell, & Sereno, 2012 for behavioral evidence; 2014).

Some conclusions might be drawn from the data reviewed here. First, there is no strong evidence for a pre-lexical locus of emotion effects. On these lines, several studies failed to find modulations of early-latency ERP components by emotion (Bayer & Schacht, 2004; Kaltwasser et al, 2013; Kissler et al., 2009; Palazova et al., 2013; Ponz et al., 2013; Recio et al., 2014; Schacht & Sommer, 2009; Yao et al., 2016). Also, those studies reporting emotion effects on early-latency components concluded that these might be attributed to associations between word forms and emotional content during language acquisition rather than to pre-lexical effects (Hinojosa et al., 2015; Keuper et al., 2014; Palazova et al., 2011). Interestingly, early effects have mostly been found for negative words. A second conclusion that might be drawn from the ERP studies reviewed here is that the first sign of reliable linguistic processing of emotional content occurs during lexico-semantic processing stages (Palazova et al., 2011, 2013). In agreement with these findings, several fMRI studies observed activations in brain areas underlying lexico-semantic processing (Beauregard et al., 1997; Kensinger & Schacter, 2006). Additionally, the most consistent early effects of emotion arise on the EPN. Emotional effects on this component have been reliable observed with a variety of tasks involving different processing demands (e.g., LTD, silent reading, counting tasks,…). Notably, the EPN peaks between 200 and 300 ms, a timing that resembles that for the access to lexical representations (Grainger and Holcomb, 2009; Kissler et al., 2006). Following EPN effects, the emotional content also influences subsequent post-lexical processes as indexed by modulations on the N400 and the LPC components, which are sensitive to task demands. In sum, ERP and fMRI evidence favors a lexico-semantic locus of emotion effects rather than a pre-lexical locus. As we shall see in the next section, additional support for this view comes from studies that made orthogonal manipulations of emotion and other linguistics variables.

The relationship between emotional content and lexico-semantic variables

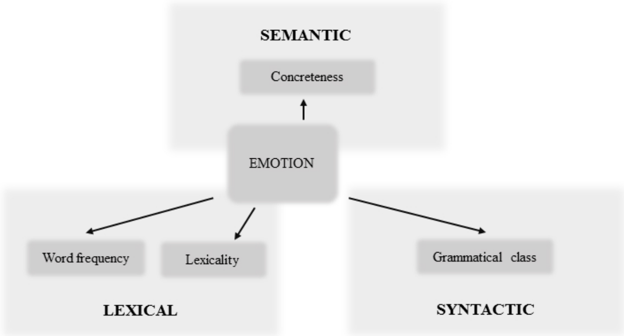
A series of studies have manipulated emotional content orthogonally to either lexical or semantic variables (see Figure 2). The logic here is that an interaction between factors may indicate a common locus of effects (Sternberg, 2011). Several LDT studies have focused on word frequency, which is a widely acknowledged lexical variable (Mendez-Bertolo, Pozo, & Hinojosa, 2011; Nakic, Smith, Busis, Vythilingam, & Blair, 2006; Palazova et al., 2011; Scott et al., 2009). Behavioral and neural data mainly suggest that emotion effects are larger in Low Frequency words (LF) than High Frequency words (HF), although emotional modulations in the processing of HF have also been found. In this sense, most studies observed faster RTs for positive and negative LF words, or a lack of RTs differences between negative and neutral HF words (Scott et al., 2009, 2014). Converging behavioral evidence comes from a LDT study (Scott et al., 2014), a megastudy involving a large quantity of words (Kuperman et al., 2014), and eye-tracking studies that manipulated word frequency in emotional words embedded in sentences (Scott et al., 2012; Sheikh & Titone, 2013); (but see, Kuchinke, Vo, Hofmann, & Jacobs, 2007, for a lack of effects with pupil responses). Neural evidence comes from a fMRI study that found greater activations in the cingulate cortex, the middle temporal cortex, and the amygdala for negative compared to neutral words (no positive words were included) in a LDT (Nakic et al., 2006). HF compared to LF words activated the inferior frontal gyrus (IFG) to a greater extent. Importantly, an interaction between emotion and word frequency was observed, since negative compared to neutral HF words activated the IFG to a lesser extent. The authors argued that the semantic representation of HF negative words receives reciprocal feedback from the amygdala, which makes a high level of activation of the IFG to achieve task requirements unnecessary. Of note, given the poor temporal resolution of fMRI, it is not possible to establish whether feedback mechanisms are related to early lexical or to late post-lexical processing stages. Effects of emotional content in both HF and LF words have also been found in ERP studies with LDTs. Scott et al., (2009) reported an early latency interaction between emotion and word frequency. In particular, HF negative words elicited smaller P1 amplitudes compared to all the other experimental conditions. Also, enhanced N1 amplitudes were found for HF relative to LF negative words. Finally, both negative and positive HF words elicited larger EPN amplitudes compared to HF neutral words. Although restricted to LF positive stimuli, Palazova et al. (2011) also observed an early-latency interaction, with LF relative to HF positive words showing increased amplitudes between 100 and 150 ms. Interestingly, effects in the same direction between 500 and 550 ms were found in this study, which also interacted with word class. In a similar vein, Méndez-Bértolo et al. (2011) reported long-latency effects of around 450 ms showing higher amplitudes for LF negative compared to LF neutral words (no positive words were included in this study).

Some authors have claimed that early word frequency effects reflect access to the lexical representation of words (the so-called "encoding hypothesis; Sereno & Rayner, 2003) whereas effects at late processing stages have been linked to response selection operations (the "decision hypothesis"; McCann, Remington, & Van Selst, 2000). While the studies reviewed here indicate that the interaction between word frequency and emotion occurs at both processing stages, the construction of the pseudowords used in LDTs might be a critical aspect that can account for discrepancies in the results. There is evidence suggesting that lexical decisions are more likely to rely on post-lexical strategies, in that the resemblance of pseudowords to words increases due to the greater difficulty in discriminating between these stimuli (Balota & Chumbley, 1985; e.g. transposing the syllables of the target words, as in Méndez-Bértolo et al., 2011, which contrasts with the absence of these constraints in creating pseudowords in Scott et al., 2009). Another issue involves discrepancies in emotion effects in either LF or HF words. The lack of a control of concreteness in some studies (e.g., Nakic et al., 2006; Scott et al., 2009) might partly explain differences between studies here. In this sense, interactions between word frequency and concreteness effects have been observed (i.e. concretness effects are only found in LF words; Davies & Funnell, 2000). Interestingly, emotion effects in HF words were reported in those studies that did not match stimuli for concreteness (Nakic et al., 2006; Scott et al., 2009), whereas these effects were found for LF words in those studies that have controlled for this variable (Méndez-Bértolo et al., 2011; Palazova et al., 2011). Additionally, as we will see in what follows, concreteness also interacts with the emotional content of words, which might also explain the distinct pattern of results.

