Temporospatial analysis of explicit and implicit processing of negative content during word comprehension

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**Abstract**

Although divergences between explicit and implicit processing of affective content during word comprehension have been reported, the underlying nature of those differences remains in dispute. Prior studies focused on either the timing or the spatial location of the effects. The present study examined the precise dynamics of the processing of negative words when attention is directed to affective content or to non-emotional properties by capitalizing on fine temporal resolution of the event-related potentials (ERPs) and recent advances in source localization. Tasks were used that required accessing knowledge about different semantic properties of negative and neutral words. In the direct task, participants' attention was directed towards emotional information. By contrast, subjects had to decide whether the words' referent could be touched or not in the indirect task. Regardless of being processed explicitly or implicitly, negative compared to neutral words were associated with more errors and greater key pressure responses. Electrophysiologically, affective processing was reflected in larger amplitudes to negative words in a late positive component (LPC) at the scalp level, and in increased activity in the pre-supplementary motor area (pre-SMA) at the voxel level. Interestingly, an interaction between emotion and type of task was observed. Negative words were associated with more errors, larger anterior distributed LPC amplitudes and increased activity in the posterior cingulate cortex (PCC) in the direct compared to the indirect task. This LPC effect was modulated by the concreteness of the words. Finally, a task effect was found in a posterior negativity around 220 ms, with enhanced amplitudes to words in the direct compared to the indirect task. The present results suggest that negative information contained in written language is processed irrespective of controlled attention is directed to it or not, but that this processing is reinforced in the former case.

**1. Introduction**

Emotional stimuli, including language, may be processed either in a relatively automatic and unintentional implicit manner or in a deliberated and controlled explicit fashion (Greenwald & Banaji, 1995; Pessoa, 2005). Thus, an important research question has to do with the modulation of brain activity by the task-dependent attentional focus of participants. The present study was concerned with the Event-related potential (ERP) correlates, the underlying neural sources, as well as the behavioral effects that are involved in explicit and implicit processing of negative information during word comprehension.

Given their precise temporal resolution, the timing of brain mechanisms underlying the processing of emotional words has been extensively examined using scalp-recorded ERPs. In those studies that used direct or explicit tasks, participants' attention was directed towards the emotional connotations of the words. Alternatively, subjects' attention was distracted from the affective content of the words in studies that used indirect or implicit tasks. Regardless of the occasional finding of modulations in the P1, N1, P2 or N400 components (e.g., Bernat, Bunce, & Shevrin, 2001; Herbert, Kissler, Junghofer, Peyk, & Rockstroh, 2006; Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009; Kanske & Kotz, 2007; Trauer, Andersen, Kotz, & Müller, 2012), effects have been mainly observed in two waves. The first component is an early posterior negativity (EPN) to emotional compared to neutral words that has been interpreted to index enhanced sensory encoding resulting from reflex-like visual attention to affective information (Herbert, Junghofer, &...
Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007; Rellecke, Palazova, Sommer, & Schacht, 2011). This effect has been observed in indirect tasks such as lexical decision (Bayer, Sommer, & Schacht, 2012a; Palazova, Mantwill, Sommer, & Schacht, 2011; Schacht & Sommer, 2009a, 2009b; Scott, O’Donnell, Leuthold, & Sereno, 2009) or word counting (Kissler, Herbert, Winkler, & Junghofer, 2009), as well as in explicit affective categorization tasks (Frühholz, Jellinghaus, & Herrmann, 2011). However, other studies failed to report ERP effects with both indirect (Carretié et al., 2008; Hinojosa, Carretié, Valcárce, Méndez-Bértolo, & Pozo, 2009; Hinojosa, Méndez-Bértolo, & Pozo, 2010; Hofmann et al., 2009; Kanske & Kotz, 2007; Méndez-Bértolo, Pozo, & Hinojosa, 2011a; Rellecke et al., 2011) and direct tasks (Naumann, Bartussek, Diedrich, & Laufer, 1992; Schapkin, Gusev, & Kuhl, 2000). Emotional words are also associated with an enhancement of a LPC in both indirect (Carretié et al., 2008; Hinojosa et al., 2010; Hofmann et al., 2009; Kanske & Kotz, 2007; Kissler et al., 2009; Méndez-Bértolo et al., 2011a; Schacht & Sommer, 2009a, 2009b) and direct tasks (Frühholz et al., 2011; Naumann, Maier, Diedrich, Becker, & Bartussek, 1996; Naumann et al., 1992; Schapkin et al., 2000), which presumably reflects higher order stimulus evaluation (Bayer, Sommer, & Schacht, 2012b; Herbert et al., 2006; Kissler et al., 2009).

The findings on the timing of emotional processing during word comprehension (when affective processing occurs) have been complemented by data on its anatomical substrates (where affective processing occurs). The results of several functional magnetic resonance imaging (fMRI) studies with both direct (Cunningham, Raye, & Johnson, 2004; Maddock, Garrett, & Buonocore, 2003; Straube, Sauer, & Mitlner, 2011) and indirect (Kensinger & Schacter, 2006; Kuchinke et al., 2005; Whalen et al., 1998) tasks indicate that the processing of emotional content in words is subserved by a brain network distributed across multiple cortical and subcortical areas. These regions include prefrontal cortices (ventromedial and ventrolateral), the insula, the pre-SMA, the anterior and posterior cingulate cortex, as well as the amygdala.

Finally, at the behavioral level some studies have found a processing advantage for emotional over neutral words, which is associated with faster responses and more accurate responses in both direct and indirect tasks (e.g., Schacht & Sommer, 2009a, 2009b). Others have shown that relative to neutral words the processing of emotional words elicited slower reaction times and lower accuracy (e.g., Algom, Chajut, & Ley, 2004; Bayer et al., 2012a; Carretié et al., 2008; Estes & Verges, 2008; Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009). Interestingly, it has been also found that emotional words and pictures prepare people to display forceful actions (Aarts, Custers, & Marien, 2008; Coombes, Cauragh, & Janelle, 2006; Coombes, Corcos, Pavuluri, & Vaillancourt, 2012).

