

## COGNITIVE NEUROSCIENCE

# Emotional context enhances auditory novelty processing: behavioural and electrophysiological evidence

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## Abstract

Viewing emotionally negative pictures has been proposed to attenuate brain responses towards sudden auditory events, as more attentional resources are allocated to the affective visual stimuli. However, peripheral reflexes have been shown intensified. These observations have raised the question of whether an emotional context actually facilitates or attenuates processing in the auditory novelty system. Using scalp event-related potentials we measured brain responses induced by novel sounds when participants responded to visual stimuli displaying either threatening or neutral sceneries. We then tested the modulatory effect of the emotional task conditions on auditory responses. Novel sounds yielded a stronger behavioural disruption on subjects' visual task performance when responding to negative pictures compared with when responding to the neutral ones. Accordingly, very early novelty-P3 responses to novel sounds were enhanced in negative context. These results provide strong evidence that the emotional context enhances the activation of neural networks in the auditory novelty system, gating acoustic novelty processing under potentially threatening conditions.

## Introduction

The ability to select salient stimuli from a complex environment is crucial for adaptive behaviour. Due to the limited processing capacity of sensory systems, only a part of the incoming information gains access to consciousness. For this purpose, the human nervous system maintains two attentional processes under constant equilibrium: active selection, or top-down control; and the breakthrough of the unattended (James, 1890), responding to bottom-up signals, which enable the conscious evaluation of potentially important events that are not being top-down selected. This has been consistently illustrated in oddball experimental designs, where the unexpected occurrence of auditory novel events recruits attentional resources from the ongoing task and leads to behavioural disruption, a phenomenon called distraction (Schröger, 1996; Alho *et al.*, 1997; Escera *et al.*, 1998, 2000, 2001, 2003; Schröger & Wolff, 1998). This effect is accompanied by a well-defined pattern of neuroelectrical activation characterized mainly by the N1-enhancement/MMN and the novelty-P3 cognitive potentials (Escera *et al.*, 1998, 2000; Escera & Corral, 2003).

In this sense, it has been suggested that involuntary attention and its underlying neural substrate may be modulated if the amount of attentional resources available is modified by a competing task (Berti & Schröger, 2003; SanMiguel *et al.*, 2008; see Lavie, 2005 for a review), that is, for instance, by increasing working memory load. In a

similar vein, this critical role of top-down processes on involuntary attention may be considered in terms of the emotional load of the task. A large body of literature has evidenced that emotional stimuli have a privileged status in the neural processing systems, eliciting stronger and faster attention capture than non-emotional stimuli (e.g. Eastwood *et al.*, 2001; Öhman *et al.*, 2001; Carretié *et al.*, 2004; Richards & Blanchette, 2004) and interfering in the processing of concomitant stimuli, not only within (e.g. Öhman *et al.*, 2001; Fox, 2002) but also across sensory modalities. Psychophysiological studies have yielded a potentiation of peripheral responses elicited by auditory stimuli while visualizing emotionally loaded pictures, such as the startle reflex, typical after the sudden burst of a white noise (Stanley & Knight, 2004; Bradley *et al.*, 2006). However, it has been suggested that less attentional resources might be available for sound processing when emotional stimuli are visualized, as a consequence of allocating more attention to these valenced stimuli (Schupp *et al.*, 1997; Cuthbert *et al.*, 1998; Keil *et al.*, 2007). In the present study, we used event-related brain potentials (ERPs) to assess the effects of manipulating the implicit emotional load in a visual task, by means of images loaded with a negative valence, towards the processing of irrelevant novel sounds. If the emotional context facilitates the processing of task-irrelevant novel events, these sounds should elicit greater distraction when subjects respond to emotionally loaded stimuli as compared with the neutral ones. If, on the contrary, emotional processing depletes most of the attentional resources, distraction should decrease. In either case, the electrophysiological pattern of novelty-processing responses should be modulated accordingly at a certain stage.

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## Materials and methods

### Subjects

Fourteen right-handed female volunteers, aged between 18 and 29 years (mean  $22 \pm 4.2$ ) without past neurological or psychiatric history, no reported specific phobias, drug consumption or abnormal audition participated in the present study. It is known that emotional processes may be subject to gender differences (e.g. Orozco & Ehlers, 1998; Kemp *et al.*, 2004; Hofer *et al.*, 2007). Thus, only women were included in the present study, to ensure a high sample homogeneity concerning the effects of emotion and avoid unwanted gender differences in the processing of the emotional pictures. All subjects had normal or corrected-to normal vision and presented anxiety levels within the normal range of the Anxiety Trait and State scale (STAI; Spielberger *et al.*, 1983). All subjects gave written informed consent and the experimental protocol was approved by the Ethical Committee of University of Barcelona, and were in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

### Stimuli

#### Emotional stimuli

The emotional stimuli were 208 pictures taken from The International Affective Picture System (IAPS, Center for Research in Psychophysiology, University of Florida, Gainesville, USA; Lang *et al.*, 2005). They included a total of 188 neutrally (e.g. a landscape or a chair) and 120 negatively valenced pictures (see Supporting information, Table S1), the latter depicting scenes of extreme violence and disgust (e.g. a snake in attack position or a mutilated body). Pictures were selected among the most highly rated at the Self-Assessment Manikin (SAM) standards (Lang, 1980) both for arousal and emotional valence dimensions, and evaluated by the participants after the experimental session. Average rates of neutral pictures were  $4 \pm 0.3$  and  $5.41 \pm 0.4$  for valence (meaning here 1 the most positive) and arousal (meaning here 1 the highest), respectively, and average rates of negative pictures were  $7.89 \pm 0.2$  and  $3.14 \pm 0.6$  for valence and arousal, respectively. Valence and arousal rates differed significantly for neutral and negative pictures (valence:  $F_{1,13} = 239.06$ ,  $P < 0.001$ ; arousal:  $F_{1,13} = 27.12$ ,  $P < 0.001$ ). SAM ratings for the pictures used here differed both for valence ( $T_{119} = 21.28$ ,  $P < 0.001$ ) and arousal ( $T_{119} = 16.63$ ,  $P < 0.001$ ).

