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Early effects of emotion on word immediate repetition priming: Electrophysiological and source localization evidence

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Abstract The processing of a stimulus benefits from the previous exposure of an identical stimulus, which is known as *immediate repetition priming* (IRP). Although several experimental manipulations modulate the size of this effect, the influence of affective information is still unclear. In order to explore the temporo–spatial characteristics of the interaction between emotion and IRP, event-related potentials (ERPs) to negative and neutral target words were measured during a lexical decision task in an IRP paradigm. Temporal and spatial versions of principal components analyses were used to detect and quantify those ERP components associated with IRP. A source localization procedure provided information on the neural origin of these components. Behavioural analyses showed that reaction times to repeated negative and neutral words differed from those to unrepeated negative and neutral words, respectively. However, the interaction between repetition and emotion was only marginally significant. In contrast, ERP analyses revealed specific IRP effects for negative words: Repeated negative words elicited reduced P120/enhanced N170 effects and weaker activation suppression in the left inferior frontal gyrus than did unrepeated negative words. These results suggest that a word's negative content captures attention interfering with IRP mechanisms, possibly at an early semantic stage of processing.

Keywords Immediate repetition priming · Emotion · Event-related potentials · Inferior frontal gyrus · Standardized low-resolution brain electromagnetic tomography (sLORETA)

Priming paradigms are among the most valuable methodologies for exploring the functional properties of conceptual representations and processing. One typical example is immediate repetition priming (IRP)—namely, the fact that the processing of a target stimulus can be facilitated by previous exposure to a similar prime stimulus with a short temporal lag and without intervening items (Crites, Delgado, Devine, & Lozano, 2000; Henson, Rylands, Ross, Vuilleumier, & Rugg, 2004; Kim, Kim, & Kwon, 2001).

Research on IRP has been mainly concerned with the presentation of images (e.g., Henson et al., 2004) or faces (e.g., Neumann & Schweinberger, 2008) as stimuli. Even though language is one of the primary sources from which we derive information, the effects of IRP on word processing have received less attention. Those few studies in which words have been presented to participants have reported shorter reaction times (RTs) to repeated than to unrepeated words (Bentin & McCarthy, 1994; Kim et al., 2001). This facilitation has been attributed to an automatic spread of activation from the prime to the target within a semantic network (McKoon & Ratcliff, 1992). In support of this view, several event-related potential (ERP) studies have found reduced P150/enhanced N170 amplitudes and/or reduced N400 responses for repeated as compared to novel words. These effects have been thought to reflect semantic access (Holcomb & Grainger, 2006; Huber, Tian, Curran, O'Reilly, & Woroch, 2008; Simon, Petit, Bernard, & Rebaï, 2007) and context integration processes guided by semantic information (Rugg, 1995), respectively. An alternative perspective assumes that IRP facilitates memory processing associated with response competition (Klinger, Burton, &

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Pitts, 2000). The presentation of the prime predisposes the individual to respond in a certain way. If the target is a repetition of the prime, response is facilitated because the response pathway is active. However, if the target is a novel word, the response suggested during the processing of the target must be inhibited in order to allow accurate responding to the target. The finding of higher amplitudes in a late positive component (also known as the P300 or P3) for repeated words has been associated with this mechanism (Patel & Azzam, 2005).

Recent research has demonstrated that IRP might be sensitive to the affective content of the words. In an fMRI study, Luo et al. (2004) used positive, negative, and neutral Chinese words that were preceded by a subliminal prime that was either a repetition of the target or an unrelated neutral word. Participants had to perform perceptual judgments on the shapes of the targets. The main finding was reduced activation of the visual word form area within the left middle fusiform gyrus for repeated words, which was more evident in positive than in negative repeated words. These results were interpreted as reflecting a “greater survival value embodied in negative signals and the potential loss if a greater adaptation took place.” Repetition enhancement effects for either negative or positive words were also found at other brain regions, including the left and right precentral gyri, left superior temporal sulcus, and the basal ganglia.

The study of Luo et al. (2004) provides valuable information about the brain areas implicated in the interaction between affective content and IRP. However, the temporal limitations of the fMRI technique do not allow for disentangling the particular processing stages at which the interaction between IRP and emotion might occur. Research on affective priming suggests that this might be an important issue. *Affective priming* refers to the faster processing of an emotional target word that is congruent in valence and/or arousal with a previously presented prime (Fazio, 2001; Spruyt, De Houwer, Hermans, & Eelen, 2007). Interestingly, this advantage has been suggested to operate at the specific processing stages involved in IRP. For instance, several authors have emphasized the role of affective content in accessing target meaning following automatic spreading activation from primes (Klauer, Musch, & Eder, 2005; Van den Bussche, Van den Noortgate, & Reynvoet, 2009), whereas emotional influences on response tendencies have been postulated by other researches (Fazio, 2001; Wentura, 1999). Supporting both views, some ERP studies have found modulations of semantic-related components (such as the N400) in accordance with a semantic locus of the affective priming effect (Zhang, Lawson, Guo, & Jiang, 2006), whereas others found modulations in late-latency positivities, suggesting that the mechanisms underlying affective priming are not semantic (Herring, Taylor, White, & Crites, 2011; Hinojosa, Carretié, Méndez-Bértolo, Míguez, & Pozo, 2009). Since tasks placing different processing demands on participants were used in these studies, the divergent patterns of results might be attributed in part to this circumstance: It might be that affective effects emerge at a semantic processing stage in those tasks that require the analysis of semantic features, whereas emotion influences response tendencies in those tasks in which a semantic analysis is not mandatory.