Only a limited number of the aforementioned studies directly compared tasks that required explicit versus implicit processing of affective properties of words. In a series of studies Naumann and collaborators (1992, 1996) explored the processing of neutral, positive and negative adjectives in emotional judgments and structural tasks, in which participants indicated if a particular word was shorter, equal, or longer than six letters. The LPC showed either different topographies (Naumann et al., 1992) or enhanced amplitude (Naumann et al., 1996) for direct compared to indirect tasks, which led the authors to establish that explicit affective processing is more intense. Recently, Frühholz and collaborators (2011) compared the processing of negative and neutral words and faces in color naming and affective categorization tasks and found that negative words elicited larger ERP amplitudes in the explicit than in the implicit task. Emotion also modulated the amplitude of the LPC, although its amplitude was not sensitive to the direct versus indirect nature of the task. Also, behaviorally, subjects took longer and were less accurate to categorize words in an affective dimension than to name their colors. None of these effects were modulated by the emotional content of the words. In an fMRI study, Straube and collaborators (2011) explored the processing of positive, negative and neutral words when participants made valence and grammatical class judgments. Regardless of task, the processing of emotional words led to increased activation in the ventromedial prefrontal cortex and the amygdala. Task effects were found that indicated that the processing of emotional words in the direct compared to the indirect task led to enhanced activation in the dorsomedial prefrontal cortex and the anterior cingulate cortex. Finally, in another fMRI study Cunningham and collaborators (2004) asked their participants to perform explicit (good-bad) and implicit evaluations (abstract-concrete) about socially relevant concepts. Amygdala activation was observed in both explicit and implicit tasks. In contrast, the explicit emotional categorization was selectively associated with increased activity in ACC, lateral areas of the prefrontal cortex and the frontal pole.

It is important to note that prior studies have focused almost exclusively on either the temporal course (when) or the anatomical substrates (where) of implicitly and explicitly processed emotional words. A further step would be to examine the ERP components that may be potentially reflecting the processing of negative words when attention is directed to affective content or to non-emotional properties, and thereafter to identify the brain regions that selectively subserve such effects. The current study was conceived to address this issue by exploiting the high temporal resolution of the ERPs and recent advances in source localization. Furthermore, in an attempt to specifically isolate the effect of attention to emotional content of words and minimize confounding factors we designed direct and indirect tasks that demanded some degree of meaning-based evaluation.

According to some theoretical proposals, word meaning is comprised of a number of semantic features that are organized in networks in which knowledge about these properties is distributed (Kissler, Assadollahi, & Herbert, 2006; Patterson, Nestor, & Rogers, 2007; Pulvermüller, 1999). There is general agreement to consider emotional significance as one of these properties (Kissler et al., 2006; Schacht & Sommer, 2009b). Another source of semantic knowledge comes from the information about the concreteness of the concept denoted by a word, which is also assumed to be stored in semantic networks (Kellenbach, Wijers, & Mulder, 2000; Reilly & Kean, 2007). Thus, in the direct task participants had to decide whether a word was negative or neutral. Alternatively, participants judged if a particular word referent could be touched or not in the indirect task.

Predictions may be outlined as follows. At the scalp level, the processing of negative words was expected to be associated with enhanced amplitudes of the LPC and/or the EPN (Frühholz et al., 2011; Kissler et al., 2009; Schacht & Sommer, 2009a, 2009b). At a neuroanatomic level, increased activity in the prefrontal (e.g., ventro-lateral and/or dorsolateral regions) and/or cingulate cortices was predicted (Cunningham et al., 2004; Maddock et al., 2003; Straube et al., 2011). Behaviorally, previous studies have shown that the processing of emotional compared to neutral words is associated with longer RTs/lower accuracy for emotional words (Bayer et al., 2012a; Hofmann, Kuchinke, Tamm, Vo, and Jacobs, 2009), whereas shorter RTs/higher accuracy were reported in others (Schacht & Sommer, 2009a, 2009b). As already noted above, the processing of emotional stimuli has been also associated to motor facilitation responses (Aarts et al., 2008; Coombes et al., 2006; Coombes et al., 2012). Thus, we measured the force generated by participants when they pressed response keys, a parameter that has not previously investigated in prior research contrasting explicit and implicit processing of negative words. Increased for production was expected for negative compared to neutral words. In order to test these hypotheses, a two-step approach analysis was devised to analyze data. First, temporospatial principal
component analysis (PCA) was employed to detect and quantify those ERP components related to the processing of negative words. PCA is a data-driven method which has shown to be a powerful approach to isolate ERP components across time course (temporal PCA) and scalp recording sites (spatial PCA). In the second step, source analyses were performed in those components that were sensitive to emotion in the scalp-level analysis to identify which brain regions are specifically involved in each processing stage.

2. Materials and methods

2.1. Participants

Forty Spanish native speakers participated in this study (26 females, age range of 18–32 years, mean = 20.72, standard deviation = 3.03). The average handedness score according to the Edinburgh Handedness Inventory (Oldfield, 1971) was 59.31 (s.d. = 51.97). They reported normal or corrected-to-normal visual acuity. The study had been approved by the Universidad Complutense de Madrid’s Ethics Committee. All participants were students of Psychology at the Universidad Autónoma de Madrid and took part in the experiment voluntarily after providing informed consent.