Pictures were presented two by two on screen, all equally and proportionally paired. Only pictures of the same valence were coupled. Pairs could consist of equal (50%) or different pictures (50%). All pictures were presented with a resolution of  $643 \times 482$  pixels, a mean luminance of 112.5–113.5 luminance units, duration on screen of 400 ms, a distance from screen of 150 cm, a vertical angle of  $9^\circ$  and a horizontal angle of  $25^\circ$  (this accounting for two pictures presented simultaneously and a white cross as a fixation point between them).

#### Auditory stimuli

The auditory stimuli were a 700-Hz standard tone (STD) and 100 unique environmental complex, novel sounds (NOV; 200 ms duration, 75 dB SPL), generated as described in previous studies (Escera *et al.*, 1998) and rated by a sample of 30 subjects on a 1–5 Likert scale of semantic familiarity (as reported in previous studies about effects of familiarity on novelty processing; Escera *et al.*, 2003), chosen between the most highly rated ( $2.54$  mean rate;  $\pm 0.5$ ). Sounds were delivered through Sennheiser® HD202 headphones (Wedemark, Germany).

### Task and conditions

Participants performed a modified version of a well-characterized auditory–visual distraction paradigm (Escera *et al.*, 1998, 2000, 2001, 2003). All stimuli were presented with the stimulation program Presentation® by Neurobehavioral Systems (Albany, CA, USA). Auditory stimuli preceded images by 300 ms, these being either a standard tone (STD condition,  $P = 0.8$ ) or a novel sound (NOV condition,  $P = 0.2$ ). Trial length ranged from 1500 to 2100 ms (mean  $1800 \pm 300$  ms). Pictures could be neutral (NEU context condition) or negative (NEG context condition) in emotional valence. Pairs of images appeared in the centre of the screen, and subjects were instructed to press a button (left or right with same dominant hand, buttons counterbalanced across subjects) to respond as rapid and accurately as possible whether the two pictures were equal or different, while ignoring the sounds and not gazing away from the fixation cross. A unique sequence was designed, which divided 1000 trials into 66 blocks of 10, 15 or 20 trials of the same valence. NEU and NEG pictures were never mixed in the same block. All blocks were pseudo-randomized in a probabilistic non-stationary way so that, in the beginning, a higher proportion of neutral blocks was presented, decreasing progressively and turning into a higher proportion of negative pictures at the end. These sequences were counterbalanced across subjects with a Latin square design, so that half of the subjects started with neutral pictures whereas the other half started with negative pictures. Previous to each experimental session, subjects performed a practice block with no sounds, in which they were required to reach a minimum of 85% hit rate.

### Electroencephalogram (EEG) recording and averaging

EEG activity was recorded during task performance from 64 scalp electrodes (ANT Software b.v., Enschede, Netherlands) following the 10/10 convention, in an electrically and acoustically shielded room. The horizontal and vertical electrooculogram (EOG) was recorded with electrodes placed at the outer canthus and above the right eye, respectively. An electrode placed on the tip of the nose was used as common reference and ground was located on the chest. The EEG was amplified and digitized at a sampling rate of 512 Hz. Impedances were kept below 15 k $\Omega$ . ERPs were averaged offline for each auditory stimulus type for an epoch of 1400 ms, including a 200-ms pre-stimulus baseline. Only those auditory stimuli surrounded (both preceded and followed) by a picture of the same valence and followed by a correct response were selected for averaging. Standard tones presented after a novel sound were excluded from analysis. Frequencies above 30 Hz were digitally filtered out from the individual ERPs. EOG artefact compensation was performed via a regression algorithm. Then, trials exceeding an amplitude of  $\pm 30$   $\mu$ V standard deviation within the continuous data (200-ms window) were manually rejected. On average, 79.3% of epochs with standard, 81.1% of epochs with novel sounds in neutral context, as well as 82.9% of epochs with standard and 84.7% of epochs with novel sounds in the negative context were retained for averaging. On average, 82 trials were included for the NOV condition and 213 trials for the STD condition.