Overall, the literature reviewed above suggests that (1) the activity of several brain regions is sensitive to the affective content of words during IRP, and (2) the emotional content of words is able to influence affective priming at different stages (namely, spreading activation or response tendencies), which might also be influenced by task demands. The present study goes farther, by trying to elucidate those processing stages that might be sensitive to affective influences in IRP, a question that has not been previously explored in affective priming research. ERPs, in conjunction with a source localization technique, were used for this purpose in a task that required explicit processing of word semantic properties, which allowed a specific focus on those semantic processes that have been demonstrated to play an important role in priming. In this regard, participants performed a lexical decision task, in which negative and neutral Spanish nouns were presented as primes followed by identical repetitions, unrepeated negative/neutral nouns, or pseudoword targets. The use of this paradigm also had the advantage of making emotional processing irrelevant for the task, which avoided possible top-down attentional biases to affective aspects. Since the lexical decision task has been shown to potentiate affective priming at semantic processing stages (Klauer et al., 2005), in our study the influence of emotion was expected to be more evident in any or all of the components that have been related to semantic processing in IRP research. This result would be in agreement with those approaches to affective priming that postulate an influence of emotion during the spread of activation in semantic networks. In particular, the finding of P150/N170 modulations would suggest that affective content operates during early semantic processing in IRP, whereas modulations of the N400 component would provide evidence for the role of emotion in the integration of semantic information during IRP. However, emotional influences at a response competition level might not be totally ruled out, which would be reflected in modulations of the P300 component. Regarding the neural origin, Luo et al. (2004) found reduced activity within the left middle fusiform gyrus for negative repeated words when participants made perceptual judgements. Therefore, reduced activation within this area might be expected in our source localization analyses. However, given the different nature of our lexical decision task, effects in other brain areas should not be ruled out. In this regard, several studies have reported consistent reductions of activation in higher-order prefrontal brain areas when participants performed semantic tasks on repeated words (Kouider, Dehaene, Jobert, & Le Bihan, 2007; Maccota & Buckner, 2004; Orfanidou, Marslen-Wilson, & Davis, 2006; Raposo, Moss, Stamatakis, & Tyler, 2006). Finally, Luo et al. found faster RTs for the processing of repeated as compared to unrepeated negative words, so the same pattern of behavioural results was predicted here.

Method and materials

Participants

A group of 28 (21 female, 7 male) native Spanish speakers participated in the experiment (mean age: 20 years, range 17–32). All were right-handed (lateralization quotient 71%–100%, mean 95%) according to the Edingburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal visual acuity. All participants gave informed consent prior to the beginning of the experiment.

Stimuli

All stimuli were displayed on a computer monitor, controlled by the Gentask module of the STIM2 package (NeuroScan Inc.), using black Arial font on a grey background. Spanish nouns were used as stimuli. The nouns were selected from a previous pilot study and from the Redondo normative list of Spanish nouns (Redondo et al., 2007). In the previous pilot study, a 720-noun list divided into three sets (240 words each) was evaluated by 45 (15 for each set) individuals, who rated valence, arousal, and the level of concreteness of each noun on a 9-point Likert scale (9 being *very positive*, *very arousing*, or *very concrete*, respectively). The 720 words were divided into three sets due to the long time that evaluating all of the words would have taken for a single sample of participants.

A total of 180 negative (mean valence = 2, mean arousal = 7.33) and 180 neutral (mean valence = 5.1, mean arousal = 4.85) nouns were used as stimuli. Verbal material has less arousing potential than do other types of visual affective items, such as facial expressions or emotional scenes (Keil, 2006; Kissler, Assadollahi, & Herbert, 2006; Vanderploeg, Brown, & Marsh, 1987), and only those linguistic items that surpass a certain arousal threshold have been shown capable of reorienting attention and interacting with the ongoing task (Carretié et al., 2008; Thomas & LaBar, 2005). Negative nouns were chosen because their average arousal rating is generally high, whereas positive nouns show more variation between high- and low-arousal ratings. In addition, 90 orthographically and phonologically legal pseudowords were created. Following previous lexical decision task studies, they did not resemble any real noun in order to minimize the influence of orthographic familiarity (Proverbio & Adorni, 2008). The pseudowords were equated to the words in length (measured as the number of word syllables) and number of written accents.

Trials were arranged according to six different experimental conditions: negative prime–repeated negative target, neutral prime–repeated neutral target, negative prime–neutral unrelated target, neutral prime–negative unrelated target, negative prime–pseudoword target, and neutral prime–pseudoword target. Each word could play one of four different roles: repeated word, prime of a pseudoword, prime of an unrelated target, or unrelated target. To cancel out item-specific effects, four different experimental sets were created by dividing the 90 pseudowords into two subgroups ($n = 45$) and each group of 180 negative and 180 neutral nouns into four subgroups ($n = 45$). Each subgroup of nouns was assigned to one of the four roles to create a set. By combining all subgroups in a Latin square design, four sets were created. Each participant was presented one of these sets. The order of presentation was counterbalanced.

Nouns that were presented to participants in the ERP experiment were selected according to several criteria that were contrasted with repeated measures ANOVAs with two within-subjects factors, emotion (negative or neutral) and subgroup (four levels), and post hoc analyses with the Bonferroni correction ($\alpha < .05$). All subgroups were equated for concreteness, frequency of use (extracted from Alameda & Cuetos, 1995), and length (measured as the number of syllables). The four negative noun subgroups were equated in valence and arousal. The four neutral subgroups also had similar valence and arousal ratings. Finally, both negative and neutral groups differed significantly in valence and arousal. Table 1 summarizes the mean values in each dimension and the results of the ANOVAs.

Procedure

Following 24 practice trials, 270 trials were presented to each participant. There were 180 trials with target words and 90 trials with target pseudowords. We used this low pseudoword ratio in order to minimize postlexical strategies (see Calvo & Castillo, 2005; Neely, 1991; Ortells, Abad, Noguera, & Lupiáñez, 2001). Each trial type occurred 45 times, distributed homogeneously across three blocks (15 trials each) with two resting intervals. Trials were pseudorandomized within each block, so no more than three trials of the same type occurred consecutively.

Each trial began with a fixation cross presented for 500 ms. Following the fixation cross, a prime word was presented for 200 ms and replaced by a white screen for 100 ms, immediately followed by a target stimulus for 300 ms. The interval between the onset of the prime and the

Table 1 Means of valence (1 *negative* to 9 *positive*), arousal (1 *calming* to 9 *arousing*), concreteness (1 *abstract* to 9 *concrete*), frequency of use (per 2,000,000 words), and length (measured in syllables) for each subgroup of words

	Stimuli (n = 45)								Statistical Comparisons	
Parameters	Neg I	Neg II	Neg III	Neg IV	Neu I	Neu II	Neu III	Neu IV	(a) Emotion (*df* = 1, 44)	(b) Subgroup (*df* = 3, 132)
Valence	1.99	2.01	2.00	2.04	5.04	5.08	5.09	5.05	$F = 3{,}385.94^{***}$	$F = 0.11^{\text{n.s.}}$
Arousal	7.31	7.31	7.35	7.35	4.86	4.84	4.83	4.83	$F = 1{,}646.93^{***}$	$F = 0.01^{\text{n.s.}}$
Concreteness	6.46	6.52	6.53	6.53	6.47	6.52	6.45	6.51	$F = 0.03^{\text{n.s.}}$	$F = 0.02^{\text{n.s.}}$
Frequency of use	36.58	35.82	36.36	35.62	35.60	35.53	36.40	35.78	$F = 0.00^{\text{n.s.}}$	$F = 0.00^{\text{n.s.}}$
Length	3.13	3.13	3.11	3.11	3.11	3.11	3.11	3.09	$F = 0.05^{\text{n.s.}}$	$F = 0.01^{\text{n.s.}}$

The last two columns show the results of the statistical analyses. Neg, negative; Neu, neutral; *df*, degrees of freedom.

onset of the target (SOA) has shown to be an important parameter in priming research with emotional stimuli. Short SOAs at or below 300 ms have been found to produce the most robust effects (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Zhang et al., 2006). The intertrial interval was 2,500 ms. Figure 1 exemplifies the experimental procedure.