2.2. Stimuli and procedure

Participants were seated in an electrically shielded, sound-attenuated room. Four types of stimuli were presented to participants in two different tasks: negative concrete nouns (NegC), negative abstract nouns (NegA), neutral concrete nouns (NeuC), and neutral abstract nouns (NeuA). Angle of vision for all stimuli was 2.52° (height). The complete stimulus set consisted of 128 Spanish nouns (64 negative, 64 neutral) and can be consulted at Appendix A. These words were selected from a pilot study that comprised 720 nouns. In that study, 45 subjects (different from those participating in the present study) rated valence, arousal, and the level of concreteness of each word in a 9-point Likert scale (for a detailed description of this pilot study see for instance Hinojosa, Carretié, Valcárcel, et al., 2009; Hinojosa et al., 2010). Half of the negative and neutral nouns denoted touchable/concrete concepts. The remaining half of the nouns had untouchable/abstract word referents. Concreteness has been interpreted sometimes as ‘sensory perceivability’ (e.g., Theijseen, van Halteren, Boves, & Oostdijk, 2011). However, a definition of concreteness in terms of the extent to which a word’s referent can be touched has been frequently used in previous research, as this concept might be easier to understand for individuals (e.g., Barca, Burani, & Arduino, 2002; Paivio, 1985; Reilly & Kean, 2007). To effectively corroborate this distinction, 61 participants (different from those participated in the previous pilot study and the current ERP recording) judged whether the concept denoted by all the 128 nouns represented something that could be touched or not in a pre-test study. In order to equate the number of response alternatives in both the direct (negative vs neutral) and the indirect (touchable vs untouchable) tasks (see below) only negative words were considered as emotional stimuli. Negative nouns were chosen because their average arousal rating is generally high, whereas positive nouns show more arousal variability (Estes & Verges, 2008; Frühholz et al., 2011; Méndez-Bértolo, Pozo, and Hinojosa, 2011a; Méndez-Bértolo, Pozo, and Hinojosa, 2011b).

An equal number of words for each of the four experimental categories were selected according to the following criteria that were contrasted with analyses of variance (ANOVA; see Table 1) and subsequent post hoc comparisons. (a) all words had similar frequency of use in Spanish (Alameda & Cuertos, 1995); (b) all nouns were equated in word length (measured as the number of syllables); (c) negative and neutral words differed in valence; (d) negative and neutral words differed in arousal; (e) concrete and abstract words differed in concreteness; (f) concrete nouns were rated as having a touchable referent by at least 70% of the ad hoc sample (see above); and (g) abstract names were considered to have touchable referents by no more than 30% of the sample. Only 32 NegC, 32 NegA, 32 NeuC and 32 NeuA words met these restricted criteria. Table 1 summarizes mean values in valence, arousal, concreteness, word frequency and word length for the stimulus categories, as well as mean percentage of individuals who rated them as being touchable.

The experimental tasks were programmed using Inquisit Millisecond software (Millisecond Software, Seattle, WA) and the stimuli were presented through a RGB projector on a back projection screen. Each task comprised the presentation of all the 128 words. Every word was displayed on the screen in capital letters for 300 ms followed by a fixation cross in the center of the screen for either 1300 or 1500 ms. As indicated, participants performed two tasks. In the direct task, subjects explicitly accessed semantic information about the affective content of the words, as they had to press one key if the word’s referent was negative or a different key if the noun was associated with a neutral concept. In the indirect task, participants’ attention was directed away from the affective content of words since they had to access semantic information about the ‘touchability/concreteness of the concepts associated with the nouns. A 10-min break was allowed between the two tasks. Responses in both tasks were provided by pressing two different pressure-sensitive keys with two different fingers of the dominant hand. Response keys, as well as task order, were counterbalanced across participants. They were told to respond as accurately and rapidly as possible, and to minimize blinking.

The order of presentation of the nouns was pseudo-randomized within each task, so no more than 5 stimuli of the same category were presented consecutively. A practice run was presented before each task. Finally, with the purpose of corroborating the rating from the pilot-study participants themselves filled out a bidimensional scale for each word, so that their assessments on valence and arousal were obtained (Table 2).

It should be noted that all words were presented twice during the experimental session, once in the direct and once in the indirect task. Recent studies determined the near absence of habituation in emotion processing indexed by the EPN and LPC effects suggesting that stimulus repetition is not critical for these emotional ERP modulations (Codispoti, Ferrari, & Bradley, 2006; Codispoti, Ferrari, & Bradley, 2007; Kessler et al., 2007; Olofsson & Polich, 2007; Rozenkrants, Olofsson, & Polich, 2008; Schupp et al., 2006; but see Codispoti et al., 2007, for habituation effects on the LPC after 90 repetition of the emotional stimuli). Nevertheless, participants read aloud the 128 experimental words in a paper list before the practice sequence for minimizing possible novelty effects (see Hinojosa, Carretié, Méndez-Bértolo, Míquez, & Pozo, 2009, for details). As a result of this procedure, all stimuli were presented three times to the participants, one pre-experimentally and two during the experiment.

2.3. Recording

Behavioral performance was recorded through a pressure-sensitive, piezoelectric-based, two-button keypad whose analog output (proportional to key pressure: 0.2 mV per 0.001 Newtons; range from 0 to 14.71 Newtons).

Electroencephalographic (EEG) activity was recorded using an electrode cap (ElectroCap International) with tin electrodes. Fifty-nine electrodes were placed at the scalp following a homogeneous distribution. All scalp electrodes were referenced to the nosetip.
Table 1
Characteristics of the stimuli used in the present study. Means and standard deviations (in parentheses) of valence (1, very negative, to 9, very positive), arousal (1, very calming, to 9, very arousing), concreteness (1, abstract to 9, concrete), frequency of use (per two millions), and word length given by independent samples of subjects to each stimulus type (more details are given in the main text). Mean percentage of subjects who rated them as being touchable is also provided.