### Data analysis

Both for behavioural and ERP analyses, only hit-trials with sounds surrounded (both preceded and followed) by a picture of the same valence were taken into account. Thus, the first trials within every emotional block were rejected for analysis. For behavioural analysis, a

correct button press within 100–1200 ms after visual stimulus onset was regarded as a hit. Hit rate and hit mean response times (RT) were computed across equal and different pairs of pictures, and compared by means of a two-factor repeated-measure ANOVA for the factors Sound (STD, NOV) and Context (NEU, NEG), and pair-wise *post hoc* comparisons with non-pooled error terms. In order to examine the effects of the emotional load of the task on attentional processes, P300 to visual targets was examined in four consecutive latency windows (600–700, 700–800, 800–900, 900–1000 ms) measured as the mean amplitude at F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8. Grand-average ERPs to STD–NEU and STD–NEG stimulus pairs were statistically compared by means of ANOVA with repeated-measures [factors: Context (NEU vs. NEG) × Frontality (F7, F3, Fz, F4, F8 vs. FT7, FC3, FCz, FC4, FT8 vs. T7, C3, Cz, C4, T8 vs. TP7, CP3, CPz, CP4, TP8 vs. P7, P3, Pz, P4, P8) × Laterality (F7, FT7, T7, TP7, P7 vs. F3, FC3, C3, CP3, P3 vs. Fz, FCz, Cz, CPz, Pz vs. F4, FC4, C4, CP4, P4 vs. F8, FT8, T8, TP8, P8)]. Scalp-distribution analyses for P300 were performed after normalizing ERP amplitudes to prevent amplitude differences between different components from washing out the genuine scalp-distribution differences. This normalization was done by dividing the amplitude at each electrode by the sum of the squared amplitudes at all electrodes (McCarthy & Wood, 1985).

Both for the NEU and the NEG context, N1-enhancement/MMN and novelty-P3 were isolated in the difference waves obtained by subtracting the standard-tone trial ERPs from those elicited to the novel-sound trial. The first deflection was measured as the mean amplitude at F3, Fz, F4, C3, Cz and C4 in the 110–160 ms latency window. ANOVA for repeated-measures of this response included the factors Context (NEU and NEG), Laterality (Left, Centre and Right) and Electrode. Early and late phases of novelty-P3 were measured as the mean amplitude at F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 in the 200–290- and 290–370-ms latency windows, respectively. ANOVA for repeated-measures of these two responses included the factors Context (NEU vs. NEG) × Phase (early vs. late) × Frontality (F3, Fz, F4 vs. C3, Cz, C4 vs. P3, Pz, P4) × Laterality (F3, C3, P3 vs. Fz, Cz, Pz vs. F4, C4, P4).

For all statistical analyses, Greenhouse–Geisser adjustments to the degrees of freedom were used when appropriate and *P*-values following this correction were reported. *Post hoc* tests were conducted wherever there were significant interactions between the main factors.

## Results

### Behavioural results

Subjects had an overall hit rate of about 91%, which decreased significantly in NEG condition (Context:  $F_{1,13} = 12.43$ ,  $P < 0.01$ ; Fig. 1a). Only a trend of main sound effect ( $F_{1,13} = 4.2$ ,  $P = 0.06$ ) was found for accuracy. In general, RTs were longer when subjects responded to negative pictures than when responding to the neutral ones (Context:  $F_{1,13} = 12.14$ ,  $P < 0.01$ ; Fig. 1b). A two-factor repeated-measurement ANOVA revealed significantly longer RTs in trials containing NOV sounds compared with those containing STD sounds (Sound:  $F_{1,13} = 11.61$ ,  $P < 0.01$ ), indicating that subjects were distracted by the unexpected occurrence of task-irrelevant novel sounds, as they delayed responses (Fig. 1b), in agreement with previous studies (Alho *et al.*, 1997; Escera *et al.*, 1998, 2001, 2003). These RT differences between STD and NOV trials were significantly larger for the NEG context compared with the NEU context (Context × Sound:  $F_{1,13} = 6.4$ ,  $P = 0.025$ ), as revealed by *post hoc t*-tests (STD–

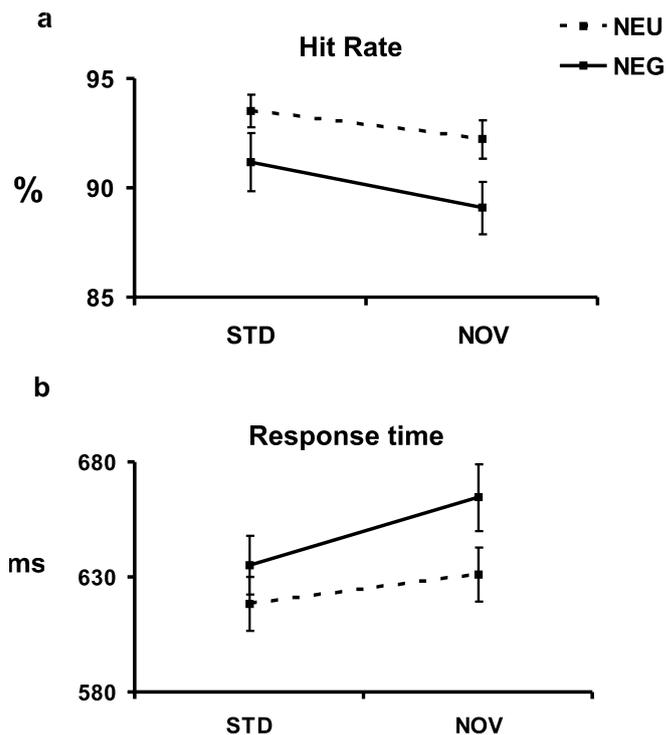


FIG. 1. (a) Mean hit rates for standard (STD) and novel (NOV) sound trials, both in neutral (NEU) and negative (NEG) context. Subjects were less accurate in their responses during processing of negative pictures, compared with the neutral ones. Bars indicate the standard error of the mean ( $\pm$  SEM). (b) Mean RTs for STD and NOV trials both in NEU and NEG context. NOV sounds caused a delay on subjects' responses, this effect being significantly enlarged when the preceding and following images were emotionally negative. Bars indicate the SEM.