Participants performed a lexical decision task on the targets. They were instructed to silently read the two words but only to respond to the second one. Responses (yes/no) were given via a two-button device. Participants were told to respond quickly and accurately.

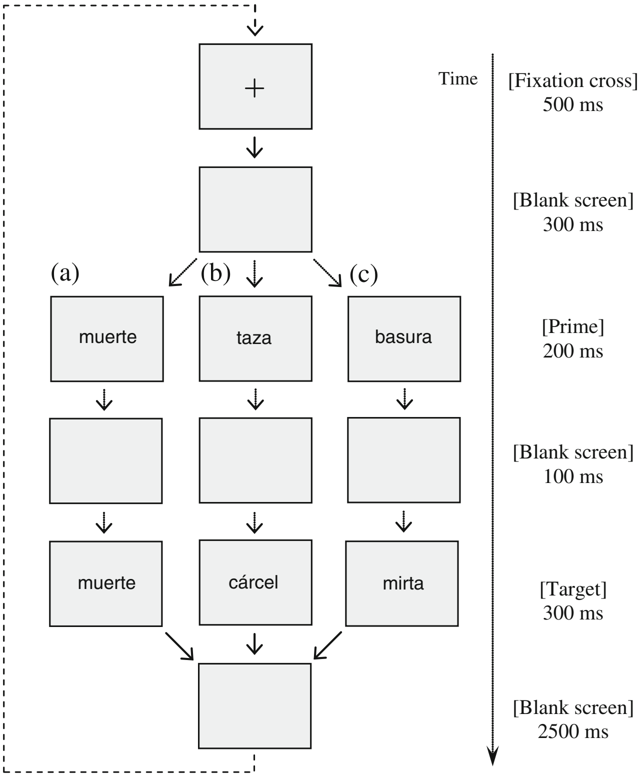

Fig. 1 Schematic illustration of the stimulation paradigm, representing (**a**) repeated, (**b**) unrepeated, or (**c**) pseudoword trials. (*muerte* = death; *taza* = cup; *basura* = garbage; *cárcel* = jail)

Prior to the practice sequence, participants were given a brief description of the ERP technique, as well as examples of the effect of muscular artefacts on the quality of the recordings, in order to motivate them to minimize possible sources of artefacts (blinks, mastoid compression, . . .).

Data acquisition

Electroencephalographic (EEG) activity was recorded using an electrode cap (Compumedics Neuroscan`s Quick-Cap) with Ag–AgCl disc electrodes. A total of 62 scalp locations homogeneously distributed over the scalp were used. All scalp electrodes were referenced to the linked mastoids. Bipolar horizontal and vertical electrooculogram was recorded for artefact rejection purposes. Electrode impedances were kept below 5 KΩ. The signals were recorded continuously with a bandpass from 0.1 to 40 Hz (3 dB points for −6 dB octave roll-off) and a digitization sampling rate of 250 Hz.

Data analysis

Trials with RTs shorter than 200 ms or longer than 1,500 ms, as well as those with incorrect responses, were excluded from the analyses. RTs and errors were analyzed by means of repeated measures ANOVAs with two within-subjects factors: condition (two levels: repeated and unrepeated) and target valence (two levels: negative and neutral). Pairwise comparisons with the Bonferroni correction ($p < .05$) were carried out in order to find out whether there were differences in repetition priming effects between negative and neutral targets.

Epochs ranging from −200 to 800 ms after target onset were defined. These epochs were baseline corrected and low-pass filtered (20 Hz/24 dB). Muscle artefacts, drifts, and amplifier blockings were removed by visual inspection before offline correction of eye movement artefacts (using the method described by Semlitsch, Anderer, Schuster, & Presslich, 1986). Individual ERPs were calculated for each experimental condition (mean number of epochs, 40) before grand averages were computed.

The components that explained the most ERP variance were detected and quantified through covariance-matrix-based temporal principal components analysis (tPCA). This method has been repeatedly recommended, since the exclusive use of traditional visual inspection of grand averages and voltage computations may lead to several types of misinterpretation (Chapman & McCrary, 1995; Coles, Gratton, Kramer, & Miller, 1986; Dien, Beal, & Berg, 2005; Foti, Hajcak, & Dien, 2009). 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. 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 (TF) score, the tPCA-derived parameter in which extracted temporal factors may be quantified, is linearly related to amplitude. In the present study, the number of components to select was based on the scree test (Cliff, 1987). Extracted components were submitted to Promax rotation, since this rotation has found to give the best overall results for tPCA (Dien, 2010; Dien et al., 2005). Repeated measures ANOVAs were carried out on TF scores. Three within-subjects factors were included in the ANOVA: condition (two levels: repeated and unrepeated), target valence (two levels: negative and neutral), and electrode (62 levels). The Greenhouse–Geisser epsilon correction was applied in order to adjust the degrees of freedom of the *F* ratios where necessary.

Signal overlapping may also occur in the space domain. At any given time point, several neural processes (and hence, several electrical signals) may occur, so the recording at any scalp location at that moment is the electrical balance of these different neural processes. While tPCA "separates" ERP components in time, spatial PCA (sPCA) separates ERP components in space, each spatial factor ideally reflecting one of the concurrent neural processes underlying each temporal factor. Additionally, sPCA provides a reliable division of the scalp into different recording regions, an advisable strategy prior to statistical contrasts, since ERP components frequently show a different behaviour in some scalp areas than in others (e.g., they present different polarity or react differently to experimental manipulations). Basically, each region or spatial factor is composed of 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 like the creation of regions of interest. 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 those temporal factors that were sensitive to our experimental manipulations—that is, exhibiting significant interactions involving condition and target valence. Again, the number of extracted factors was based on the scree test, and their spatial factor scores were submitted to Promax rotation. Repeated measures ANOVAs on spatial factor scores were carried out. Two within-subjects factors were included: condition (two levels: repeated and unrepeated) and target valence (two levels: negative and neutral). Greenhouse–Geisser epsilon correction was applied to adjust the degrees of freedom of the *F* ratios. Again, only those spatial factors showing significant condition × target valence interactions were further explored, so pairwise comparisons with the Bonferroni correction ($p < .05$) were carried out to search for differences between negative and neutral repetition priming effects.