<table>
<thead>
<tr>
<th></th>
<th>Negative concrete</th>
<th>Negative abstract</th>
<th>Neutral concrete</th>
<th>Neutral abstract</th>
<th>One-way ANOVA on each factor</th>
<th>Post hoc comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valence</td>
<td>2.23 (0.65)</td>
<td>1.99 (0.52)</td>
<td>5.35 (0.24)</td>
<td>5.16 (0.39)</td>
<td>(F_{3,124} = 473.82) * (NeuC = NeuA) &gt; (NegC = NegA)</td>
<td></td>
</tr>
<tr>
<td>Arousal</td>
<td>7.36 (0.64)</td>
<td>7.10 (0.96)</td>
<td>5.02 (0.38)</td>
<td>5.32 (0.65)</td>
<td>(F_{3,124} = 97.54) * (NeuC = NeuA) &gt; (NegC = NegA)</td>
<td></td>
</tr>
<tr>
<td>Concreteness</td>
<td>8.42 (0.30)</td>
<td>4.58 (0.59)</td>
<td>8.36 (0.23)</td>
<td>4.32 (0.59)</td>
<td>(F_{3,124} = 790.05) * (NeuC = NegC) &gt; (NegA = NegA)</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>35.63 (78.93)</td>
<td>56.26 (48.53)</td>
<td>39.94 (39.30)</td>
<td>52.69 (73.80)</td>
<td>(F_{3,124} = 0.78) ns</td>
<td></td>
</tr>
<tr>
<td>Word length</td>
<td>2.91 (0.82)</td>
<td>3.00 (0.88)</td>
<td>2.75 (0.88)</td>
<td>3.28 (0.82)</td>
<td>(F_{3,124} = 2.22) ns</td>
<td></td>
</tr>
<tr>
<td>% Touchable</td>
<td>94.72 (7.98)</td>
<td>3.18 (4.64)</td>
<td>98.51 (2.26)</td>
<td>6.25 (7.85)</td>
<td>(F_{3,124} = 2374.87) * (NeuC = NegC) &gt; (NeuA = NegA)</td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.001.
\(\text{n.s.}\) = non-significant; NeuC, negative concrete nouns; NeuA, neutral abstract nouns; Neu, neutral concrete nouns; Neu, neutral abstract nouns.

2.4.2. ERP analysis
Detection and quantification of early negative and late positive effects was carried out through covariance-matrix-based temporal principal component analysis (tPCA). The main advantage of tPCA over traditional procedures based on visual inspection of recordings and on ‘temporal windows of interest’ is that it presents each ERP component separately and with its ‘clean’ shape, extracting and quantifying it free of the influences of adjacent or subjacent components (Chapman & McCrary, 1995; Dien & Frishkoff, 2005). Indeed, the waveform recorded at a site on the head over a period of several hundreds of milliseconds represents a complex superposition of different overlapping electrical potentials. Such recordings can stymie visual inspection. In brief, tPCA computes the covariance between all ERP time points, which tends to be high between those time points involved in the same component, and low between those belonging to different components. The solution is therefore a set of independent factors made up of highly covarying time points, which ideally correspond to ERP components. Temporal factor scores, the tPCA-derived parameter in which extracted temporal factors may be quantified, is linearly related to amplitude. In the present study, the decision on the number of components to select was based on the scree test (Cattell, 1966). Extracted components were submitted to promax rotation, as recently recommended (Dien, 2010; Dien, 2012; Dien, Khoe, & Mangun, 2007).

Signal overlapping may occur also at the space domain. At any given time point, several neural processes (and hence, several electrical signals) may concur, and the recording at any scalp location at that moment is the electrical balance of these different neural processes. While temporal PCA “separates” ERP components along time, spatial PCA (sPCA) separates ERP components along space, each spatial factor ideally reflecting one of the concurrent neural processes underlying each temporal factor. Additionally, sPCA provides a reliable division of scalp into different recording regions, an advisable strategy prior to statistical contrasts, since ERP components frequently behave differently in some scalp areas than in others (e.g., they present opposite polarity or react differently to experimental manipulations). Basically, each region or spatial factor is formed with the scalp points where recordings tend to covary. As a result, the shape of the sPCA-configured regions is functionally based, and scarcely resembles the shape of the geometrically configured regions defined by traditional procedures. Moreover, each spatial factor can be quantified through the spatial factor score, a single parameter that reflects the amplitude of the whole spatial factor. Therefore, sPCAs were carried out for the relevant temporal factors (EPN and LPC). Also in this case, the decision on the number of factors to select was based on the scree test, and extracted factors were submitted to promax rotation.
Finally, repeated-measures ANOVAs on early negative and late positive spatial factor scores were carried out with respect to Task (two levels: Direct and Indirect) and Emotion (two levels: Negative and Neutral). Due to the purposes of the current study, our focus was on main effects of Emotion and/or its interaction with Task.

2.4.3. Source localization analysis

In order to three-dimensionally locate the cortical regions that were sensitive to the experimental effects, exact low-resolution brain electromagnetic tomography (eLORETA; Pascual-Marqui, 2007; Pascual-Marqui et al., 2011) was applied to relevant temporal factor scores. eLORETA is a 3D, discrete linear solution for the EEG inverse problem. Although, in general, solutions provided by EEG-based source-location algorithms should be interpreted with caution due to their potential error margins, LORETA solutions have shown significant correspondence with those provided by haemodynamic procedures in the same tasks (Diers et al., 2000; Mulert et al., 2004; Vitacco, Brandeis, Pascual-Marqui, & Martin, 2002). Moreover, the use of tPCA-derived factor scores instead of direct voltages (which leads to more accurate source-localization analyses: Carreté et al., 2004; Dien, 2010; Dien, Spencer, & Donchin, 2003) and the relatively large sample size employed in the present study (N = 40), contribute to reducing this error margin. In its current version, eLORETA computes the current density at each of 6239 voxels mainly located in the cortical gray matter, as well as in some deeper limbic regions (e.g., parahippocampal gyrus and uncus), of the digitized Montreal Neurological Institute (MNI) standard brain.

Specifically, three-dimensional current–density estimates for relevant temporal factor scores were computed for each participant (N = 39) and each experimental condition. Subsequently, the voxel-based whole-brain eLORETA-images (6239 voxels at a spatial resolution of 5 mm) were compared between conditions using the non-parametric mapping (SnPM) tool, as implemented in the sLORETA/eLORETA software package. As explained by Nichols and Holmes (2002), the non-parametric methodology inherently avoids multiple comparison-derived problems and does not require any assumption of normality. Voxels that showed significant differences between conditions (two-tailed corrected p < 0.05) were located in anatomical regions and Brodmann areas (BAs).