NEU vs. NOV–NEU:  $T_{13} = 2.13$ ,  $P = 0.053$ ; STD–NEG vs. NOV–NEG:  $T_{13} = 3.84$ ,  $P = 0.002$ ). Specifically, mean RTs in the NEU context were 618 ms for STD sounds and 631 ms for NOV sounds. Likewise, mean RTs in the NEG context were 635 ms for STD sounds and 664 ms for NOV sounds. Thus, the RT cost of NOV sounds was 13 ms in NEU context and 29 ms in NEG context. No statistical differences were seen between counterbalanced runs or response button, either for RT or hit rate.

### Electrophysiology

#### Emotional picture processing

Grand-average ERPs to STD–NEU and STD–NEG stimulus pairs revealed a sequence of auditory P1, N1 and P2 and visual target-related P300 deflections (Fig. 2). The statistical scalp-distribution analyses of target-P300 across NEU and NEG conditions yielded a P300 distribution over posterior electrodes, both for NEU and NEG context, in the four consecutive latency windows analysed (Frontality; 600–700 ms:  $F_{4,52} = 6.99$ ,  $P < 0.02$ ; 700–800 ms:  $F_{4,52} = 40.46$ ,  $P < 0.001$ ; 800–900 ms:  $F_{4,52} = 61.05$ ,  $P < 0.001$ ; 900–1000 ms:  $F_{4,52} = 76.32$ ,  $P < 0.001$ ), and over lateral more than central regions (Fig. 2; Laterality; 600–700 ms:  $F_{4,52} = 5.12$ ,  $P < 0.05$ ; 700–800 ms:  $F_{4,52} = 49.85$ ,  $P < 0.001$ ; 800–900 ms:  $F_{4,52} = 66.87$ ,  $P < 0.001$ ; 900–1000 ms:  $F_{4,52} = 77.31$ ,  $P < 0.001$ ; Frontality × Laterality; 700–800 ms:  $F_{16,208} = 41.62$ ,  $P < 0.001$ ; 800–900 ms:  $F_{16,208} = 58.82$ ,  $P < 0.001$ ; 900–1000 ms:  $F_{16,208} = 73.3$ ,  $P < 0.001$ ). P300 amplitude was enhanced in the NEG context as compared with the

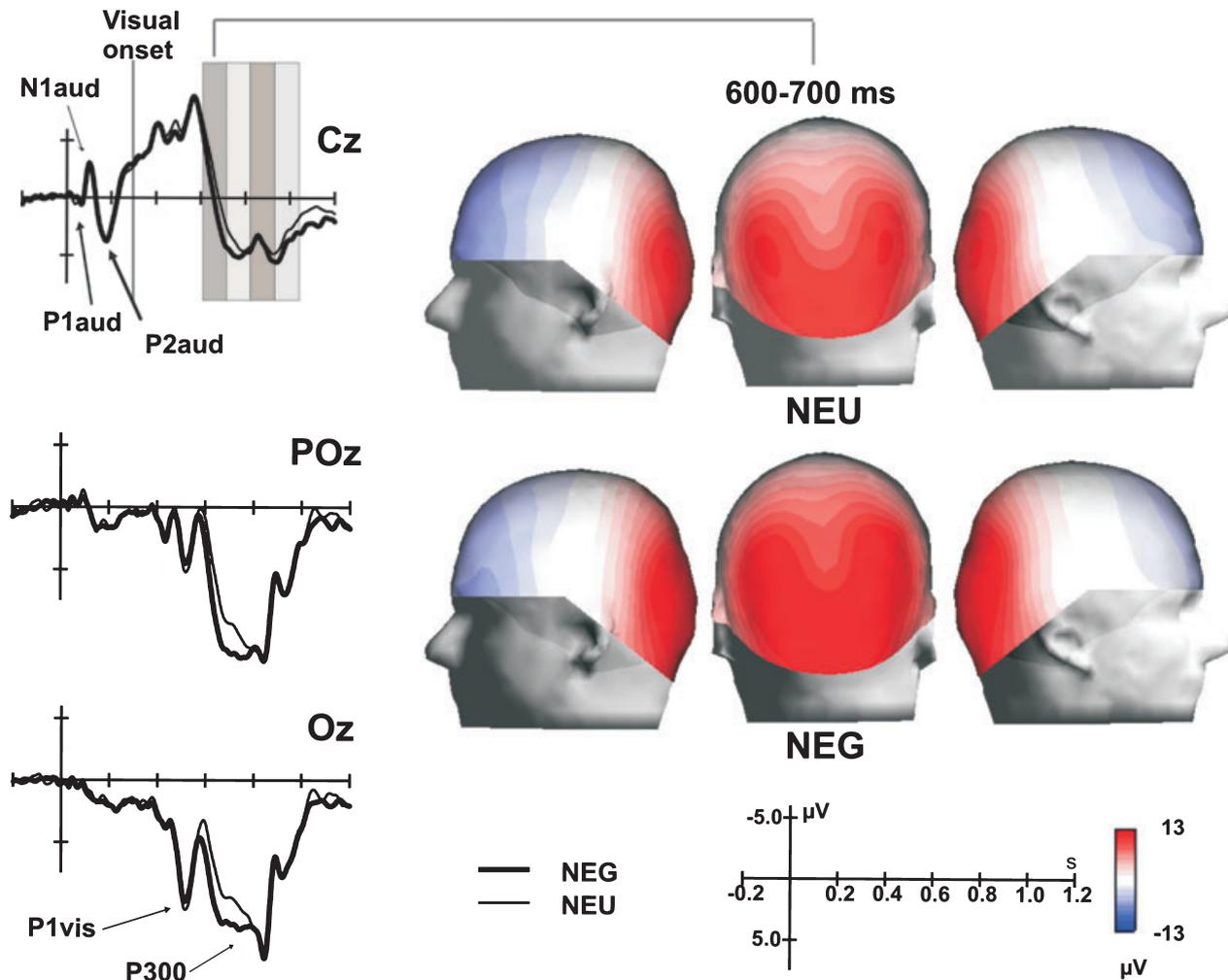


FIG. 2. ERPs for STD trials only: neutral (NEU, thin line) vs. negative context (NEG, thick line), and scalp-distribution maps. An early P300 enhancement shows that emotionally negative pictures were more deeply processed as compared with neutral pictures.