Concreteness is a semantic property that indicates the extent to which a word refers to features of objects or persons that can be experienced with the senses (Paivio, Yuille, & Madigan, 1968; Palazova, 2014). Only a few studies have orthogonally manipulated emotion and concreteness. Behaviorally, larger emotion effects in abstract words relative to concrete ones have been reported (Ferré, Ventura, Comesaña, & Fraga, 2015; Palazova et al., 2013; Ponari, Norbury, & Vigliocco, 2018; Yao et al., 2016; but see Kanske & Kotz, 2007; Yao et al., 2018). In agreement with these findings, the results of ERP studies also showed a close relationship between emotional content and the processing of abstract words. In this vein, to examine the role of valence and reward expectation in emotional word processing, Kaltwasser et al. (2013) presented positive, neutral and negative abstract and concrete nouns preceded by a cue indicating that performance could lead to monetary loss or gain. Participants had to indicate whether the words denoted abstract or concrete concepts. The authors found that between 400 and 700 ms emotional effects were more pronounced in abstract relative to concrete words, with both positive and negative abstract words eliciting enhanced amplitudes in comparison to neutral abstract words. This finding has been further replicated in an emotion categorization task for negative abstract nouns (Hinojosa, Albert, Lopez-Martin, & Carretie, 2014). In contrast, Kanske and Kotz (2007) reported emotion effects in concrete nouns relative to abstract ones, when participants were asked to identify pseudowords that were presented on the left or right visual hemifields (Exp. 2).

Concrete negative words elicited enhanced LPC amplitudes compared to concrete positive and neutral words. Interestingly, this difference disappeared when participants had to respond to words instead of pseudowords (Exp. 1). Also, in a LDT Palazova et al. (2013), reported that only concrete positive and negative verbs elicited enhanced EPN amplitudes compared to neutral verbs, whereas larger LPC effects for emotional verbs relative to neutral ones were observed in both abstract and concrete words. Differences in the latency of the emotional effects in concrete words across studies might be attributed to the hemifield versus the central presentation of the stimuli, differences in the proportion of neutral-emotional words (1/2 - 1/2 in Kanske & Kotz, 2007; 1/3 – 2/3 in Palazova et al. 2013), as well as to the use of different word categories (nouns in Kanske & Kotz, 2007; verbs in Palazova et al. 2013). Overall, the literature reviewed here suggests that the interplay between emotion and concreteness is modulated by task demands (Kanske & Kotz, 2007). Emotional effects in abstract words were mainly found in those studies that required semantic judgements (Hinojosa et al., 2014; Katwasser et al., 2013) whereas effects in concrete words occurred when the focus was on lexical aspects (Kanske & Kotz, 2007; Palazova et al., 2013). These inconsistent results might be interpreted in light of prior findings showing that associative linguistic information (i.e., emotional features) is more critical for the processing of abstract than concrete words (Crutch & Warrington, 2005; Danguecan & Buchanan, 2016). Thus, tasks emphasizing explicit semantic processing may be better at facilitating access to the emotional properties of abstract words compared to tasks that do not require explicit semantic processing (e.g., LDT; Pexman, Hargreaves, Edwards, Henry, & Goodyear, 2007).

Figure 2 shows a summary of the interactions between emotional features and lexico-semantic variables reported in prior studies. The results of the studies that manipulated orthogonally lexical and semantic variables point to a lexico-semantic locus of emotion effects. On these lines, although early latency effects have been observed (Scott et al., 2009), most studies reported a reliable interaction between emotional content and both word frequency and concreteness at middle- (EPN) and long-latency (LPC) ERP components (Hinojosa et al., 2014; Kaltwasser et al., 2013; Kanske & Kotz, 2007; Méndez-Bértolo et al. 2013; Palazova et al., 2011, 2013), which reflects access to the semantic representation of words and post-lexical processing stages (Grainger & Holcomb, 2009). Thus, we suggest that emotional content is a conceptual attribute that contributes to the semantic richness of words (Yap & Seow, 2014), like some other aspects, such as the number of semantic features (McRae, Cree, Seidenberg, & McNorgan, 2005), the number of meanings (Haro, Comesaña, & Ferré, in press), or sensory experience (Juhasz & Yap, 2013). Some of these variables have been shown to affect lexical and orthographic processing through feedback mechanisms (Haro et al., in press). Thus, similar feedback mechanisms could also explain emotion effects in both lexical and pre-lexical processing stages (e.g., the interaction between emotion and word frequency, Palazova et al., 2011; Scott et al., 2009). The question as to whether emotional content shares some processing characteristics with other semantic features like concreteness is also relevant. Current data argues against this possibility, since the processing of emotional features precedes concreteness effects (Kanske & Kotz, 2007; Palazova et al., 2013). Thus, emotion might be viewed as the first semantic feature retrieved from semantic memory during word processing, possibly due to its biological significance (Kisslet et al., 2006; Palazova et al., 2014). Nonetheless, research investigating how emotional features are represented in the brain might be of some help in order to arrive at a more comprehensive view of the relationship between emotion and other semantic features. In the next section, we will examine this question further.



The representation of emotional content in the brain

Some neuroimaging studies within embodied approaches to language processing have explored the relationship between emotion and other semantic properties in an attempt to characterize the representation of the emotional content of words in the brain. One line of research has linked emotional content to abstractness. An alternative view has focused on the pattern of brain activations specifically associated with the processing of emotion-label words (i.e., words referred to emotional states, Pavlenko, 2008) in comparison to abstract words. The first of these approaches assumes that meaning representation in concrete and abstract words is based on experiential (i.e., sensory, motor and affective information) and linguistic (i.e., verbal associations resulting from co-occurrence patterns) information (Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Vigliocco G., 2009). Crucially, while sensorimotor associations based on experience with the external world predominate in the representation of the meaning of concrete words, the meaning of abstract words is mainly grounded in linguistic and internal affective experience. Evidence supporting this view comes from the results of regression and hierarchical clustering analyses showing that abstract words tend to be more emotionally loaded than concrete words (G. Vigliocco et al., 2014) and that emotional valence is a relevant organizing principle for abstract words (Crutch, Troche, Reilly, & Ridgway, 2013). Moreover, the results of some studies suggest that affective content might provide a bootstrapping mechanism for the acquisition of abstract words during childhood (e.g., Kousta et al., 2011; Ponari, Norbury, & Vigliocco, 2018) and during the first stages of second language acquisition (Ferré et al., 2014).