3. Results

3.1. Behavioral data

Data from RTs, force pressure and error rates (percentages) for emotional and neutral nouns in both the direct and the indirect task are shown in Table 3. For RTs, no significant effects of Emotion or the interaction between Emotion and Task were observed (F(1,38) = 2.15, p = .15 and F(1,38) = 1.47, p = .23). However, the main effect of Task was significant (F(1,38) = 15.48, p < .001, ηp² = .29): RTs were shorter in the direct task (mean ± standard error: 688.83 ± 15.75) than in the indirect task (731.48 ± 14.7). With respect to force pressure, a significant main effect of Emotion was found (F(1,38) = 7.1, p < 0.05, ηp² = .16): negative words (2.97 ± 3) caused increased key pressure compared to neutral nouns (2.82 ± 3). By contrast, the main effect of Task, as well as the interaction between Emotion and Task, was not significant (F(1,38) = 2.2, p = 0.15 and F(1,38) = 3.1, p = 0.09, respectively). Finally, with respect to error percentages, the main effect of Task was not significant (F(1,38) = 2.55, p = 0.12), but significant effects were observed for Emotion (F(1,38) = 48.85, p < .001, ηp² = .56) and its interaction with Task (F(1,38) = 31.06, p < .001, ηp² = .45). The main effect of Emotion revealed that negative words (16.42 ± 1.2) caused more errors than neutral ones (6.95 ± 8.1). Post hoc tests of simple effects performed to further explore the interaction between Emotion and Task revealed that negative words elicited more errors in the direct than in the indirect task (Bonferroni-corrected p < .001), whereas neutral words elicited more errors in the indirect than in the direct task (Bonferroni-corrected p < .01).

3.2. ERP data

3.2.1. Effects of emotion and task

Fig. 1 shows a selection of grand averages once the baseline value (prestimulus recording) had been subtracted from each ERP. These grand averages correspond to those electrode sites where the critical experimental effects (described below) were most prominent. As a consequence of the application of the tPCA, eight components1 were extracted from the ERPs (Fig. 2). Factor latency and topography characteristics revealed temporal factors 1 (peaking around 500 ms) and 5 (peaking around 220 ms) as the key components. Both, in terms of their scalp distribution and temporal characteristics, these ERP effects resembled the LPC and the EPN, respectively. As can be seen in Fig. 3, the sPCAs subsequently applied to temporal factor scores extracted two spatial factors for the LPC and three spatial factors for the EPN.

Repeated-measures ANOVAs on EPN and LPC spatial factor scores (directly related to amplitudes, as previously indicated) were carried out for Emotion and Task factors. The main effect of Task was not significant in either the posterior (F(1,38) = 0.16, p = .69) or the anterior (F(1,38) = 2.34, p = .13) LPC spatial factors. Regarding the main effect of Emotion, significant differences were found in the LPC both in posterior (F(1,38) = 22, p < .001, ηp² = .37) and anterior (F(1,38) = 40.25, p < .001, ηp² = .51) spatial factors (Fig. 3). In both cases, amplitudes were maximal in response to negative as compared to neutral nouns (Fig. 1B). Interestingly, the effect at the anterior LPC was modulated by task requirements as reflected by the Emotion × Task interaction (F(1,38) = 6.83, p < .05, ηp² = .15; Fig. 3). Post hoc tests of simple effects indicated that negative words elicited greater LPC amplitudes in the direct than in the indirect task (p < 0.01; see Fig. 1C). In the case of neutral nouns, no such differences were observed (p = .94).

In the EPN, no significant effects in any of the three spatial regions were observed (see Fig. 3) in either the main effect of Emotion (Fs(1,38), between .001 and 2.74, p > .05 in all cases) or the interaction between Task and Emotion (Fs(1,38), between .37 and .71, p > .05 in all cases). The main effect of Task was not significant in anterior (F(1,38) = 2.24, p = .14) or left posterior spatial factors (F(1,38) = 1.97 p = .17), but reached significance in the right posterior spatial factor of EPN (F(1,38) = 7.34, p < .05, ηp² = .16; Fig. 3A). Specifically, larger right posterior amplitudes were found in the direct than in the indirect task (Fig. 1A).

3.2.2. Additional analyses

Presenting the emotional direct task first in half of the participants, may have directed participants’ attention to the emotional

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1 Although the EPN and the LPC were the main focus of the current study, additional analyses on every temporal factor were conducted (two factors: Emotion and Task). These analyses showed no significant effects of either the main factors or their interaction.
aspects of the words during the subsequent implicit task. In order to disregard this possibility, a $2 \times 2 \times 2$ ANOVA with Emotion and Task as within-subject factors and Sequence order as a between-subjects factor was subsequently performed on each of the spatial factors of EPN and LPC. Results replicated those of our main analyses. Thus, the main effect of Emotion was significant for both anterior ($F(1,37) = 38.98, p < .001, \eta^2_p = .51$) and posterior LPC ($F(1,37) = 21.75, p < .001, \eta^2_p = .37$), whereas the interaction of Emotion x Task was only significant for the former ($F(1,37) = 6.4, p < .05, \eta^2_p = .15$). Importantly, the interactions between Emotion and Sequence order and the triple interaction of Emotion x Task x Sequence order were not significant in either the anterior or the posterior LPC ($Fs(1,37)$ between .06 and 2.97, $p > .05$ in all cases). With respect to the EPN, the only significant result was the main effect of Task in the right posterior spatial factor ($F(1,37) = 7.56, p < .01, \eta^2_p = .16$). The interaction of Emotion x Sequence order or the triple interaction of Emotion x Task x Sequence order was not significant in any of the spatial factors ($Fs(1,37)$ between .000 and .8, $p > .05$ in all cases).