In order to three-dimensionally locate the cortical regions that were sensitive to the experimental effects, standardized low-resolution brain electromagnetic tomography (sLORETA: Pascual-Marqui, 2002) was applied to relevant TF scores. sLORETA is a 3-D discrete linear solution for the EEG inverse problem. Although, in general, solutions provided by EEG-based source localization algorithms should be interpreted with caution due to their potential error margins, sLORETA solutions have no localization error in ideal conditions (Greenblatt, Ossadtchi, & Pflieger, 2005; Sekihara, Sahani, & Nagarajan, 2005; Soufflet & Boeijinga, 2005) and have shown significant correspondence with the solutions provided by hemodynamic procedures in the same tasks (Dierks et al., 2000; Mulert et al., 2004; Vitacco, Brandeis, Pascual-Marqui, & Martin, 2002), including the lexical decision task (Proverbio, Zani, & Adorni, 2008) and immediate repetition priming procedures (Kim et al., 2008). Moreover, the use of tPCA-derived factor scores instead of direct voltages (which leads to more accurate source localization analyses; see Carretié et al., 2004), the spatial density of recording active electrodes (62), and the relatively large sample size employed in the present study ($N = 28$) all contribute to reducing this error margin. In its current version, sLORETA computes the standardized current density at each of 6,239 voxels in the cortical grey matter and the hippocampus of the digitized Montreal Neurological Institute (MNI) standard brain.

With the aim of identifying the neural mechanisms underlying specific modulations of IRP by negative words, an analysis was carried out for the relevant temporal factors for each participant and electrode. The voxel-based whole-brain sLORETA images were compared between negative repeated and negative unrepeated words (whenever specific effects were found for negative stimuli) using the sLORETA built-in voxelwise randomization test (5,000 permutations) based on the statistical nonparametric mapping (SnPM) methodology (see Nichols & Holmes, 2001, for details). The significance threshold was fixed at $p < .05$.

Results

Behavioural data

Repeated measures ANOVAs on RTs showed main effects of condition [$F(1, 27) = 63$, $p < .001$] and target valence [$F(1, 27) = 21$, $p < .001$]. The interaction between condition and target valence was only marginally significant [$F(1, 27) = 3.3$, $p = .08$]. Pairwise comparisons ($p < .05$) showed that participants' lexical decisions were faster for repeated words (527 ms) than for unrepeated words (638 ms). Further analyses revealed that RTs were shorter for repeated negative nouns (531 ms) than for unrepeated negative nouns (648 ms), as well as for repeated neutral nouns (523 ms) than for unrepeated neutral nouns (629 ms). Finally, negative repeated nouns showed significantly longer RTs than neutral repeated words.

Regarding accuracy ratings, repeated measures ANOVAs showed a significant main effect of condition [$F(1, 27) = 20.8$, $p < .001$]. Participants made fewer errors to repeated target words (0.84 errors) than to unrepeated target words (2.29 errors). However, this effect was not modulated by target valence [$F(1, 27) = 1.9$, $p > .05$]. Table 2 summarizes the mean RTs and accuracy ratings on each condition.

Electrophysiological data

A selection of the grand averages is represented in Figure 2. These grand averages correspond to those scalp areas where experimental effects (described later) were most evident. As a consequence of the application of the tPCA, five components were extracted from the ERPs. The factor loadings are represented in Figure 3. Repeated measures ANOVAs carried out on the TF scores for the factors condition, target valence, and electrode revealed that three of these components were sensitive to our experimental manipulations. Hereafter, to make the results easier to understand, the ERP components associated with TF2, TF3, and TF5 will be labelled P300, P120/N170 complex[1] (which roughly corresponds to previous P150–N170 effects), and N500 (which roughly corresponds to previous N400 effects), respectively, due to their latencies and polarities. The interaction between condition, target valence, and electrode was significant in the P300 [TF2; $F(61, 1647) = 5.33$, $p < .01$], the P120/N170 complex [TF3 (see note 1); $F(61, 1647) = 3.67$, $p < .05$], and the N500 [TF5; $F(61, 1647) = 7.46$, $p < .001$]. The effect of condition alone was significant in both the P300 [$F(1, 27) = 121.26$, $p < .001$] and the N500 [$F(1, 27) = 10.1$, $p < .01$]. Finally, target valence was significant in the P120/N170 complex [$F(1, 27) = 5.63$, $p < .05$]. Therefore, our data suggest that IRP modulated the amplitude of several components that were previously associated with different processing stages: the P120/N170 complex (which roughly corresponds to previous P150/N170 effects) and the N500 (which roughly corresponds to previous N400 effects), which have been related to early and late semantic processing, and the P300, which has been thought to index memory-related processes (e.g., Holcomb & Grainger, 2006; Rugg, 1995).

Subsequent sPCAs were applied to the TF scores with the purpose of specifically locating those scalp regions that were associated with the effects found in the tPCA and further confirming that the components are sensitive to our experimental manipulations, based on the scalp regions that showed the effects. As is shown in Table 3, the sPCAs extracted four spatial factors for the P120/N170, two spatial factors for the P300, and two spatial factors for the N500. Repeated measures ANOVAs on the P120/N170, P300, and N500 spatial factor scores (directly related to amplitudes, as previously indicated) were carried out for the condition and target valence factors. First, we examined the main effect of condition to confirm that P120/N170, P300, and N500 amplitudes were associated with IRP: As expected, they were larger in repeated relative to unrepeated targets at right and left posterior regions for the P120/N170 component and at anterior and posterior regions for the P300 (Table 3, column a). Repeated words also showed enhanced N400 amplitudes as compared to unrepeated words (Table 3,

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[1] Two different components can be appreciated in the pattern of ERPs (P120 and N170; see Fig. 4). However, the results of the tPCA analysis unequivocally grouped them into one temporal factor. Although the scree test and the eigenvalues clearly indicated that five factors should be extracted, we tried to increase the number of extracted factors up to eight. These analyses were not able to segregate the P120/N170 complex into two independent temporal factors. As noted before, tPCA indicates which ERP time points have greater covariance. Therefore, our results suggest that these components behave in a similar way. In agreement with our findings, Holcomb and Grainger (2006) reported a P150 component that seemed to be superimposed on a large N170 component during word IRP.