A prediction derived from the proposal of Vigliocco and co-workers is that emotional content should affect the processing of abstract words to a greater extent than the processing of concrete words. As we have shown above, some studies found larger emotional effects for (or restricted to) abstract words (Ferré et al., 2014; Hinojosa et al., 2014; Palazova et al., 2013; Ponari et al., 2018). Recently, Yao and co-wokers (2016) manipulated orthogonally the valence and the arousal of concrete (Experiment 1) and abstract words (Experiment 2) in a LDT. A valence effect was found in Experiment 1, since positive compared to negative and neutral words showed reduced N400 and larger LPC amplitudes. Valence effects for the N400 were replicated in Experiment 2, although an early interaction between valence and arousal was also reported in the 40-200 ms time window (N170). In particular, only negative abstract words with high arousal (but not positive words) elicited larger N170 amplitudes than negative abstract words with low arousal. An interaction was also observed in the LPC, with enhanced amplitudes for positive abstract words with high arousal (but not negative words) compared to positive abstract words with low arousal. In agreement with the proposal of Vigliocco et al. (2009) the lack of arousal effects in concrete words might reflect the low degree of affective associations between sensorimotor information and arousal in concrete relative to abstract words.

Another prediction that can be derived from the proposal of Vigliocco and colleagues is the involvement of similar neural systems in the processing of emotional and abstract concepts. This prediction was tested in two fMRI studies. In a LDT experiment, Vigliocco et al. (2014) examined the processing of concrete and abstract words that were matched for several variables, but not for affective properties (i.e., abstract words showed more extreme valence scores and were more arousing than concrete words). Increased activation in the rostral anterior cingulate cortex (rACC) was found for abstract compared to concrete words. Furthermore, the degree of activation of this brain region was modulated by hedonic valence (i.e., the distance from neutrality regardless of whether the word is positive or negative). The rACC regulates the processing of emotional stimuli in conflicting situations, and thus it seems to be part of the cortical network engaged in emotion processing (e.g., Etkin, Egner, & Kalisch, 2011; Kanske & Kotz, 2011). These findings provide evidence of a link between the processing of abstract concepts and emotion processing. In a further fMRI study, Skipper and Olson (2014) claimed that the differential activation of the rACC by concrete and abstract words observed by Vigliocco et al. (2014) could possibly be due to the mismatching of the two sets of words in terms of affective properties. To overcome these limitations the authors orthogonally manipulated concreteness and hedonic valence in a task in which participants had to think deeply about the concepts described by the words. Again, activation of the rACC to hedonic valence was found, although concrete words activated this region to a greater degree than abstract words. These findings suggest that the rACC is sensitive to emotional stimuli but it is not involved in the emotional grounding of abstract concepts. However, some caution is required when comparing the results of these studies, given the important methodological differences here. In this sense, Vigliocco and co-workers considered a number of additional variables such as imageability, context availability, familiarity, age of acquisition, and mode of acquisition that were not controlled in Skipper and Olsson (2015). As already noted, some of these variables play a critical modulatory role in the processing of emotional words.

An alternative account that seeks to characterize the neural representation of emotion words is the Action-Perception Theory proposed by Pulvermüller and colleagues (Moseley, Carota, Hauk, Mohr, & Pulvermuller, 2012; Pulvermuller, 2013a, 2013b; Pulvermuller & Fadiga, 2010). These authors pointed out that most research on the neural basis of emotional word processing has examined words with an emotional connotation (i.e., emotion-laden words), generally referring to events or objects in the world. Instead, brain activity elicited by emotion-label words (i.e., words referring to affective states) has not been systematically investigated. To fill this gap, the authors conducted a series of studies in which emotion-label words were considered a special category of abstract words that refer to internal states. According to this approach the neural representation of emotion concepts would involve both the limbic system (which processes the affective experience) and the motor system (which controls body and facial movements used to express emotions, Pulvermuller, 2013a; Pulvermuller, 2013b). Connections between these regions would arise during language acquisition, when children experience and express particular emotions. Once care-givers produce the corresponding emotion word, the meaning is incorporated into the child's semantic system through co-activation of brain circuits involved in the processing of word forms, internal states, and actions (Moseley et al., 2012). Evidence for the Action-Perception Theory comes from an fMRI study that compared the processing of emotion words (verbs related to emotions, e.g. *hate*) to action words (arm and face related verbs, e.g., *grasp, cough*) and to animal names during a silent reading task (Moseley et al., 2012). Although arousal was not matched across conditions in this study, emotion words activated limbic areas such as the insula, the basal ganglia, and the anterior cingulate cortex. Notably, emotion words also activated a large part of the premotor cortex, including the inferior and dorsolateral motor areas. In a further passive reading study, Dreyer and Pulvermüller (2018) found increased activation in motor regions for the processing of abstract emotional words compared to words denoting mental concepts.

The data summarized in this section points to a role for emotional content in the semantic representation of abstract words. Even though abstract words tend to be more emotionally loaded than concrete ones (Vigliocco et al., 2014), it is important to note that emotional words are only a subtype of abstract words that also includes concepts denoting magnitudes, cognitive entities, time periods, and moral and social constructs (Borghi, Barca, Binkofski, & Tummolini, 2018). Therefore, the inconsistent results in the studies reviewed here might reflect differences in the proportion of abstract words belonging to each of these types. Also, there was great variability across studies in terms of the control of linguistic variables, stimuli (emotional-label vs emotional-laden words), imaging designs, and tasks. Nonetheless, the results of the hemodynamic studies that examined the processing of abstract words denoting emotions suggest that the representation of emotional features is supported by a set of distributed brain regions underlying the processing of different linguistic, affective and sensorimotor aspects (Dreyer & Pulvermüller, 2018; Mosseley et al., 2012). A second conclusion that can be drawn from the data is that the reactivation of the internal affective experiences involved during encoding (Kousta et al., 2011) and motor patterns linked to the expression of emotions (Pulvermuller, 2013a) might be crucial aspects for the semantic representation of emotional concepts.

Effects of emotion during sentence processing

In previous sections, we reviewed ERP and fMRI studies that investigated the impact of emotional variables on the processing of words presented in isolation. Most commonly, meaningful lexical items are combined into larger units to form sentences. The process of combining smaller units to form larger units takes place through unification operations. Sentence comprehension entails incremental and dynamic processes that rely on the anticipation or prediction as to what will come next and the integration of lexical-syntactic information into a coherent discourse representation (Hagoort, 2005; Hagoort & Indefrey, 2014; Vosse & Kempen, 2000). Unification is one of the elements that constitute the core of language processing, hence one of the most central elements, and comprises different levels of linguistic representations including semantics, syntax, morphosyntax and phonology. In the following sections we will concentrate on neuroimaging studies that explore the issue of whether emotional content interacts with syntactic and semantic unification processes. No studies have thus far been conducted on the impact of emotion variables during phonological unification processes.