NEU context for the 600–700-ms latency window (see Fig. 2; Context:  $F_{1,13} = 11.82$ ,  $P < 0.01$ ), showing in NEG context a more posterior-central distribution, as revealed by the interactions Context  $\times$  Frontality ( $F_{4,52} = 5.53$ ,  $P < 0.05$ ), Context  $\times$  Laterality ( $F_{4,52} = 5.79$ ,  $P < 0.05$ ) and Context  $\times$  Frontality  $\times$  Laterality ( $F_{16,208} = 6.51$ ,  $P < 0.03$ ). Only a trend of Context interaction effect was found for the 700–800-ms latency window (Context  $\times$  Frontality:  $F_{4,52} = 3.12$ ,  $P = 0.098$ ), and no effects of Context appeared in further windows.

#### Auditory novelty processing

Both for NEU and NEG contexts, difference waves between NOV-sound and STD-sound ERPs revealed the neuroelectric activation underlying auditory novelty processing, which was characterized by a well-defined N1-enhancement, possibly composed of overlapping N1 and MMN components (Alho *et al.*, 1998; Escera *et al.*, 1998) and a novelty-P3 deflection (Fig. 3).

The ANOVA on the two phases of the novelty-P3 across both conditions confirmed that both early and late phases were maximal over the fronto-central scalp (Frontality:  $F_{2,26} = 14.14$ ,  $P < 0.01$ ; Laterality:  $F_{2,26} = 28.36$ ,  $P < 0.001$ ), with the late phase having larger amplitude at frontal and right sites (Phase  $\times$  Frontality:  $F_{2,26} = 8.77$ ,  $P < 0.01$ ; Phase  $\times$  Laterality:  $F_{2,26} = 5.14$ ,  $P < 0.02$ ; Frontality  $\times$

Laterality:  $F_{4,52} = 6.74$ ,  $P < 0.01$ ; Phase  $\times$  Frontality  $\times$  Laterality:  $F_{4,52} = 6.56$ ,  $P < 0.01$ ).

Novelty-P3 analyses for NEU and NEG context separately revealed a main effect of Frontality in both context conditions (NEU:  $F_{2,26} = 12.15$ ,  $P < 0.01$ ; NEG:  $F_{2,26} = 13.81$ ,  $P < 0.01$ ), Laterality (NEU:  $F_{2,26} = 24.28$ ,  $P < 0.001$ ; NEG:  $F_{2,26} = 25.1$ ,  $P < 0.001$ ), Phase  $\times$  Frontality (NEU:  $F_{2,26} = 9.31$ ,  $P < 0.01$ ; NEG:  $F_{2,26} = 7.78$ ,  $P < 0.01$ ), Phase  $\times$  Laterality (NEU:  $F_{2,26} = 3.96$ ,  $P < 0.05$ ; NEG:  $F_{2,26} = 6.41$ ,  $P < 0.01$ ), Frontality  $\times$  Laterality (NEU:  $F_{4,52} = 5.49$ ,  $P < 0.01$ ; NEG:  $F_{4,52} = 7.34$ ,  $P < 0.01$ ) and Phase  $\times$  Frontality  $\times$  Laterality (NEU:  $F_{4,52} = 5.49$ ,  $P < 0.01$ ; NEG:  $F_{4,52} = 6.81$ ,  $P < 0.01$ ). The late novelty-P3 presented similar amplitude from parietal to frontal sites (Frontality:  $F_{2,26} = 2.91$ ,  $P = 0.108$ ), whereas its early phase was more prominent in fronto-central locations ( $F_{2,26} = 34.3$ ,  $P < 0.001$ ). Indeed, the early novelty-P3 inverted polarity at posterior and lateral sites (Fig. 3), whereas the late subcomponent did not.

#### Gating of auditory novelty processing in emotional context

Early stages of novelty processing did not present effects due to emotion. Accordingly, N1 enhancement was of similar amplitude both for the NEU and NEG context, as the ANOVA yielded no significant