Table 2 Means and standard deviations (in parentheses) of reaction times (RTs) and error rates on each condition

	NegRep	NeuRep	NegUnr	NeuUnr	NegPse	NeuPse
RTs (ms)	531 (128)	523 (127)	648 (94)	629 (102)	713 (125)	720 (123)
Errors rate	0.61 (1.13)	1.07 (1.49)	2.25 (2.17)	2.32 (1.52)	1.64 (2.28)	1.64 (1.47)

NegRep, negative repeated targets; NeuRep, neutral repeated targets; NegUnr, negative unrepeated targets; NeuUnr, neutral unrepeated targets; NegPse, pseudoword targets preceded by negative nouns; NeuPse, pseudoword targets preceded by neutral nouns.

column a). The second objective of the analyses was to examine whether the amplitude of those components that showed sensitivity to IRP was influenced by emotion. In this case, the condition × target valence interaction was the relevant contrast. This interaction was significant in posterior regions for the P300, and in anterior regions for the N500 (Table 3, column c). However, pairwise comparisons showed that this interaction reflected differences between negative and neutral unrepeated targets, since both negative and neutral repeated targets differed from negative and neutral unrepeated targets, respectively. The condition × target valence interaction also reached significance in right posterior regions for the P120/N170 component (Table 3, column c): In this case, pairwise comparisons indicated that whereas repeated negative words elicited higher amplitudes than did unrepeated negative words in this component, no differences were found for the comparison between repeated and unrepeated neutral targets. Figure 4 shows this specific effect found for negative words

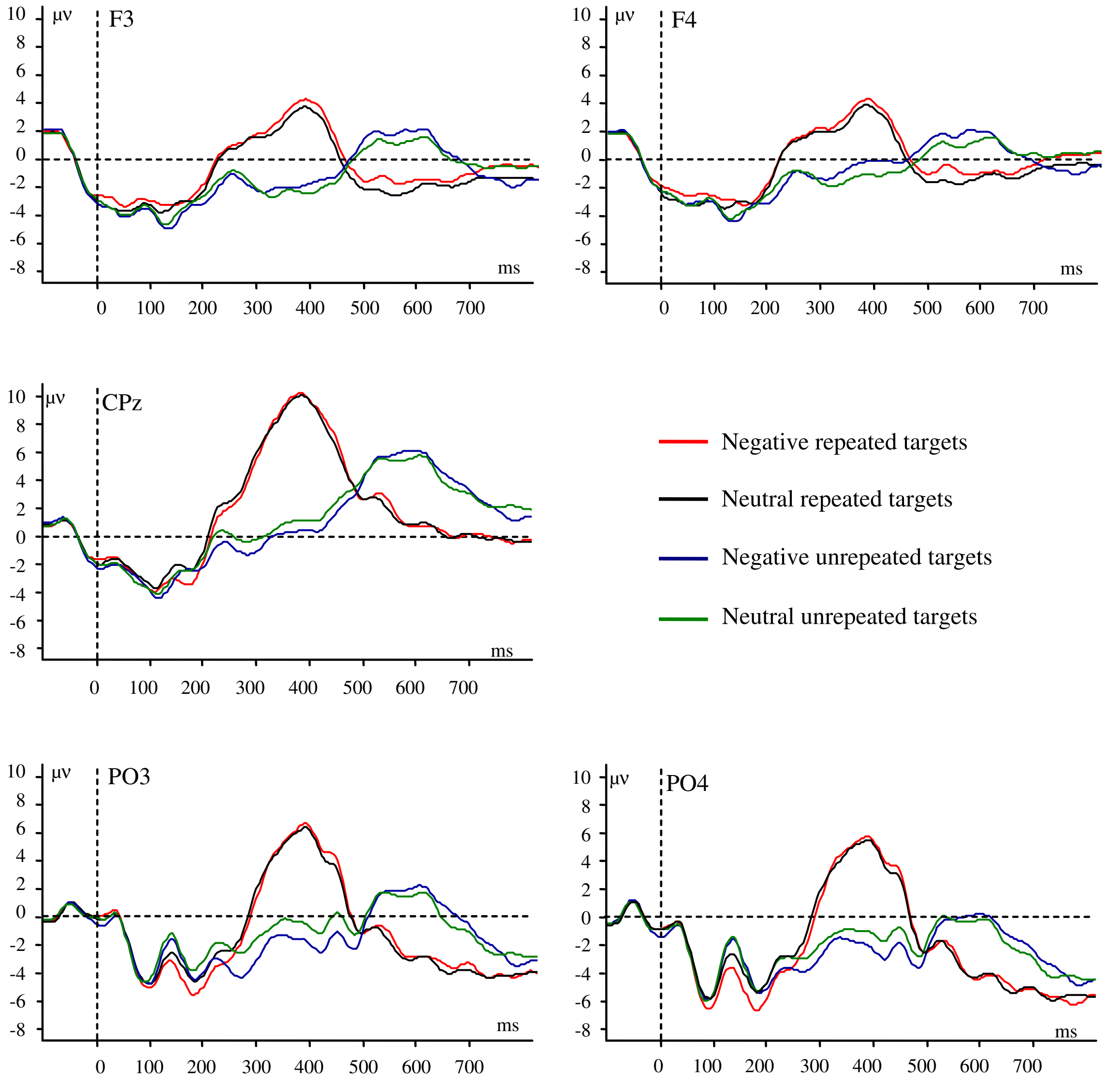

Fig. 2 Grand averaged ERPs elicited by the target words in all six experimental conditions at a selected sample of electrodes

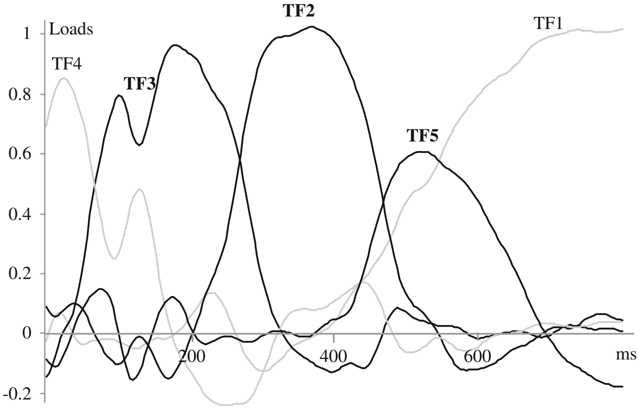

Fig. 3 tPCA: Factor loadings after Promax rotation. Temporal factors 3 (TF3; P120–N170 complex), 2 (TF2; P300), and 5 (TF5; N500) are drawn in black

at a representative electrode, as well as the topographical difference map after subtracting the activity elicited by unrepeated negative words from that elicited by repeated negative words. In sum, the ERP data summarized in Table 3 show that although late semantic stages and memory-related processes are sensitive to the IRP of both negative and neutral words (as reflected in P300 and N400 modulations), specific effects of emotion were only evident during early stages of language processing, as reflected by the reduced P120/enhanced N170 amplitudes found for repeated negative words at right posterior electrodes.