Syntactic unification and emotion

Syntactic unification refers to the set of rules for the construction of sentence or discourse structures. The neuroanatomical circuitry underlying the computation of syntactic structures engages the dorsal pathway within a language network that includes left inferior frontal (i. e., pars opercularis and triangularis) and temporal regions (i.e., the superior and middle temporal gyri) (Bornkessel-Schlesewsky & Schlesewsky, 2013; Carreiras, Quinones, Mancini, Hernandez-Cabrera, & Barber, 2015; Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Hagoort & Indefrey, 2014; Newman, Just, Keller, Roth, & Carpenter, 2003). Current neurocognitive models assume that syntactic information is taken into account at an early point in sentence comprehension, and that the computation of syntactic structures involves at least three processing stages (Bornkessel-Schlesewsky & Schlesewsky, 2013; Grodzinsky & Friederici, 2006; Hagoort, 2005; Hagoort & Indefrey, 2014; L. Osterhout, Kim, A. & G.R. Kuperberg, 2012; Tyler et al., 2011; G. Vigliocco, 2000). First, an initial processing of local phrase structure based on lexical category information occurs. In a subsequent feature-checking stage, the computation of dependency relations between constituents at the sentence level takes place. Finally, an interpretation of the feature-consistent syntactic object is assigned and the current word is integrated within the previous discourse context based on both semantic and syntactic cues. Also during this phase, repair and reanalysis operations are performed whenever needed. Three ERP components have been suggested to index each of these processing stages, respectively: an early left anterior negativity peaking at between 100 and 300 ms (ELAN; e.g., Friederici et al., 2003; Lau, Stroud, Plesch, & Phillips, 2006; Steinhauer & Drury, 2012), a left anterior negativity in the time-window between 300 and 500 ms (LAN; Hagoort, 2003; Hinojosa, Martin-Loeches, Casado, Munoz, & Rubia, 2003; Molinaro, Barber, & Carreiras, 2011) and a late posterior positivity that starts at around 500 ms (P600; Kuperberg, 2007; L. Osterhout & Holcomb, 1992; L. Osterhout & Nicol, 1999).

To date, only a few studies have examined the interplay between emotion and syntactic unification processes. These have explored the effects of emotional properties on the processing of agreement dependencies between sentence constituents. Agreement might be defined as “the covariation of the inflectional (functional) morphology between related words” (Molinaro et al., 2011, p. 908). A unification process combines incoming words and constituents with an unfolding partial phrase marker based on the variation of *formal* features such as number, gender or person (Carreiras et al., 2015; Hagoort, 2005; Wechsler, 2008). Using tasks in which participants judged sentence grammaticality, neuroimaging studies have reported valence effects in the temporal brain dynamics of the processing of number (Martin-Loeches et al., 2012) and gender (Diaz-Lago, Fraga, & Acuna-Farina, 2015; Fraga, Padron, Acuna-Farina, & Diaz-Lago, 2017; Hinojosa, Albert, Fernandez-Folgueiras, et al., 2014) agreement features in phrases or sentences that were either correct or contained agreement mismatches between two constituents.

Martín-Loeches and colleagues (2012) manipulated number agreement between nouns and adjectives in simple transitive Spanish sentences with a [determiner-noun-adjective-verb] structure. Critically, the adjectives were emotionally neutral, positively- or negatively-valenced. These authors reported an interaction between emotion and the computation of agreement relationships between sentence constituents. In particular, number agreement anomalies in negative adjectives [e.g., La chica$_{sg}$ fea baila$_{sg}$/*bailas$_{pl}$ (The ugly girl$_{sg}$ dances$_{sg}$/*dance$_{pl}$)] compared to neutral ones were associated with enhanced LAN effects between 350 and 450 ms, which indicated additional costs for the processing of agreement dependencies when negative-valenced words were involved. In contrast, the mismatch of number agreement features in positive adjectives did not elicit a LAN component. This reduction in the LAN in positive words, relative to neutral and negative words, suggests a prevalence of heuristic (less computationally demanding) over algorithmic strategies, which ultimately facilitated number agreement operations. Ungrammatical sentences also elicited increased P600 amplitudes between 600 and 700 ms, which were unaffected by emotional valence.

The effects of emotion on the processing of agreement dependencies based on gender features have been explored in three studies. Hinojosa et al. (2014) used noun phrases [determiner- subject noun- predicative adjective] in which negative and neutral adjectives matched or mismatched the gender of neutral nouns [e.g., *El camarero$_m$ furioso$_m$/*furiosa$_f$ (The waiter furious$_m$/*furious$_f$)*]. An interaction between the gender agreement condition and emotion was found in the LAN between 250 and 450 ms. Specifically, while gender agreement anomalies in neutral adjectives elicited a LAN effect, no LAN modulations were observed for gender agreement anomalies in negative adjectives. This result indicates that negative content facilitated the detection of gender agreement errors, which allowed participants to move straight on to further analysis of the words. Additionally, P600 effects between 500 and 800 ms were found for agreement errors in negative and neutral conditions. Similar studies failed to observe emotion influences on the processing of gender features. In Díaz-Lago et al. (2015) the authors examined the effects of positive content on gender agreement in sentences with a [subject-verb-direct object] structure. Direct objects were phrasal nouns that included a neutral noun and a modifying positive or neutral adjective that either agreed or disagreed in gender with the head noun. For grammatically incorrect sentences [e.g., *La joven se comió una hamburguesa$_f$ tierna$_f$/*tierno$_m$ con patatas (The young girl ate a hamburger$_f$ tender$_{fem}$/*tender$_{masc}$ with potatoes)*], both positive and neutral adjectives elicited similar LAN and P600 components relative to correct sentences in the 350-450 ms and 500-700 ms time windows. Likewise, Fraga et al. (2017) used the same sentence structures as Díaz-Lago et al. (2015) and failed to observe LAN and P600 differences between neutral and negative adjectives (Exp. 1), or between positive, negative and neutral adjectives (Exp. 2) when they violated gender agreement dependencies with their head nouns.

Taking a different approach, Jiménez-Ortega, Espuny, Herreros de Tejada, Vargas-Rivero and Martín-Loeches (2017) examined how subliminally presented neutral, positive and negative adjectives modulated the processing of local subject-modifier agreement relations in neutral sentences with the following structure: determiner-noun-subliminal adjective-mask-adjective-verb. Half of the sentences included either number [e.g., *Las frutas*$_{pl}$ *sabrosas ######## maduras*$_{pl}$*/*madura*$_{sg}$ *abundan (The fruits tasteful ######## ripen*$_{pl}$*/*ripen*$_{sg}$ *abound)*] or gender agreement [e.g., *El dinero*$_{m}$ *falso ######## suelto*$_{m}$*/*suelta*$_{f}$ *tintinea (The money*$_{m}$ *false ######## loose*$_{m}$*/*loose*$_{f}$ *chinks)*] mismatches between the nouns and the adjectives, whereas the inserted subliminal adjectives were always matched to previous nouns in terms of gender and number. As expected, agreement errors preceded by neutral subliminal adjectives elicited a LAN component between 500 and 600 ms followed by a P600 in the 650-850 ms time interval. Interestingly, LAN effects disappeared when subliminal negative adjectives preceded agreement mismatches between nouns and verbs and the onset of the P600 was earlier. Seemingly, the processing of agreement features when a negative subliminal adjective was inserted between nouns and adjective took place earlier and recruited additional automatic syntactic resources relative to the neutral subliminal adjectives. As a consequence, the subsequent checking of agreement anomalies between nouns and supraliminal adjectives was impaired. In contrast, the processing of morphosyntactic errors preceded by positive subliminal adjectives relative to neutral ones elicited a negative component between 450 and 550 ms in central electrodes (N400), which was thought to reflect the use of non-syntactic based strategies at the discourse level to cope with gender/number agreement violations.