Also, as suggested by one reviewer, the lack of any other ERP emotion effects besides the LPC could not be properly assessed with our data. It should be first noted that our study was not originally conceived to explore the interactions between emotion and concreteness, a question that has been the specific focus of previous research (e.g., Kaltwasser, Ries, Sommer, Knight, & Willems, 2013; Kanske & Kotz, 2007; Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2013; Palazova, Sommer, & Schacht, 2013; Vigliocco et al., 2013). Also, as we already mentioned in the methods the strong constraints imposed to the selection of the stimuli limited the number of trials available for each experimental condition. As a result, including concreteness as a factor in the statistical analyses would lead to a low signal-to-noise ratio since most of the participants had less than 20 valid trials in at least one of the eight new experimental conditions. Nevertheless, in order to tentatively explore this question we run an additional analysis with the factors Emotion (2 levels), Concreteness (2 levels) and Task (2 levels). Given the limitations of these analyses, the results and discussion of the data are detailed in a Supplementary materials appendix.

3.3. Source-location data

The last analytic step consisted of three-dimensionally localizing the cortical regions that were responsible for the main effect of Emotion, as well as the interaction between Emotion and Task.

![Fig. 1](image_url)
in the LPC. To achieve this, LPC temporal factor scores of each subject, electrode and condition were submitted to eLORETA. Then, the voxel-based whole brain eLORETA-images (6239 voxels at a spatial resolution of 5 mm) were compared between conditions using SnPM statistics, as implemented in the eLORETA software package. Similar to what we observed at the scalp level, LPC-related activation in response to negative words was associated with enhanced activity compared to neutral words in several voxels (threshold for two-tailed corrected \( p < 0.05 \) was 3.61). As illustrated in Fig. 4, these voxels were located in the pre-SMA (peak MNI coordinates: \( X = 15, Y = 25, Z = 60; \) BA 6/8). By contrast, neutral words did not differ between the indirect and the direct tasks in any region.

4. Discussion

In the current study we found that processing negative words implicitly and explicitly shared some brain mechanisms. Also, dissociations between explicit and implicit processing of negative content during word comprehension were observed, even though participants had to access semantic knowledge in both circumstances. Below, the main results are discussed and several implications and conclusions are presented at the end of this section.

4.1. Common mechanisms in explicit and implicit processing

Negative words elicited enhanced LPC amplitudes than neutral nouns in both the direct and the indirect task, indicating more attention allocation to the processing of these stimuli (Hinojosa et al., 2010; Kessler et al., 2009; Schacht & Sommer, 2009a, 2009b). Thus, affective significance was detected even when participants ignored the affective content and directed their attention to other features of the message. We also observed lower accuracy rates for negative compared to neutral words. This finding is in agreement with prior research and has been related to an inhibitory role of negative valence on word recognition (Bayer et al., 2012a; Borg et al., 2012; Hofmann et al., 2009).

Further analyses revealed that irrespective of the type of task (direct or indirect), the pre-SMA (BA 6/8) was responsible for the negative content-related LPC effects observed at the scalp level. This result is consistent with those of previous hemodynamic studies demonstrating that the pre-SMA is involved in the processing of words with emotional connotation in both visual and auditory
modalities (Beauregard et al., 1997; Crosson et al., 2002; Isenberg et al., 1999; Kensinger & Schacter, 2006; Warren et al., 2006). A general role of pre-SMA has been related to attentional control (Boussaoud, 2001; Hanakawa et al., 2002; Hopfinger, Buonocore, & Mangun, 2000). It is also thought to underlie representation of intentional action, as well as preparation and selection of movements (Kober et al., 2008; Lau, Rogers, Haggard, & Passingham, 2004; Nachev, Kennard, & Husain, 2008; Picard & Strick, 1996).

A primary function of emotion is the preparation for action, which can be achieved by generating action programs that are adequate for the environmental context elicited by a particular emotion (Coombes et al., 2006; Schupp, Junghöfer, Weike, & Hamm, 2003). In support of this view, recent evidence has shown response-locked ERP modulations that suggest an early impact of the positive content of words on response-preparation mechanisms in a lexical decision task (Kissler & Koessler, 2011). Interestingly, increased activity in pre-SMA has been recently reported during force production in emotional contexts (Coombes et al., 2012). Indeed, pre-SMA activation found in our study may account for the increase in key-pressure when participants responded to negative words. Our behavioral findings are in line with the results of studies that used negative pictures as stimuli with lever pushing and pulling protocols (Coombes et al., 2006). Also, Aarts and collaborators (2008) have demonstrated that participants increased their force to squeeze a handgrip when they had to detect dots either above or below positive words briefly presented. Thus, in our study pre-SMA activation during the processing of negative words could be related to a preparatory component of the efferent network required for action, which presumably resulted in enhanced pressure production as a behavioral output (Coombes et al., 2006; Coombes et al., 2012; Isenberg et al., 1999). Remarkably, these effects were evident not only when participants’ attention was directed to affective cues but also when the processing of non-affective information was emphasized.

The lack of emotion differences in RTs, which did not mirror increased pressure for negative words, deserved some comment. Although this question has not been specifically explored in the affective domain, prior research has shown that the relation between force production measures and reaction times is at least equivocal. Some reports indicate that force and timing may be dissociated as separate components in motor programming (Ivry, 1986). Alternatively, there is evidence suggesting that RTs decrease as function of rate of force production independent of force duration and peak force (Carlton, Carlton, & Newell, 1986; Carlton & Newell, 1987). Interestingly, increased peak force responses have been found to be related to shorter RTs only under conditions of time constraints (Jäskowski, van der Lubbe, Wauschkunh, Wascher, & Verleger, 2000). Thus, it seems that only some of the parameters involved on force production modulate RTs (e.g., rate of force production). In accordance with previous studies, our data suggest that greater force intensity may not necessarily be related to modulations in RTs.

4.2. Differences between explicit and implicit processing

The finding of specific effects for the explicit processing of negative words was of the greatest relevance for the purposes of the current study. In this regard, more errors were observed for negative words.
nouns in the direct compared to the indirect task. Previous reports failed to find behavioral differences between explicit and implicit processing of affective information in words, although in situations in which emotional processing could be confounded with task-demands other that implicit versus explicit processing of affective information (Frühholz et al., 2011; Straube et al., 2011). In contrast, we reported a greater disruption in the processing of negative words when affective compared to non-affective processing is emphasized even when both direct and indirect tasks required semantic evaluation to some extent. This finding suggests that negative words were more difficult to process in the direct than in the indirect task, which is probably reflecting the prolonged attentional monitoring of negative stimuli when participants’ attention was directed to the categorization of negative information (Algom et al., 2004; Estes & Verges, 2008).