Source localization data

The last analysis consisted of three-dimensionally localizing the cortical regions that were responsible for the specific effects of negative content on word IRP described above. To this end, P120/N170 TF scores for each participant and electrode for the negative repeated and negative unrepeated targets were compared using nonparametric randomization tests ($p < .05$). As can be observed in Figure 5, certain voxels in the left frontal cortex showed significantly higher activity for negative repeated versus negative unrepeated targets. The voxel showing the greater enhancement of activity for negative repeated nouns was located at the left inferior frontal gyrus (IFG)[2] (BA 47; MNI coordinates: $x = -45$, $y = 40$, $z = -15$). Twenty-five more voxels belonging to left BAs 10, 11, and 47 (inferior and middle frontal gyrus) exceeded the statistical threshold (see the table attached to Fig. 5 for detailed descriptions of these voxels). Similar analyses were conducted to compare the P120/N170 effects for repeated and unrepeated neutral words. The results of the nonparametric randomization tests revealed no differences between these conditions at any brain region.

Discussion

IRP reflects the facilitated processing of a stimulus when an identical stimulus has been exposed immediately before. The present study aimed to identify those processing stages that could be sensitive to the impact of affective information during IRP. In accordance with our hypothesis and those proposals that highlight the role of spreading activation in semantic networks during affective priming, reduced P120/enhanced N170 amplitudes at right posterior electrodes and increased activity in the left IFG (BA 47) was specifically found for negative repeated as compared to negative unrepeated targets.

Behavioural effects

Replicating the findings of previous studies, behavioural results showed a significant priming effect for both neutral and negative repeated words as compared to unrepeated words[3] (Bentin & Peled, 1990; Rugg, 2007). Although the pairwise comparisons revealed that negative repeated words elicited longer responses than neutral repeated words, the interaction between emotion and repetition was only marginally significant. Interestingly, similar marginal effects in the RTs were found in the study of Luo et al. (2004; $p = .09$). Research on affective priming has shown inconsistent results at a behavioural level. Overall, it seems that those tasks that require explicit affective categorization of the stimuli show robust effects, but affective priming is much harder to find when participants perform implicit tasks (De Houwer, Hermans, Rothermund, & Wentura, 2002; Klauer & Musch, 2003; Storbeck & Robinson, 2004). In accordance with our data, several priming studies have failed to observe affective effects on target processing when using lexical decision tasks (e.g., Kissler & Koessler, 2011; Storbeck & Robinson, 2004; but see Wentura, 2000). The present data generalizes these findings to a particular type of priming by suggesting that the influence of emotion on IRP at a behavioural level is rather

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[2] The inferior frontal gyrus has been involved in several aspects of IRP, language, and affective processing (see the Discussion section). Besides the results of the tPCA analyses, the plausibility of this finding argues in favour of considering the P120/N170 a unitary effect instead of two separate components.

[3] The RT results found in the present study diverged to some extent from those reported in the study of Luo et al. (2004), who also explored the interaction between emotion and IRP. In that study, no significant priming was obtained for neutral repeated words. The authors attributed this lack of an effect to the predominant emotional context (2/3 of the total number of trials included emotional targets), which made participants bias their attention to emotional trials. In support of this view, we found repetition priming in the absence of such a proportion-related bias.

Table 3 Results of the statistical contrasts and pairwise comparisons on P120/N170, P300, and N500 spatial factors: (**a**) main effects of condition, (**b**) main effects of target valence, and (**c**) main effects of condition × target valence interaction

Temporal Factor	Spatial Factor	(a) Condition	Pairwise	(b) Target Valence	Pairwise	(c) Condition × Target Valence	Pairwise
TF 3 (P120–N170)	Anterior	$F = 14.99^{**}$	Rep < Unr	$F = 0.10^{\text{n.s.}}$		$F = 2.93^{\text{n.s.}}$	
	Central	$F = 2.20^{\text{n.s.}}$		$F = 6.29^{*}$	Neg > Neu	$F = 0.59^{\text{n.s.}}$	
	Right posterior	$F = 8.84^{*}$	Rep > Unr	$F = 7.40^{*}$	Neg > Neu	$F = 6.20^{*}$	NegRep > NegUnr NegRep > NeuRep
	Left posterior	$F = 4.98^{*}$	Rep > Unr	$F = 9.41^{*}$	Neg > Neu	$F = 2.53^{\text{n.s.}}$	
TF 2 (P300)	Anterior	$F = 96.15^{***}$	Rep > Unr	$F = 2.13^{\text{n.s.}}$		$F = 0.07^{\text{n.s.}}$	
	Posterior	$F = 129.31^{***}$	Rep > Unr	$F = 9.24^{*}$	Neg < Neu	$F = 8.00^{*}$	NegRep > NegUnr NeuRep > NeuUnr NegUnr < NeuUnr
TF 5 (N500)	Anterior	$F = 19.13^{***}$	Rep > Unr	$F = 8.81^{*}$	Neg < Neu	$F = 5.76^{*}$	NegRep > NegUnr NeuRep > NeuUnr NegUnr < NeuUnr
	Posterior	$F = 2.46^{\text{n.s.}}$		$F = 0.04^{\text{n.s.}}$		$F = 0.73^{\text{n.s.}}$	

Degrees of freedom = 1, 27. Neg, negative; Neu, neutral; NegRep, negative repeated targets; NeuRep, neutral repeated targets; NegUnr, negative unrepeated targets; NeuUnr, neutral unrepeated targets; NegPse, pseudoword targets preceded by negative nouns; NeuPse, pseudoword targets preceded by neutral nouns. $^{*}p < .05$; $^{***}p < .001$; n.s., nonsignificant.

weak. One advantage of using ERPs is that the components can be examined in the absence of a behavioural response. Therefore, the finding of electrophysiological effects in the absence of behavioural modulations is not rare (e.g., Hinojosa et al., 2009; Kissler & Koessler, 2011), and indeed it is also the case in the present study.