Overall, although evidence of the impact of emotion in syntactic unification processes is still scarce, the results of several studies (Hinojosa, Albert, Fernandez-

Folgueiras, et al., 2014; Martin-Loeches et al., 2012) indicate that emotion modulates the establishment of dependency relations between sentence constituents – particularly those based on gender and number features – as reflected in the aforementioned LAN effects. Neurocognitive models of language comprehension assume that the computation of agreement relations between elements of a sentence is followed by reanalysis and repair processes, when needed. Current evidence suggests that these processes are equally triggered by neutral and emotion words embedded in sentence contexts since both elicited similar P600 effects in all studies. Some conclusions might be drawn from the data reviewed here. First, emotion information seems to exert different influences on the processing of gender and number features (i.e., by impairing the processing of number vs. facilitating the processing of gender for negative words). These divergent results might arise in part from differences in the representation of these two features. In this sense, while grammatical gender is an intrinsic syntactic property which is word-specific and lacks a conceptual basis, number is an extrinsic syntactic property which is considered a conceptual feature indicating the quantity of the referent (Antón-Méndez, 2002; Barber & Carreiras, 2005; Nickels, Biedermann, Fieder, & Schiller, 2015). Second, negative and positive emotional features were associated with different (dis)agreement effects (i.e., negative content disrupted number agreement processes, whereas positive content facilitated such processes). Finally, differences in the pattern of results across gender agreement studies point to a modulatory role of both arousal (higher levels of arousal in Hinojosa et al., 2014, relative to Díaz-Lago et al., 2015 and Fraga et al., 2017) and syntactic structure (isolated noun phrases with minimal sentence contexts in Hinojosa et al., 2014, compared to direct objects in more constrained sentence contexts in Díaz-Lago et al., 2015 and Fraga et al., 2017) in the interplay between emotion and gender agreement. The effects of emotion on the different processing levels involved in syntactic unification are summarized in Figure 3.

Semantic unification and emotion

In parallel to syntactic unification processes, unification operations also take place at the semantic level. Semantic unification refers to the integration of word meaning into an unfolding discourse representation (Hagoort, 2005). In the time domain, the best index of such integrative process is the N400 component. N400 effects during sentence processing indicate whether the verbal input is relatively easier or harder to integrate into the preceding context and/or whether it might have been anticipated before the lexical item appeared in the unfolding sentence (Baggio & Hagoort, 2011; Kutas & Federmeier, 2011; Szewczyk & Schriefers, 2018). From an anatomical point of view, semantic unification processes take place in the ventral pathways between the middle and posterior superior and middle temporal gyri (STG/MTG) (Friederici, 2011, 2012; Hagoort & Indefrey, 2014). Two groups of studies focused on the integration of the emotional content of words in either neutral (Bayer, Sommer, & Schacht, 2010; Holt, Lynn, & Kuperberg, 2009; Martin-Loeches et al., 2012) or emotional sentence contexts (Delaney-Bush and Kuperberg, 2013; Moreno & Vázquez, 2011; Moreno & Rivera, 2014). A third set of studies used fMRI measures to characterize the brain regions that sub-serve affective processes and language operations involved in sentence comprehension in order to address questions such as the contribution of emotional features of single words to whole sentence emotional effects (Hsu, Jacobs, Citron, & Conrad, 2015) or the processing of implicit emotional meaning (Lai, Willems, & Hagoort, 2015).

Studies examining the processing of emotional words within the context of neutral sentences typically observed enhanced LPC amplitudes for negative words relative to either neutral ones (Bayer et al., 2010; Fields & Kuperberg, 2012) or positive ones (Holt et al., 2009). This effect indicates further efforts to integrate and re-evaluate negative words with respect to their preceding context relative to positive or neutral words. Fields and Kuperberg (2012) presented two-sentence scenarios that included a positive, negative or neutral critical word in the second sentence (*A man knocks on Sandra's hotel room door/ She sees that he has a gift/tray/gun in his hand*). The participants' task was to generate a short sentence that continued the story. The authors observed enhanced LPC amplitudes for negative relative to positive words, which elicited a larger LPC compared to neutral words. These effects were linked to a deeper processing at post-lexical stages in emotional written discourses. The study of Holt et al. (2009) also used neutral two-sentence contexts (*Sandra´s old boyfriend stopped by her apartment today. This time he brought a rose/gun/letter with him*), under both explicit evaluation of emotional content (experiment 1) and passive reading (experiment 2) conditions. Besides the LPC, a larger N400 to both negative and positive words relative to neutral words was observed under the passive reading condition. Taken together the results of this study suggest an initial specific influence of positive and negative content on semantic integration processes (N400), which are then followed by re-analysis (LPC) processes that are only triggered by negative, potentially harmful stimuli. Increased cognitive demands to map emotional meaning to neutral contexts (N400) could be explained either by a relatively longer semantic distance between emotional and neutral knowledge stores and/or a more in-depth semantic memory-based analysis for emotional relative to neutral content. In contrast, Martín-Loeches et al. (2012; Experiment 2) reported N400 reductions for positive relative to neutral and negative emotional words when readers made decisions on semantic congruency. Both semantically correct and incorrect positive adjectives produced an N400 reduction, possibly reflecting the use of heuristic strategies and an increased cognitive flexibility for the processing of positive words.