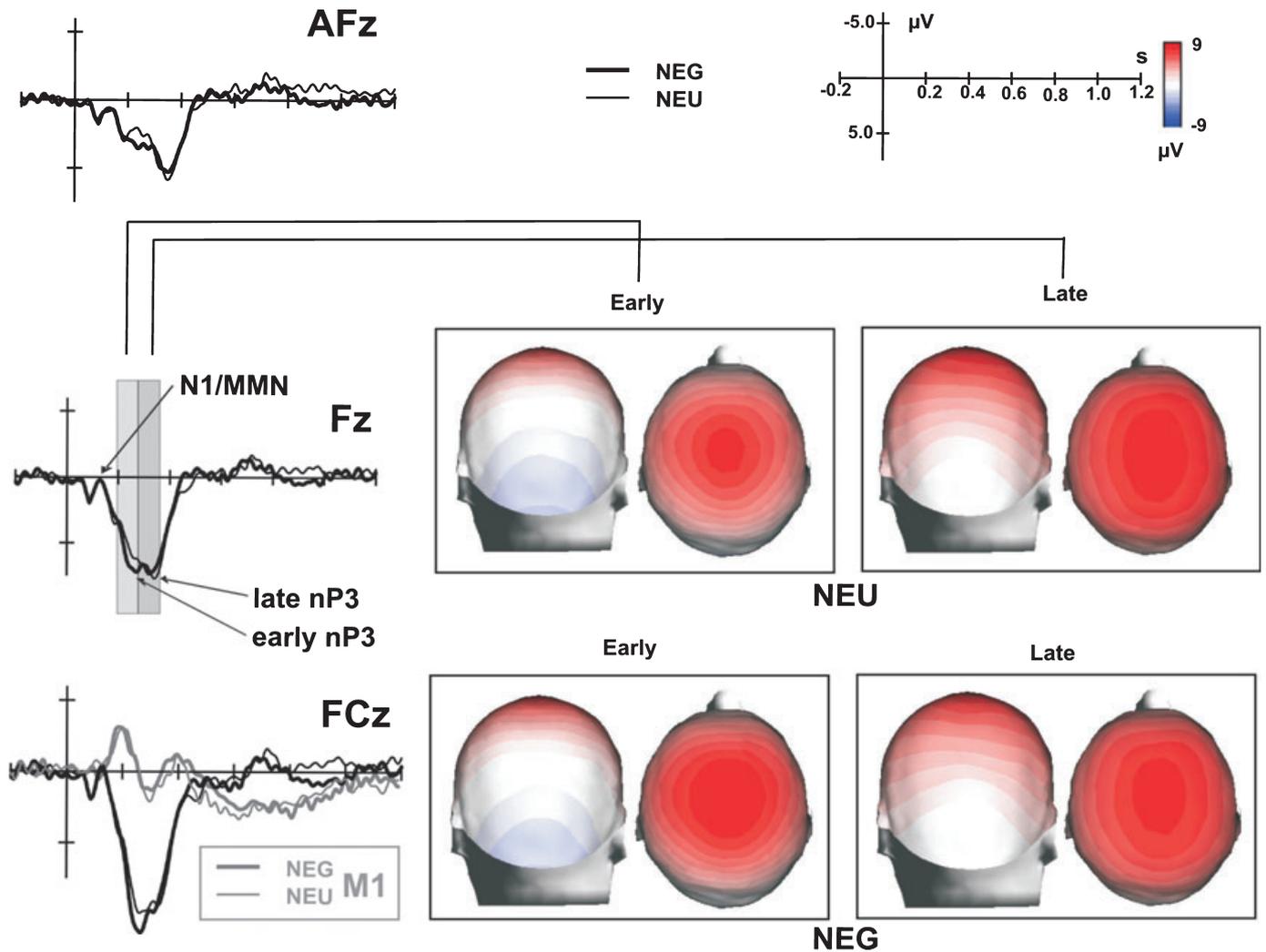


FIG. 3. Difference waves obtained by subtracting the standard (STD) sound ERPs from those elicited to novel (NOV) sounds both for neutral (NEU, thin line) and negative context (NEG, thick line) and scalp-distribution maps. Early novelty-P3 responses to novel sounds were enhanced in the NEG context. The early novelty-P3 inverted polarity at posterior and lateral sites, for instance as shown at the left mastoid electrode (M1), whereas the late subcomponent did not.

effects of these factors or interactions between them. However, early novelty-P3 responses showed enhanced amplitude in NEG context (Fig. 3), as indexed by the interaction Context  $\times$  Phase ( $F_{1,13} = 9.52$ ,  $P = 0.009$ ). Subsequent separate ANOVAs for NEU and NEG context revealed that no main effect of Phase is present in NEG, due to the enhancement of the early deflection in this condition (NEU:  $F_{1,13} = 7.62$ ,  $P = 0.016$ ; NEG:  $F_{1,13} = 1.24$ ,  $P = 0.286$ ). In general, no topographical differences between NEU and NEG were observed for both phases of novelty-P3, suggesting a pure enhancement of the early phase in NEG context.

## Discussion

### Emotional picture processing

The results of the present study provide an illustration of how emotion mediates involuntary attention and awareness. Subjects were unable to fully ignore emotional information even when it was task-irrelevant, in agreement with a variety of studies (Vuilleumier *et al.*, 2001; Anderson *et al.*, 2003). The amplitude enhancement of visual P300 over centro-parietal sites revealed that participants processed negative pictures more deeply as compared with the neutral ones. In this sense,

subjects might have remained engaged in the emotional content of the display at the expense of processing the relevant aspects of the task. This interpretation would be supported by the behavioural results, in which subjects were shown to be slower and less accurate when responding to negative pictures than to the neutral ones. This target-related ERP component is known to represent memory updating mechanisms (Donchin & Coles, 1988) and has been shown to be sensitive to the intrinsic affective properties of pictures in previous studies (Amrhein *et al.*, 2004; Delplanque *et al.*, 2005). Thus, amplitude modulation of visual P300 was a necessary requirement for evaluating any emotional effect on auditory novelty processing.