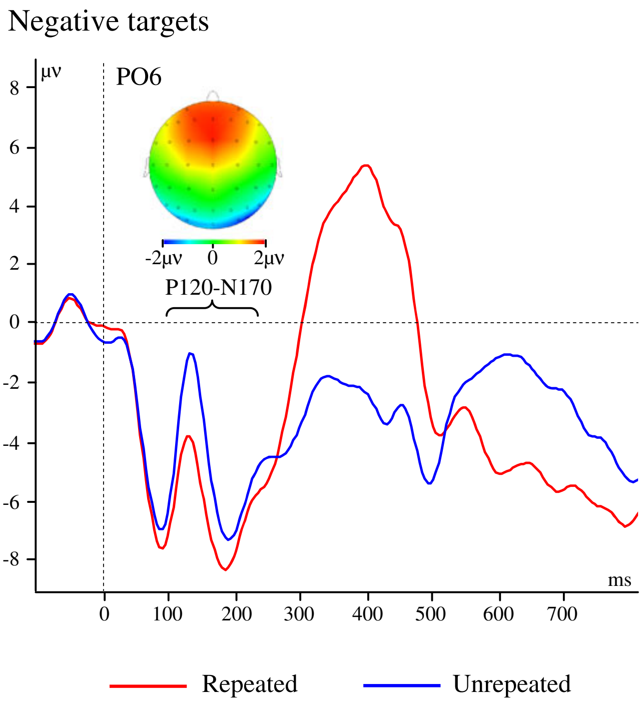
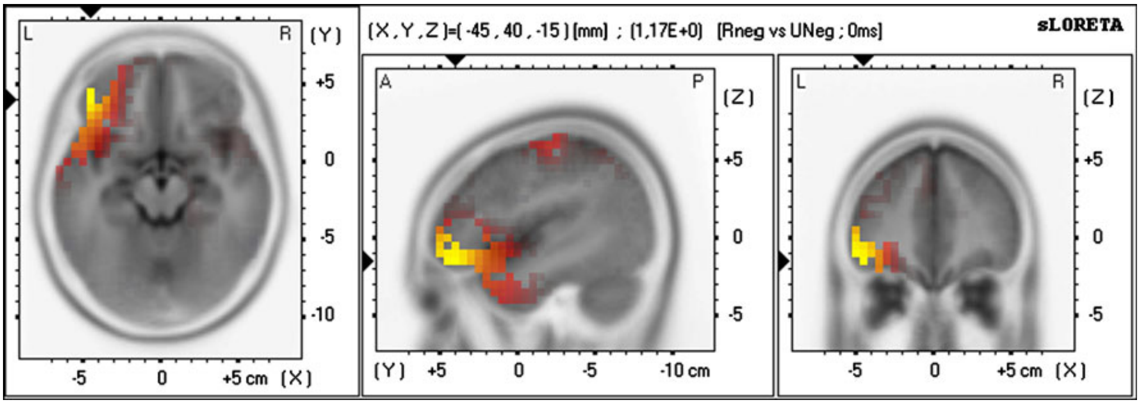

Negative targets

Fig. 4 Grand averages at the PO6 electrode, along with a topographic difference map of the distribution of the P120/N170 complex for negative stimuli. In the map, the activity associated with unrepeated stimuli has been subtracted from the activity elicited by repeated stimuli

Electrophysiological effects

IRP influenced the amplitude of the P300 and N500 waveforms in the present study. Replicating previous findings, repeated words elicited higher P300s than did unrepeated words, although no specific effects were observed for negative words. The P300 has been considered to reflect several implicit and explicit aspects of memory that have to do with word recollection (Patel & Azzam, 2005). Also, IRP studies have usually found that repeated words are associated with reduced N400 responses as compared to unrepeated words, which has been linked to facilitated lexico–semantic and context integration analyses for repeated words (Rugg, 1995). However, in the present study we found larger amplitudes for repeated than for unrepeated words. Similar reversed N400 effects have been observed in those studies that used short prime presentations (Bermeitinger, Frings, & Wentura, 2008; Paulmann & Pell, 2010), and such effects have been attributed to the weak concept activation of primes with brief durations. Our data suggest that during the integration of semantic information in context, repeated targets become less accessible than unrepeated targets following a short prime presentation, resulting in larger N400 amplitudes. Therefore, it seems that the processing of neutral and negative repeated words was facilitated at some memory-related stages, whereas it was disrupted at late semantic stages (for a detailed discussion of



X (MNI)	Y (MNI)	Z (MNI)	VoxelValue	Brodmann Area	Structure
-45	40	-15	1.16589E+0	47	Inferior Frontal Gyrus
-50	40	-10	1.16472E+0	47	Inferior Frontal Gyrus
-50	45	-10	1.16277E+0	47	Inferior Frontal Gyrus
-45	45	-15	1.16012E+0	11	Middle Frontal Gyrus
-45	40	-10	1.15378E+0	47	Middle Frontal Gyrus
-45	45	-10	1.14874E+0	11	Middle Frontal Gyrus
-50	40	-5	1.14812E+0	47	Middle Frontal Gyrus
-45	40	-5	1.13342E+0	47	Middle Frontal Gyrus
-45	35	-15	1.13329E+0	47	Inferior Frontal Gyrus
-45	35	-10	1.13028E+0	47	Inferior Frontal Gyrus
-50	35	-5	1.12934E+0	47	Inferior Frontal Gyrus
-45	50	-10	1.12392E+0	11	Middle Frontal Gyrus
-50	40	0	1.11860E+0	47	Middle Frontal Gyrus
-40	40	-10	1.10574E+0	47	Middle Frontal Gyrus
-45	50	-5	1.10276E+0	10	Middle Frontal Gyrus
-50	30	-10	1.10251E+0	47	Inferior Frontal Gyrus
-50	35	0	1.09292E+0	47	Inferior Frontal Gyrus
-45	45	0	1.09174E+0	10	Inferior Frontal Gyrus
-40	40	-5	1.08175E+0	47	Middle Frontal Gyrus
-55	30	-5	1.08090E+0	47	Inferior Frontal Gyrus
-45	30	-10	1.07731E+0	47	Inferior Frontal Gyrus
-40	35	-10	1.07549E+0	11	Middle Frontal Gyrus
-55	35	0	1.07483E+0	47	Inferior Frontal Gyrus
-40	35	-15	1.07332E+0	11	Middle Frontal Gyrus
-45	30	-15	1.06946E+0	47	Inferior Frontal Gyrus
-40	50	-10	1.06824E+0	11	Middle Frontal Gyrus

Fig. 5 sLORETA solutions to nonparametric randomization tests on P120/N170 complex temporal factor scores, showing voxels in which the negative repeated > negative unrepeated contrast was significant ($p < .05$)

these effects, see Dehaene et al., 2001; Matsumoto, Iidaka, Nomura, & Ohira, 2005; Paulmann & Pell, 2010; Rugg, 1995; Rugg & Nagy, 1987).