A second differential effect was that negative words elicited larger amplitudes in anterior LPC scalp activity in the direct than in the indirect task. This finding is in line with the results of previous studies that showed the high sensitivity of the LPC to the difficulties and requirements of different tasks. Schacht and Sommer (2009b) observed emotion effects on LPC amplitude in lexical, semantic and valence categorization tasks that disappeared in a shallow structural task. Also, Fischer and Bradley (2006) found emotional LPC effects in semantically engaging tasks but not in lexical decision tasks or judgments based on orthographic information. Late positivities have generally been associated with top-down attentional modulation, evaluation or memory encoding (Dien, Spencer, & Donchin, 2004; Kessler et al., 2008; Schupp et al., 2003). Specifically, LPCs with anterior distributions, such as those observed here, have been related to word processing costs that reflect the focus of attention during monitoring and integration of information (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Hinojosa, Méndez-Bértolo, & Pozo, 2012; Molinario, Carreiras, & Duñabeitia, 2012; Méndez-Bértolo et al., 2011a).

In accordance with previous findings (Kaltwasser et al., 2013; but see Kanske & Kotz, 2007) our supplementary analyses showed that the emotional effect in the anterior LPC was modulated by the concreteness of the words since larger LPC amplitudes were only observed when comparing abstract negative with abstract neutral nouns. This is in line with recent studies showing that emotional content is crucial in the processing and representation of abstract concepts (Kousta et al., 2011; Vigliocco et al., 2013). Notably our results also indicated that the processing of abstract negative words elicited enhanced amplitudes in a task that required a focus on the processing of emotional properties compared to a task that directed participants’ attention to the concreteness of the words. As one reviewer suggested these findings may partly account for the lack of ERP emotional effects beside the LPC in our study, although some caution is needed to interpret these analyses due to the low signal-to-noise ratio of the data.

One source was linked to the increased anterior LPC scalp differences between explicit and implicit processing of negative words. The explicit processing of negative content recruited additional processing resources than accessing semantic knowledge about the meaningfulness and task-relevance of the presented words (see Hinojosa, Martín-Loeches, & Ruíba, 2001 and Martín-Loeches, 2007, for reviews). Taking into account these findings, the enhanced amplitude of the early negative component in to a greater extent than a focus on non-emotional features. This possibly reflects a deeper and more salient processing, which might be the consequence of the greater processing costs associated to the monitoring and integration of the information in the explicit condition.

4.3. Task effects and the EPN

Differences between the direct and the indirect tasks were found at several levels. Directing people’s attention towards the categorization of affective properties compared to ‘touchability’ judgments was associated with faster responses, as well as enhanced amplitudes of an early negativity that peaked around 220 ms in parieto-occipital scalp regions. The emotional insensitivity of this effect suggests that it is not the EPN found in some studies (Herbert et al., 2008; Kessler et al., 2009; Schacht & Sommer, 2009a, 2009b). The EPN was initially interpreted as an index of automatic attentional allocation to emotional content (Kessler et al., 2006). In this regard, Schacht and Sommer (2009b) showed a similar EPN modulation in tasks that required structural, lexical or semantic processing of the words. A possible task dependence of the EPN is supported by the results of a different set of studies where early emotion effects were observed only under certain task demands. In particular, Bayer and co-workers (2012) showed EPN effects in a lexical decision task that vanished in a passive reading task. Similarly, emotional words did not elicit EPN effects in a superficial face-word decision task (Rellecke et al., 2011), whereas the same words did so during lexical decision (Palazova et al., 2011). Finally, Frühholz and co-workers (2011) observed that emotional words only affected the EPN during an affective categorization task but not when participants had to name the color of emotional words. These results would rather suggest that the EPN to emotional words is more likely to be triggered by tasks that explicitly require in-depth or semantic processing of the word stimuli, such as those used in our study (e.g., Rellecke et al., 2011). However, recent reports challenged this view by showing an absence of EPN effects in tasks that involved semantic analyses such as concreteness judgments (Kaltwasser et al., 2013) or emotional categorization (Tempel et al., 2013).

It seems thus plausible to assume that task requirements demanding cognitive resources and competing with the automatic attention capture by emotion modulate and/or may even prevent the occurrence of the EPN (Kaltwasser et al., 2013). In fact, in the current study the presence of task effects within the time window typically associated with the EPN –and with a similar negative polarity and posterior distribution- might have contributed to attenuate EPN effects. Specifically, our results seem to indicate that evaluating affective semantic properties is faster and engage more processing resources than accessing semantic knowledge about ‘touchability’/concreteness. This can be interpreted on the light of the results of previous studies that found differences in the categorization of semantic information in posterior negativities within the time range of our effects (Adorni & Proverbio, 2012; Assadollahi & Rockstroh, 2005; Dehaene, 1995; Hinojosa, Martín-Loeches, Casado, et al., 2001; Martín-Loeches, Hinojosa, Gómez-Jarabo, & Ruíba, 2001; Mari-Beffà, Valdès, Cullen, Catena, & Houghton, 2005). In particular, between 200- and 250 ms a parieto-occipital negativity termed the ‘recognition potential’ (RP) has been shown to be sensitive to semantic aspects of visual word processing (Hinojosa, Martín-Loeches, Muñoz, et al., 2001; Martín-Loeches, Hinojosa, Gómez-Jarabo, & Ruíba, 1999; Rudell, 1992). The RP responds to manipulations of depth of semantic analysis, its amplitude increasing with the meaningfulness and task-relevance of the presented words (see Hinojosa, Martín-Loeches, & Ruíba, 2001 and Martín-Loeches, 2007, for reviews). Taking into account these findings, the enhanced amplitude of the early negative component in
the direct task would reflect that categorizing semantic knowledge about emotion compared to other semantic properties may be more accessible because of its intrinsic biological relevance.