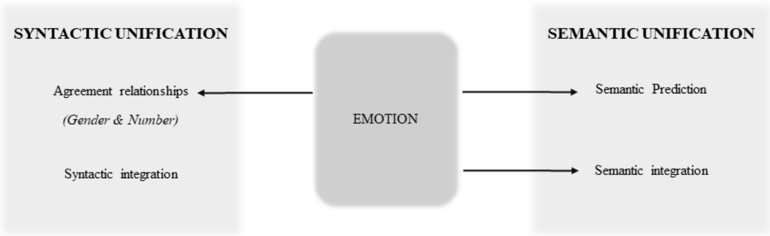
In another set of studies, a highly constraining context was either positively or negatively biased intentionally for the subsequent matching or mismatching of an emotional outcome (e.g., *At the edge of the cliff someone came from behind and pushed*/*rescued [him]* or *Those little thoughtful details revealed how much he/she loved/envied [me]*). Some of these studies used a passive reading paradigm and asked participants about some of the sentences at the end of the experimental session. Moreno and Vázquez (2011) found that highly expected negative outcomes elicited a smaller N400 than highly expected positive ones, suggesting that participants made stronger predictions of future negative rather than positive outcomes to "protect" themselves from the harm of unexpected negative outcomes (a phenomenon called "defensive pessimism). In a similar vein, Moreno and Rivera (2014) found a larger post-N400 frontal positivity to unexpected positive outcomes than to unexpected negative ones, which suggests that more effort was needed to override pessimistic than optimistic predictions, since this frontal component has been linked to the "cost" associated with processing disconfirmed predictions (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Van Petten & Luka, 2012). Interestingly, these effects contrast with previous results on how people tend to be optimistically biased within neutral contexts (Holt et al., 2009; Martín-Loeches et al., 2012) and highlight the relevance of prior sentence context in the processing of subsequent emotional words. The study by Moreno and Rivera (2014) found additional modulations of emotion in very early ERP components, such as the N1 and the P2, which resemble those observed during single word processing (Scott et al., 2009). Early effects were also reported in a study manipulating the emotional consistency between a story discourse and a sentence conveying the most likely emotion of the protagonist (Leon, Diaz, de Vega, & Hernandez, 2010). Inconsistent emotions relative to consistent ones (e.g. *He felt totally fulfilled vs. a complete failure*) elicited larger N100/P200 and N400. Early latency effects (N1 and P2) suggest a very rapid establishment of expectations based on emotion features in discourse-level violations, which are followed by difficulties in the integration of words which are emotionally-incongruent with sentence contexts. In contrast, several studies in which participants were asked to answer comprehension questions during the experimental session found that emotional salience overrides discourse incongruities, which suggests that accessing emotional features is prioritized over accessing other sources of semantic information. In this sense, Delaney-Bush and Kuperberg (2013) showed that positive and negative words elicited reduced N400 amplitudes following an emotional two-sentences context regardless of congruity (e.g. *Lucy was a(n) awful/great/female engineer. Her creations were big failures/successes or bridges/murals every time*). Subsequently, larger LPCs were elicited by emotional versus neutral words, indicating that readers bypass deep semantic processing (N400) so as to rapidly move to evaluate the emotional properties of words (LPC). Similarly, Wang et al. (2013) reported a reduction in N400 amplitudes for both positive and negative words relative to neutral words embedded in question-answer pairs of sentences. Also, the results of a magnetoencephalography study (Parkes, Perry, & Goodin, (2016) indicated that in the context of negatively biased sentences, incongruent neutral endings but not incongruent positive ones enhanced the amplitude of the M400. Finally, enhanced EPN amplitudes for negative compared to both neutral and positive critical words were observed in high- and low- relevance sentence contexts (Bayer, Ruthmann, & Schacht, 2017). The EPN had a longer duration in highly-relevant sentence contexts, which suggests prioritized lexico-semantic processing in this condition.

Following a different approach, several fMRI studies indicate that the emotional brain network and the brain network for combinatorial processing in sentence and text comprehension are intricately related (Ghio, Vaghi, Perani, & Tettamanti, 2016; Hsu et al., 2015; Mellem, Jasmin, Peng, & Martin, 2016). Importantly, they also suggest that similar language- and affective- related regions underlie the processing of emotional features in both single words and sentences (see Figure 1). This is not surprising if we take into consideration the poor temporal resolution of the hemodynamic changes underlying this technique and the fact that sentence comprehension is a very fast integrative process. Thus, it is difficult to disentangle effects elicited by single successive words from those associated with unification processes at the sentence level (L. Osterhout, Kim, A. & G.R. Kuperberg, 2012). Moreover, emotion effects for short texts can be predicted from modulations observed at the word level. In this sense, Hsu and collaborators (2015) correlated affective ratings of words and passages with brain activation while participants read passages from Harry Potter books. Despite the finding of specific language-related activations for words and passages within temporal and frontal cortices, lexical emotion effects (i.e., the affective content of words) were associated with the activation of the insula and the amygdala, while no differential effects were found for passages in emotion-related brain regions. In a different fMRI study using a silent reading paradigm (Mellem et al., 2016) the authors compared the processing of sentences with emotional-social, social or object content and Jabberwocky sentences with a syntactic mimicking structure that is devoid of meaning (e.g. *All zearts plored its denual dinvature*). Emotion sentences specifically activated the anterior superior temporal gyrus, which is thought to be involved in the composition of sentence meaning through combinatorial semantic processes (Vandenberghe, Nobre, & Price, 2002). Finally, activations in both emotion-related (i.e., the amygdala, the insula and prefrontal cortices) and language-related areas (i.e. the IFG, the MTG, the STG) have been found when participants read sentences with an implied negative connotation (e.g., *the boy fell asleep and never woke again*, in which none of the words is negative; Lai et al., 2015). In a recent ERP study with similar sentence materials (Cao, Yang & Wang, 2018), the authors showed that the timing of emotional and semantic unification processes overlapped, which suggests that emotional features operates concurrently with semantic unification.

The literature reviewed in this section indicates that emotional features influence semantic unification processes in sentence and discourse contexts (see Figure 3) through activations in a set of language- and affective-related brain areas that are also involved in the processing of single emotional words, as well as in brain regions linked to combinatorial semantic processes such as the anterior superior temporal gyrus. However, with the data at hand we cannot draw strong conclusions regarding the contributions of valence and arousal, as both dimensions seem to impact similar processing stages during sematic unification. Divergences in the pattern of results found in some studies may simply arise at a lexical level as a result of some or all of the linguistic and emotional factors that we have discussed in prior sections (e.g., differences in word class, stimulus duration, controlled lexical variables, word valence and/or arousal scores,…). Inconsistencies might also be attributable to context-dependent effects and the overlap of distinct levels of post-lexical analyses, such as the use of pragmatic cues in prediction and integration processes. Emotion dependent modulations in early components (such as the N1, P2) to both positive and negative words were observed in the context of highly constrained sentences (Moreno & Rivera,

2014) and in wider discourse contexts (Leon et al., 2010). The presence of late ERP modulations (LPC effects) is unreliable, with studies showing enhanced LPCs indicative of additional processing costs for either negative highly arousing vs. neutral words (Bayer et al., 2010), negative vs. positive ones (Holt et al., 2009), for overall emotional vs. neutral words (Delaney-Busch & Kuperberg, 2013), or even showed no posterior LPC modulations at all (Leon et al., 2010; Martin-Loeches et al., 2012; Moreno & Vazquez, 2011). These long-latency positivities reflect a final processing stage at which several sources of linguistic information are integrated. Thus, many factors might account for these inconsistent findings. One possibility concerns the use of different tasks, given the strong task-dependency of late positivities (e.g., their amplitude is attenuated in tasks that do not require judgements about sentence correctness; (Schacht, Sommer, Shmuilovich, Martienz, & Martin-Loeches, 2014). Also, differences in the number of sentence scenarios (e.g., two-sentences scenarios: Holt et al., 2009; Delaney-Bush and Kuperberg, 2013; Bayer et al., 2017, vs. one sentence scenarios: Martín-Loeches et al., 2012; Moreno & Rivera, 2014) or words in a sentence (e.g., 4 words in Martín-Loeches et al., 2012, 6-8 words in Holt el al. 2009, 4-17 words in Fields & Kuperberg, 2012), sentence structure (with variations not only between studies but also within the same study), sentence plausibility ratings (which were collected in only a few studies, e.g., Delaney-Bush and Kuperberg, 2013; Holt et al., 2009) and the position of the critical word within the sentence (e.g., end position: León et al., 2010; Moreno & Vázquez, 2011, middle position: Bayer et al., 2017; Felds & Kuperber, 2012) might account for the discrepant findings here, in that all these factors are known to influence the amplitude of late positive components (DeLong, Quante, & Kutas, 2014; Kuperberg, 2007).