Of the greatest interest for the purposes on this study was the finding of reduced P120/enhanced N170 amplitude for immediately repeated negative targets as compared to unrepeated negative targets. This early latency effect has been linked to the spreading of activation in semantic networks in previous priming research (Holcomb & Grainger, 2006; Huber et al., 2008; Simon, Petit, Bernard, & Rebaï, 2007). In accordance with this view, amplitude modulations in several positivities and negativities around 150 ms have been interpreted in terms of access to the semantic properties of words (Bentin, McCarthy, & Wood, 1985; Hauk, Davis, Ford, Pulvermüller & Marslen-Wilson 2006a; Hauk et al. 2006b; Penolazzi, Hauk, & Pulvermüller, 2007; Pulvermüller, Lutzenberger, & Birbaumer, 1995; Segalowitz & Zheng, 2009; Sereno, Brewer, & O'Donnell, 2003; Sereno, Rayner, & Posner, 1998), although the involvement of orthographic processing might not be totally excluded (Holcomb & Grainger, 2006; Proverbio, Vecchi, & Zani, 2004).

Amplitude enhancements in several ERP components during the processing of negative words have been mainly thought to reflect disruption during the performance of the ongoing task due to the capacity of negative stimuli to capture attention and engage processing resources (Carretié et al., 2008; Hinojosa, Méndez-Bértolo, & Pozo, 2010; Kissler et al., 2006). Taking all of these findings into consideration, our ERP data might be interpreted as reflecting that the immediate repetition of negative words attracts attention, prompting the allocation of further processing resources in a way that impairs the spreading activation mechanisms associated with the processing of the orthographic and/or early semantic aspects of the target words.

Source localization effects

The results of the sLORETA analysis showed that the reduced P120/enhanced N170 amplitude for negative repeated as compared to unrepeated words was associated with greater activity in BA 47, which is located in the ventral part of the left IFG. Previous fMRI studies reported a "suppression effect" consisting of a decrease in the signal in left inferior frontal and prefrontal cortices after the repetition of words, which reflects more efficient processing of the repeated stimulus (Raposo et al., 2006; Thiel et al., 2005; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997). However, the lack of differences between repeated and unrepeated neutral words also indicated that this region is not merely involved in IRP regardless of the emotional valence of the stimuli. In fact, some neuroimaging studies have found greater activation for negative than for neutral words during lexical decision and silent reading tasks (Demirakca et al., 2009; Kuchinke et al., 2005).

Interestingly, the results of a recent meta-analysis of fMRI and PET literature point to a crucial role of the left IFG (in particular, BA 47) in semantic processing (Binder, Desai, Graves, & Conant, 2009). Activation of the left IFG has been consistently found in semantic tasks that require effortful retrieval of semantic representations (Fiez, 1997) or selection among competing semantic representations (Thompson-Schill, D'Esposito, & Kan, 1999). It has been proposed that the IFG could be a semantic executive system that controls the access, retrieval, selection, and gating of semantic information by the modulation or reactivation of representations in posterior brain regions (Goldberg, Perfetti, Fiez, & Schneider 2007; Roskies, Fiez, Balota, Raichle, & Petersen, 2001; Simmons, Miller, Feinstein, Goldberg, & Paulus, 2005; Wagner et al., 1997). Interestingly, MEG activity in the left IFG has been recorded during the passive viewing of words as compared to consonant strings and unfamiliar faces around 150 ms, which points towards the implication of this region in very early semantic processing (Cornelissen et al., 2009). Therefore, our source localization data indicate that, in agreement with views that have postulated that emotional influences operate at a semantic level in priming, the left IFG might be an important region for the processing of the early semantic aspects of negative information during immediate word repetition.

It should be noted that our results differed in some aspects from those reported in Luo et al.'s (2004) work. In the present study, affective effects on IRP were found to modulate the activity of the IFG, whereas the main emotional effects in Luo et al.'s study were located within the fusiform gyrus. The divergent results might reflect differences in task requirements. In Luo et al.'s study, participants were required to judge the shape of the target, which was in either an italic or an upright shape. Therefore, attention was directed to the perceptual features of the stimuli, which might explain the greater involvement of the visual word form area. In contrast, participants' attention was explicitly directed to the semantic aspects of the targets in our experiment, since they had to decide whether a particular stimulus was a word or a pseudoword.

Limitations of the present study and open questions

The present study constitutes a first attempt to explore the temporal course of emotional influences on immediate word repetition. Therefore, it is important to note several limitations of this study. First, it could be argued that the specific IRP effect for negative words found in our study could simply reflect an effect of affective congruency, such as that found in typical affective priming research. However, including a control condition in which negative and neutral targets were preceded by negative and neutral unrelated words, respectively, might be problematic. This way of proceeding would imply an additional repetition of the target during the experimental session, so no "pure" affective priming effects could be unequivocally disentangled from the effects of emotional content on IRP. Nonetheless, several considerations prevent us from attributing our results to general affective priming effects. It should be noted that previous research on affective priming with ERPs found modulations of late-latency components (Hinojosa et al., 2009; Zhang et al., 2006). In contrast, the modulation of the P120/N170 found in the present study seems to fit very well with the findings of previous ERP studies on IRP with nonaffective stimuli (Holcomb & Grainger, 2006; Raposo et al., 2006). Clarifying the relationship between affective and IRP will be an important objective for future research.

Second, our methods did not allow us to disentangle the contributions of arousal and valence to the IRP effect, since neutral and negative words differed in both affective dimensions. It remains an open question whether the immediate repetition of positive words would result in similar modulations of the P120/N170 and of IFG activity (thus suggesting an arousal effect) or would lead to a different pattern of results (which would rather suggest a valence-driven effect). Measuring ERP changes associated with the immediate repetition of both positive and negative words would shed light on this issue.

Conclusions

The results of this study extend previous findings by delineating the temporal course of affective effects on IRP. Convergent electrophysiological and source localization data were found that showed that negative content modulates IRP in a task that demands explicit semantic processing of the stimuli. Specific effects for negative repeated words were associated with reduced P120/enhanced N170 amplitudes in right posterior electrodes and with weaker suppression of activity in the left IFG. These combined effects were interpreted as reflecting that negative information attracted attention and disrupted early semantic processing that has to do with the modulation of word representations in posterior brain regions. Therefore, by using a task that involved lexico–semantic processing of the stimuli, our data support those theoretical views that postulate a spreading activation mechanism within semantic networks.

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