### Gating of auditory novelty processing in emotional context

Brain responses to stimulus salience not only depend on novelty or frequency of occurrence, but also on the behavioural context (Katayama & Polich, 1998) and, particularly, on the emotional relevance of the context. Novel sounds elicited a distraction effect on subjects' performance, as indexed by a prolonged RT both during neutral and negative picture processing. This effect was paralleled by the well-defined N1-enhancement and novelty-P3 ERP components

observed in the difference waves, both for neutral and negative context conditions separately. The morphology and distribution of this pattern would represent the neuroelectric activation underlying novelty processing, a mechanism concerned with the evaluation of novel stimuli that have already captured attention (Escera *et al.*, 1998, 2000; Friedman *et al.*, 2001) or, in line with a recent interpretation from task-switching experiments (Barceló *et al.*, 2006), an internal updating of goals, a goal-directed response selection elicited by sensory signals, rather than a simple orientation response.

Both behavioural and electrophysiological results in our study are consistent with literature (Alho *et al.*, 1997, 1998; Escera *et al.*, 1998, 2000, 2001, 2003; Yago *et al.*, 2003) and confirm that auditory novel events were processed differently with regard to the repetitive standard sounds (novelty processing), recruiting attentional resources from the ongoing task in subjects and causing a delay in the average performance (distraction) regardless of the emotional load within the task. Crucially, these novel sounds elicited a stronger distraction effect when preceded and followed by pictures of emotionally negative valence, in contrast to the neutral ones. In other words, when novel sounds were surrounded by emotionally negative pictures and thus processed in a negative context.

N1-enhancement, consistently associated with novelty detection in the auditory cortex (Alho *et al.*, 1998; Escera *et al.*, 1998), was not affected by the emotional load of the task, indicating that the transient and change-detection mechanisms indexed by this deflection may be independent of task conditions. Interestingly, novelty-P3 amplitude appeared enhanced to novel sounds processed during the performance of the task involving negative pictures. Studies showing that novelty-P3 amplitude increases linearly as a function of the eliciting stimulus salience (Yago *et al.*, 2001; Escera *et al.*, 2003), that the more salient the sound the larger the behavioural distraction and novelty-P3 (Escera *et al.*, 1998, 2003; Zink *et al.*, 2006), or that behavioural distraction and novelty-P3 amplitude are modulated in parallel by working memory load (Berti & Schröger, 2003; SanMiguel *et al.*, 2008), support the notion that a larger novelty-P3 denotes stronger orienting of attention to distractors and, in the present study, under a negative emotional context.

#### *Temporality and distribution of emotional gating effects*

The emotional load of the task exerted a modulation of the early novelty-P3. This subcomponent has been proposed to be associated with the violation of the regularity registered by the automatic novelty detection system (Escera *et al.*, 1998, 2001), whereas late novelty-P3 would reflect the actual orienting of attention towards odd auditory stimuli (Escera *et al.*, 1998). Although the aim of the present study was not to examine the sensitivity of early novelty-P3 to task conditions, our data clearly indicate that this phase may be responsive to certain attentional manipulations, contrary to what was previously proposed (Escera *et al.*, 1998) and to what was reported in recent experiments (Royer *et al.*, 2007; SanMiguel *et al.*, 2008). However, modulation of early novelty-P3 has been observed in another study where, for instance, identifiable novel sounds enhanced novelty-P3 responses compared with the non-familiar novels along a 100-ms window (covering both early and late phases; Escera *et al.*, 2003). In either case, it can be concluded from our results that the emotional context modulates novelty processing in immediately previous stages to the orientation response, about 200 ms after sound occurrence. Early novelty-P3, and not the late phase, showed inverted polarity at posterior and lateral electrodes (Fig. 3), suggesting generators bilaterally located in the vicinity of the temporal and parietal lobes (Scherg & von Cramon, 1986; Alho *et al.*, 1998; Escera *et al.*, 1998). A study in which functional magnetic resonance imaging (fMRI) and ERP results were combined by

dipole seeding during auditory oddball sessions (Opitz *et al.*, 1999) revealed novelty processing responses in the middle part of the superior temporal gyrus and, furthermore, proposed these areas (together with the anterior part of the superior temporal gyrus; Alho *et al.*, 1998) to subservise novelty-P3 (Opitz *et al.*, 1999). Temporo-parietal lesions, centred in the superior temporal cortex, have been shown to attenuate P3 to novel sounds (Knight *et al.*, 1989). The modulation of early novelty-P3 obtained in this study may thus be in agreement with recent fMRI data, using a related paradigm (J. Domínguez-Borràs, S.A. Trantmann, P. Erhard, T. Fehr, M. Herrmann and C. Escera, unpublished results), where activation induced by novel sounds in bilateral superior temporal gyri was enhanced when participants responded to negative emotional faces in contrast to neutral ones. Moreover, and according to the results in the present experiment, novel sounds yielded a stronger behavioural disruption on subjects' visual task performance when these responded to faces with a negative expression than when responding to neutral faces (J. Domínguez-Borràs, S.A. Trantmann, P. Erhard, T. Fehr, M. Herrmann and C. Escera, unpublished results). Emotional faces and IAPS pictures have been reported to elicit similar haemodynamic responses on emotion-sensitive areas, such as the amygdala, ventromedial prefrontal and visual cortices (Britton *et al.*, 2006). This fact makes results in both studies comparable.