With regard to N400 effects, the results are also mixed. When sentence contexts were neutral, both negative and positive words relative to neutral words elicited enhanced N400 effects in one study (Holt et al., 2009), whereas in another study only positive words relative to negative and neutral ones elicited smaller N400 amplitudes (Martin-Loeches et al., 2012). By contrast, when emotion is biased within the contextual frames, highly expected negative outcomes elicit smaller N400s than highly expected positive ones (Moreno & Vazquez, 2011), or both positive and negative words elicit smaller N400 amplitudes, regardless of semantic congruity (Delaney-Busch & Kuperberg, 2013). Moreover, embedding comprehension questions within experimental sentences seems to be associated with a facilitation of the post-lexical integration of emotional information in sentence contexts (Delaney-Busch & Kuperberg, 2013) whereas delaying comprehension questions until the end of the experimental session impairs post-lexical processing (Leon et al., 2010; Moreno & Rivera, 2014). This is consistent with the previous literature suggesting that the amplitude of the N400 is modulated by the amount of attentional resources engaged in semantic processing (Bentin, Kutas, & Hillyard, 1993; Holt et al., 2009). All in all, current data suggest that N400 modulations might reflect the unexpectedness of emotional words within neutral contexts (Holt et al., 2009), increased cognitive flexibility in the processing of positive lexical inputs (Martin-Loeches et al., 2012), the withholding of strong positive expectations possibly driven by defensive pessimist strategies (Moreno & Vazquez, 2011) and a less in-depth semantic processing for emotionally salient stimuli (Delaney-Bush and Kuperberg, (2013).



General discussion and future directions

The affective neurolinguistics perspective aims to delineate the neural architecture underlying the influence of emotional properties on the processing of lexical items and other linguistic units. As reviewed, a substantial body of neuroimaging evidence shows effects of emotional features at different linguistic representational levels during the processing of words and sentences. The results of these studies have implications for psycholinguistic and neurocognitive models of conceptual representation as well as for the debate between modular and interactive views of language processing, and suggest promising paths for future research.

Current findings suggest that emotion is a part of the conceptual representation of words, which interacts with other semantic properties such as concreteness (Kissler et al., 2006; Kissler & Herbert, 2013; Moseley et al., 2012; Palazova, 2014; G. Vigliocco et al., 2014). In this sense, the temporal brain dynamics for the processing of emotion information in words reported in most studies approximately match those proposed for semantic processing in neurocognitive models of word reading (Carreiras et al., 2014; Grainger & Holcomb, 2009; Price, 2012). In particular, the most consistent effects of emotion on word processing arise in the EPN component between 200 and 300 ms. Interestingly, the emotional properties of words also modulate the processing of several lexical features. Thus, in resemblance of the semantic effects on lexical processes observed in neurocognitive studies of language (Halgren et al., 2002; Hauk et al., 2006), the emotional properties of words seem to modulate brain activity linked to lexical access at around 150 ms (i.e., word frequency or orthographic neighbor effects; Gobin, Faita-Ainseba, & Mathey, 2012; Palazova et al., 2011; Scott et al., 2009). Prior findings (Palazova et al., 2013; Yap & Seow, 2014) suggest that these effects may arise from semantic feedback to early lexical processing related to the increased semantic richness of emotion words (i.e., higher number of semantic features or proximity of semantic neighbors; Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008). Interactions between emotion features and other variables that are partly lexically related such as age of acquisition (Juhasz, 2005; Menenti & Burani, 2007) have also been reported, although their neural bases remain unexplored. In this sense, the results of developmental and normative studies with adults indicate that positive words are learned earlier than neutral or negative words (Hinojosa et al., 2016; Moors et al., 2013; Ponari et al., 2018; Ridgeway, Waters, & Kuczaj, 1985) and that words with high valence scores are acquired before less emotionally-intense words (Niedenthal et al., 2004). Future studies should explore whether manipulating the emotion properties of early and late learnt words modulates the activation of some brain regions (Mayberry, Chen, Witcher, & Klein, 2011) or the temporal brain dynamics (Cuetos, Barbon, Urrutia, & Dominguez, 2009) that have been previously linked to age of acquisition effects in neurolinguistic studies.

Apart from the characterization of the time course of emotion effects, a critical issue for affective neurolinguistics is to define how emotional features are represented in the brain network underlying the semantic system. Featural views of semantic representations assume that word meanings are either derived from abstract conceptual primitive features (Jackendoff, 1992, 2002) or embodied in perception and action (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; G. Vigliocco, & Vinson, D. P. , 2007; G. Vigliocco, Vinson, Lewis, & Garrett, 2004). Here, we have described results from several source estimation and fMRI studies indicating that the processing of the emotional properties of words activates brain areas underlying semantic processing (i.e., the MTG or the IFG), affective evaluations (i.e., orbitofrontal and ventromedial prefrontal cortices, the insula, or the amygdala), internal affective experiences (rACC), or actions expressing emotions (frontocentral cortices), although the flow of information between brain areas underlying affective and linguistic processes should be explored in functional and anatomical connectivity studies. These findings suggest that the representation of emotional features involves the combination of at least verbal information, affective experience, and motor components distributed in a set of brain areas, which is in line with neurobiological componential theories of lexical semantics (Binder et al., 2016). An important question that needs to be addressed in future studies concerns the structure of the representation of the different attributes or dimensions that comprise the ‘core’ concept of emotional content. In this sense, there is behavioral evidence indicating that valence is more penetrable by cognitive processing than arousal. Even though these dimensions depend to some degree on general comprehension of meaning during reading, only valence is modulated by the consistency of sentences with participant’s beliefs about the world (Nicolle & Goel, 2013). Of note, the greater involvement of higher-cognitive processes associated with the valence dimension is in agreement with the specific involvement of the orbitofrontal cortex in the processing of this dimension, as opposed to the more important role of the amygdala in arousal processing (Lewis et al., 2007). Finally, evidence from ERPs suggests that the arousal dimension modulates the implicit automatic processing of word emotional features (EPN) whereas the valence dimension has more impact on subsequent evaluative processes (LPC). Nonetheless, current research on affective neurolinguistics with an explicit focus on the specific contribution of these components to the linguistic processes reviewed here is scant (e.g., Yao et al., 2016) and indirect evidence from studies that included positive and negative words matched in arousal is inconclusive. Also, future studies should examine brain activity elicited by the interaction between the processing of emotion attributes and other conceptual features such as animacy or sensory experience ratings, which refer to the sensory and/or perceptual experience elicited by words in a broad sense that is not limited to the visual modality (Hinojosa et al., 2016; Juhasz & Yap, 2013; Juhasz, Yap, Dicke, Taylor, & Gullick, 2011).