An alternative explanation for the lack of EPN effects in our study may be outlined in terms of word frequency effects, which have been found to modulate the EPN. Scott and co-workers observed that high frequency negative words (50 per million) eliciting larger amplitudes than low frequency negative words (8 per million). In our study negative words had a medium frequency of use (on average, 46 per two million). Thus the frequency of the words used in our study may have partially contributed to the diminished EPN effects.

4.4. Limitations

It has been noted that the exact meaning of concreteness is often unclear so this dimension has been mainly interpreted as either ‘specificity’ or ‘sensory perceivability’ (Theijse et al., 2011). A potential confound of the current study relates to the definition of ‘concreteness’ in terms of the ‘touchability’ of the concepts denoted by the words. It should be remarked that ‘concreteness’ and ‘touchability’ are technically different psycho-linguistic constructs. In this sense, in our study it could be argued that tactile features may be a central aspect of ‘touchability’ whereas visual features may be more relevant in the case of ‘concreteness’. However, the correlation between these variables seems so strong that in several studies concreteness ratings are obtained by asking participants to rate the extent to which a word’s referent can be touched (e.g., Bird, Franklin, & Howard, 2001; Reilly & Kean, 2007). In fact, recent evidence has confirmed the close relation between ‘touchability’ and ‘concreteness’. In a study by Grondin, Lupker, and McRae (2009) these authors found that the tactile features of the word referents predicted response latencies in concreteness judgments. In contrast, knowledge regarding how the word’s referent is used did not predict decision latencies in the same task, even though functional knowledge was expected to be a reliable cue to concreteness. Also, the results from our pre-test study indicated that most of the concrete words were judged by participants as having touchable referents (95%), while only few abstract words were judged to denote touchable concepts (6%). Nonetheless, in our study we could not exclude the possibility that the dimensions ‘concreteness’ and ‘touchability’ denote non-exactly matching sources of semantic features. Although this potential confound may have some implications for the interpretation of the interactions between ‘concreteness’ and emotion found in our supplementary analyses, it may be less relevant when interpreting the explicit and implicit processing of emotional words.

5. Conclusions

The dissociation between the neural correlates involved in deliberate explicit and unintentional implicit processing of the affective content of words has been claimed to be important in domains such as the understanding of the mechanisms governing social interactions or the assessment of the relative usefulness of different experimental paradigms for research on emotional processing during language comprehension (Critchley et al., 2000). Previous research has been concerned with either the timing or the neural sources of intentional explicit and attention-independent implicit processing of affective information. The present study provided further evidence about the existence of commonalities and differences between these processes. By using a methodology that combined ERP and source location analyses we were able to identify a specific processing stage, as well as the underlying brain structures that were commonly and distinctively involved in implicit and explicit processing of negative words. Our data suggest that the negative content of words is processed irrespective of the focus of attention on affective or non-affectice characteristics, as revealed by the increased activity in pre-SMA around 500 ms for negative compared to neutral words. Furthermore, directing attention to the affective content of the words involved additional activation on the PCC in the same time window. A recent proposal postulated the existence of at least three stages of emotion processing during visual language comprehension (Kotz & Paulmann, 2011): (1) analysis of visual features, (2) derivation of affective meaning based on these sensory cues, and (3) evaluative processing. According to this model, our results would indicate that additional activity involved in explicit processing of negative-content words engages additional attentional resources during higher-order stimulus evaluation.

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Appendix A

Word stimuli used in the current study with their approximate translation into English.

<table>
<thead>
<tr>
<th>Negative concrete</th>
<th>Negative abstract</th>
<th>Neutral concrete</th>
<th>Neutral abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acné (acne)</td>
<td>Abismo (abyss)</td>
<td>Alfombra (carpet)</td>
<td>Adscrito (attached)</td>
</tr>
<tr>
<td>Araña (spider)</td>
<td>Agonía (agony)</td>
<td>Armario (closet)</td>
<td>Algoritmo (algorithm)</td>
</tr>
<tr>
<td>Asesino (murderer)</td>
<td>Amargura (bitterness)</td>
<td>Bolso (bag)</td>
<td>Aplicación (application)</td>
</tr>
<tr>
<td>Ataúd (coffin)</td>
<td>Ansiedad (anxiety)</td>
<td>Botón (button)</td>
<td>Baza (trick)</td>
</tr>
<tr>
<td>Babosa (slug)</td>
<td>Asco (disgust)</td>
<td>Cable (cable)</td>
<td>Budismo (buddhism)</td>
</tr>
<tr>
<td>Basura (rubbish)</td>
<td>Ataque (attack)</td>
<td>Cajón (drawer)</td>
<td>Cartesiano (cartesian)</td>
</tr>
<tr>
<td>Basturí (scalpel)</td>
<td>Ausencia (absence)</td>
<td>Calzén (stock)</td>
<td>Causa (cause)</td>
</tr>
<tr>
<td>Bomba (bomb)</td>
<td>Bajón (slump)</td>
<td>Calculadora (calculator)</td>
<td>Cifrado (encryption)</td>
</tr>
<tr>
<td>Cadáver (corpe)</td>
<td>Cansancio (tiredness)</td>
<td>Camiseta (t-shirt)</td>
<td>Comentario (comment)</td>
</tr>
<tr>
<td>Celulitis (cellulitis)</td>
<td>Castigo (punishment)</td>
<td>Cepillo (brush)</td>
<td>Definición (definition)</td>
</tr>
<tr>
<td>Cucaracha (cockroach)</td>
<td>Chapuza (botched job)</td>
<td>Corcho (cork)</td>
<td>Desierto (desert)</td>
</tr>
</tbody>
</table>
Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at [http://dx.doi.org/10.1016/j.bandc.2014.03.008](http://dx.doi.org/10.1016/j.bandc.2014.03.008).

References