In conclusion, emotion modulates attentional and perceptual processes not only within a single sensory modality, as has been previously reported (Öhman *et al.*, 2001; Fox, 2002), but also exerts a strong influence on the processing of other sensory signals presented concomitantly through an effect of facilitation. This modulation might be independent from voluntary mechanisms of attentional control but still would respond to common top-down regulation (Vuilleumier, 2005). In this sense, top-down mechanisms would refer to any component, cognitive or sensory, that is not a feature of the incoming distractor stimulus and, nevertheless, modifies its processing and distractor effects (Pashler *et al.*, 2001).

Our results show a spread emotional modulation over frontal sites during novelty processing stages (Fig. 3). These results could confirm the role of ventral prefrontal areas on emotional processing reported in different studies (Northoff *et al.*, 2000; Kawasaki *et al.*, 2001), giving support to a role of this area on emotional top-down regulation of attention (Armony & Dolan, 2002; Carretié *et al.*, 2005).

In general, the present results are in agreement with some observations reported in previous studies. Yamashita *et al.* (2005) reported that auditory P50 suppression became attenuated while subjects visualized negatively valenced slides. Suppression of P50, known as auditory sensory gating, responds to the pre-attentive ability of the brain to modulate its excitability to an incoming stimulus. It is hypothesized to be a protective mechanism that prevents sensory overload of higher brain functions by filtering out the irrelevant sensory inputs (Braff & Geyer, 1990). Thus, all sounds in their study were presumably better processed under negative emotional conditions, surpassing these protective mechanisms.

However, the emotional effects on auditory-P3 observed in the present experiment differ notably from a number of studies using startle reflex measurements (Schupp *et al.*, 1997; Cuthbert *et al.*, 1998; Bradley *et al.*, 2006; Keil *et al.*, 2007). In these studies, whereas the blink reflex was enhanced for startle probes while viewing unpleasant pictures (Schupp *et al.*, 1997; Cuthbert *et al.*, 1998; Bradley *et al.*, 2006 – the latter only for probes presented at late stages after picture onset), auditory-P3 decreased in amplitude (Schupp *et al.*, 1997; Cuthbert *et al.*, 1998; Keil *et al.*, 2007) even for unexpected simple tones (Cuthbert *et al.*, 1998), suggesting a greater allocation of attentional resources to the affective visual stimuli in a limited-capacity system. Although still unclear, we suggest that the reasons for this disagreement

might be the presence or absence of perceptual competence in the studies. In their experiments, sounds appeared while the picture was on screen, and the stimulus display was 1.5 or 6 s. In our study, sounds appeared when no image was being displayed. Sounds were presented on average 1400 ms after the picture offset and always 300 ms before the onset of the next image. With this and the short duration of the stimuli, we manipulated the emotional load of the task while images and sounds never overlapped and attentional resources were never forced to compete. This trial structure was optimal, on the other hand, to favour novelty processing and behavioural distraction (Escera *et al.*, 1998, 2000). Yet, any comparison between these studies and the one reported here should be taken with caution. In startle experiments, probes were identical across presentations, whereas we used 100 different novel sounds. Although both startle probes and novel sounds appeared unexpectedly in all studies and, thus, can be treated as novel auditory events, the structure of the audio–visual oddball paradigm used here differs notably from that used by startle reflex measurements.

On the other hand, an alternative explanation is still possible to the emotional effects towards distraction and novelty processing reported in the present study. The RT cost of novel sounds in the neutral context was only marginally significant, in contrast to the negative context. In addition, the neutral stimuli used here might not serve properly as an emotional baseline, being evaluated thus as ‘not negative, but still emotional’. Therefore, it might also be concluded that the neutral context decreased distraction and processing of novel sounds, instead of the negative context enhancing this effect. Further studies should experimentally discard this alternative. In addition, neutral and negative pictures used in the present study differed both in valence and arousal dimensions, as threat and arousal are usually highly correlated (Vuilleumier, 2005). Therefore, with the present results we cannot conclude that the effects of the emotional context were solely due to the emotional valence, disregarding arousal as an important factor of modulation.

Moreover, future research should assess whether this context of emotional processing is strictly induced by the preceding stimulus, that is, trial by trial, or a more general emotional state along the emotional block. However, the design of the present study does not allow us to fully discard one argument or another. In any case, a possible ‘mood’ effect, stable over time, might be disregarded as the only source of modulation. This is supported by the fact that we still observed similar results in a previous experiment (Domínguez-Borrás *et al.*, 2008), using the same task settings, where the emotional load of the visual stimuli was not blocked but induced with neutral and negative IAPS pictures presented randomly instead.

In summary, the results of the present study show that a context of processing negative emotional pictures results into an enhanced processing of novel auditory events. These effects are reflected in an increased behavioural distraction by the novel sounds and enhanced amplitude of the auditory novelty-P3 component in its early phase when the task is loaded with a negative emotion. Thus, processing emotionally salient information influences mechanisms of involuntary attention at very early stages of the orientation response. Such a mechanism would make possible that unexpected auditory events, irrelevant in neutral environmental conditions *per se*, become more available to the attentional set in a threatening context, providing thus, if necessary, crucial information for survival.

## Supporting information

Additional supporting information may be found in the online version of this article:

Table S1. IAPS identification numbers for emotional pictures and neutral pictures.

Please note: Blackwell Publishing are not responsible for the content or functionality of any supporting material supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

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## Abbreviations

EEG, electroencephalogram; EOG, electrooculogram; ERP, event-related brain potential; fMRI, functional magnetic resonance imaging; NEG, negative context; NEU, neutral context; NOV, novel sound; RT, response time; SAM, Self-Assessment Manikin; STD, standard sound.

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