Another relevant issue concerns the modulation of syntactic processes by emotional features. In agreement with the proposals of lexicalist approaches to language comprehension (Trueswell, Tanenhaus, & Garnsey, 1994; Vosse & Kempen, 2000), the finding of an interaction between emotional features and words' grammatical class at a word level (Palazova et al., 2011) suggests that information stored in the lexicon might play an important role in the representation of syntactic forms (Kim, 2002). This possibility awaits further confirmation from studies investigating how the emotional features of words interact with word category information during the building of phrase structures. Emotional properties of words also modulate parsing operations involved in the computation of agreement dependencies between sentence constituents based on gender and number features (Hinojosa, Albert, Fernandez-Folgueiras, et al., 2014; Martin-Loeches et al., 2012). Interestingly, emotional features exert a different influence in the processing of gender and number features, which might be explained in part by the fact that information conveyed by number and gender is different (Carminati, 2005). Also, in a broad sense these results challenge the proposals of modular syntax-first neurocognitive models of language processing (Grodzinsky & Friederici, 2006), which assume that syntactic representations do not interact with other sources of information until agreement relationships have been computed. In contrast, current evidence agrees with interactive neurocognitive models of language processing in suggesting that at least some syntactic operations are penetrable by emotional features at early processing stages (Hagoort, 2005).

Finally, emotional information also influences unification processes involved in the understanding of sentences and larger texts. Besides the finding of activations in affective-related brain areas, the processing of emotional sentences is linked to the activation of language-related brain regions such as the MTG, the STG or the IFG, which according to some neurobiological models of language processing are thought to play a fundamental role in prediction and integration mechanisms associated with the unification of conceptual information (Friederici, 2011; Hagoort, 2005). In particular, the IFG is more strongly activated with higher semantic selection demands (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Thus, increased activation for emotional sentences may reflect additional costs for processing the complex representation of emotional features during unification processes, which possibly arises from their high biological relevance. Accordingly, the results of ERPs studies show that integrating emotional features is more demanding when an upcoming emotional word cannot be predicted based on a prior neutral sentence context (Bayer et al., 2010; Holt et al., 2009). However, a processing advantage for the emotional features of words was observed when the emotional sentence context biased predictions towards a forthcoming emotional word (Delaney-Busch & Kuperberg, 2013; Moreno & Vazquez, 2011). Interestingly, these effects resemble the faster first fixation durations for negative words reported in eye-tracking studies (Knickerbocker, Johnson, & Altarriba, 2015; Scott et al., 2012; Sheikh & Titone, 2013). These context-dependent predictability effects suggest that the lexical representation of emotional features might be preactivated during unification processes involved in the processing of words embedded in sentences (e.g., Szewczyk & Schriefers, 2018).

As we have shown and discussed throughout this review, there are some methodological considerations that might partially explain the inconsistent findings in research here. To summarize, one issue concerns the matching of linguistic properties in different studies. In this sense, although word frequency, concreteness and word length have been generally taken into account in the majority of studies, other variables such as familiarity, number of orthographic neighbors, age of acquisition and bigram and trigram frequency have only been considered in some of them. Also, not all studies addressing a similar question matched emotional words in terms of the same linguistic variables. Similarly, there are differences regarding affective dimensions across studies. Positive, negative and neutral words were not always included. Neutral words differed in valence and arousal ratings from neutral words in most studies, although they shared similar arousal values in others. Also, there are important differences in the extremity or the standard deviation of valence and arousal scores. A second caveat concerns the sensitivity of the effects to task demands, since the results seem to be stronger in tasks that require deep (LTD or semantic categorization tasks) relative to shallow (counting stimuli or directing attention to the perceptual properties of words) language processing. Finally, experimental parameters such as the number, duration and the grammatical category of the stimuli, pseudoword features in LDTs, the lateralized vs centered presentation of words, and the structure and number of words in sentences also modulate the interplay between language and emotion. Thus, the high number of variables, tasks effects and experimental parameters that might influence results should be carefully considered in designing future studies in the field of affective neurolinguistics in order to achieve reliable interpretations of the findings.

In conclusion, affective neurolinguistics seems to be a promising framework that has the potential to contribute to the development of neurobiologically grounded explanations for the puzzling dynamic interplay between language and emotion. In line with the claims made by some recent theoretical proposals, such as the Affective Language Comprehension model (J. J. A. van Berkum, in press-a, in press-b), current neuroimaging studies show that emotion plays a crucial role in language processing. Further work is required to answer more definitively some of the questions that have previously been addressed in neurocognitive studies of language, such as the involvement of emotional features in computing local phrase structure, in thematic-role assignment, in the disambiguation of temporally ambiguous sentences, in attachment preferences, or in the processing of sentence elements that are not found in canonical positions (as with passive constructions or relative clauses). Nonetheless, the literature reviewed here suggests that neurocognitive studies and models of language comprehension should consider emotional features when selecting linguistic stimuli or describing the relationships between different levels of linguistic representation in the same vein as they attend to word frequency, concreteness or age of acquisition. Indeed, as we have shown in this review, prior effects on these variables were partially modulated by the lack of control over the emotional features of the linguistic stimuli. Similarly, those researchers interested in affective neuroscience should be aware of the idiosyncrasy of the processes underlying the processing of emotional linguistic stimuli relative to those involved in the processing of emotional images or facial expressions. Also, the current review highlights the importance of a careful control of the linguistic properties of the stimuli used in emotion studies. In sum, current evidence suggests that the honeymoon between neurolinguistics and affective neuroscience might have only just begun.

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Figure Legends

Figure 1. Brain regions most consistently activated during the processing of emotional features in word and sentence processing studies. The red circles denote areas that have been mainly associated with affective processing, whereas the blue circles indicate regions mainly subserving language-related processes. Abbreviations: ACC, anterior cingulate cortex; PCC, posterior cingulate cortex; OFC, orbital prefrontal cortex; DLPFC, dorsolateral prefrontal cortex; mPFC, medial prefrontal cortex; IC, insular cortex; SPL, superior parietal lobe; EC, extra-striate cortex; Am, amygdala; BG, basal ganglia; PC, premotor cortex; MTC, middle temporal cortex; IFG, inferior frontal gyrus; FG, fusiform gyrus; MTG, middle temporal gyrus; LTP, left-temporal pole, ITG, inferior temporal gyrus; ILFC, inferior left frontal cortex; MLFC, middle left frontal cortex; ASTG, anterior superior temporal gyrus.

Figure 2. Relations between emotional features and different lexical, semantic and syntactic features at the word level.

Figure 3. Emotional effects on different semantic and syntactic processing stages involved in sentence comprehension. The absence of an arrow indicates that prior studies failed to observe a relation.