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Does emotion change auditory prediction and deviance detection?

Ana P. Pinheiro[a,b,*], Carla Barros[a], Marcelo Dias[a], Margaret Niznikiewicz[c]

[a] Neuropsychophysiology Lab, School of Psychology, University of Minho, Braga, Portugal
[b] Faculty of Psychology, University of Lisbon, Lisbon, Portugal
[c] VA Boston Healthcare System, Department of Psychiatry, Harvard Medical School, Boston MA, USA

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ABSTRACT

In the last decades, a growing number of studies provided compelling evidence supporting the interplay of cognitive and affective processes. However, it remains to be clarified whether and how an emotional context affects the prediction and detection of change in unattended sensory events.

In an event-related potential (ERP) study, we probed the modulatory role of pleasant, unpleasant and neutral visual contexts on the brain response to automatic detection of change in spectral (intensity) *vs.* temporal (duration) sound features. Twenty participants performed a passive auditory oddball task. Additionally, we tested the relationship between ERPs and self-reported mood.

Participants reported more negative mood after the negative block. The P2 amplitude elicited by standards was increased in a positive context. Mismatch Negativity (MMN) amplitude was decreased in the negative relative to the neutral and positive contexts, and was associated with self-reported mood.

These findings suggest that the detection of regularities in the auditory stream was facilitated in a positive context, whereas a negative visual context interfered with prediction error elicitation, through associated mood changes. Both ERP and behavioral effects highlight the intricate links between emotion, perception and cognitive processes.

1. Introduction

Imagine that, while walking, you suddenly encounter a bloody accident scene. While overwhelmed by the emotional content of that visual scene and by the powerful emotions elicited by the dramatic situation, your capacity to detect changes in the auditory environment may be compromised. For example, you may fail to notice that a nearby church bell started ringing.

In the last decades, a growing number of studies demonstrated that emotion and cognition are not separate systems (as proposed, for example, by Zajonc, 1980) but, instead, interact in a dynamic way (e.g., Cohen, 2005; LeDoux, 1989; Pessoa, 2008). A robust body of evidence suggests that the affective properties of a stimulus, such as its valence (i.e., the perceived pleasantness *vs.* unpleasantness of a stimulus or event – Bradley & Lang, 1994) and arousal (i.e., how aroused the subject feels in response to a stimulus or event, ranging from an excited to a calm state – Bradley & Lang, 1994), rather than their strictly sensory properties, affect both sensory-driven and higher-order cognitive processes. Characterized by millisecond time resolution, event-related potential (ERP) studies provided consistent evidence for a rapid differentiation between emotional and neutral stimuli. For example, aversive and neutral stimuli are differentiated as early as 65–90 ms after stimulus onset in the visual modality (C1 component to pictures – Stolarova, Keil, & Moratti, 2006), and between 25 and 80 ms in the auditory modality (P50 component to nonverbal vocalizations – Liu et al., 2012). Compared to neutral cues, emotional stimuli are also associated with speeded visual search (e.g., Fox et al., 2000), increased attention-grabbing properties (e.g., Pinheiro, Barros, & Pedrosa, 2016; Vuilleumier, Armony, Driver, & Dolan, 2001), enhanced memory (e.g., Hamann, Ely, Grafton, & Kilts, 1999), and enhanced sustained elaborative processing (e.g., Schupp et al., 2000).

Perception is also not immune to the emotional features of the context in which a stimulus is encoded. Context may refer to the external surroundings in which a stimulus is presented (e.g., other sensory input with informational value), but also to perceiver-related processes, such as mood states and expectations, which shape the way a stimulus is perceived (e.g., Barrett, Mesquita, & Gendron, 2011). For example, as described below, the affective properties of a visual or auditory context may interfere with the processing of otherwise neutral cues. Nonetheless, compared to the number of studies probing the effects of stimulus affective properties *per se,* the effects of emotional context on neutral sound processing have been by far less explored. The

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* Corresponding author at: Neuropsychophysiology Lab, CIPsi, School of Psychology, University of Minho, Campus de Gualtar, 4710-957 Braga, Portugal.
E-mail addresses: appinheiro@psicologia.ulisboa.pt, ana.pinheiro@psi.uminho.pt (A.P. Pinheiro).

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existing evidence indicates that the emotional quality of visual stimuli affects how neutral auditory stimuli are perceived, already at early sensory processing stages (e.g., Tartar, de Almeida, McIntosh, Rosselli, & Nash, 2012 – see Supplementary Table 1).

The current study aimed to clarify whether and how a visual emotional context impacts the capacity to predict the type of upcoming sounds that are not in the focus of attention. Probing this question is particularly relevant as most of the stimuli we continuously receive are often processed in an implicit way and without full conscious awareness. A neurophysiological signature of predictive processes is the Mismatch Negativity (MMN; e.g., Garrido, Kilner, Stephan, & Friston, 2009). This negative event-related potential (ERP) component reflects an automatic brain mechanism that signals preattentive change detection, based on a comparison between the neural representation of a repetitive stimulus and incoming sensory input from a deviant stimulus (e.g., Näätänen, 1995). In the auditory modality, the MMN is an important index of sound representation and auditory discrimination accuracy (e.g., Näätänen, 1995, 2001; Näätänen, Paavilainen, Rinne, & Alho, 2007). The MMN literature supports the automaticity of auditory processing, even when attention is not focused on the sounds. The experimental design typically used to elicit the MMN involves listening to sounds while being engaged in a distractive and unrelated task, such as watching a movie (e.g., Näätänen, 1995, 2001; Näätänen et al., 2007). This component is obtained through the subtraction of ERP to frequent (standard) and infrequent (deviant) stimuli (e.g., Näätänen et al., 2007). Reflecting the difference between top-down expectations (generated based on preceding stimuli) and incoming sensory input (e.g., Garrido et al., 2009; Schröger et al., 2014), the MMN is thought to reflect a prediction error signal and, therefore, represents a major target of studies investigating sensory prediction (e.g., Todd, Michie, Schall, Ward, & Catts, 2012; Wacongne, Changeux, & Dehaene, 2012). The stronger the mismatch between the expected and perceived sound, the more negative the MMN amplitude (e.g., Garrido et al., 2009; Picton et al., 2000). This neural mechanism may differ with the type of stimulus deviance (e.g., the frequency *vs.* intensity *vs.* duration of the deviant; Giard et al., 1995; Molholm et al., 2005; Rosburg, 2003).

Two important processes underlie the MMN elicitation: first, the detection of regularities in a stimulus stream (based on the presentation of high-probability or standard sounds); second, the detection of a mismatch between the expected and perceived sensory input (i.e., a prediction error) when a low-probability or deviant sound is presented. The studies that analyzed the response to standard and deviant sounds separately in passive auditory oddball tasks indicated effects of stimulus predictability and deviance type on the N1 (elicited at about 100 ms) and P2 (elicited at about 200 ms) components. The N1 response reflects the encoding of the acoustic features of the stimulus (e.g., Naatanen & Picton, 1987), and is modulated by the level of attention (e.g., Woldorff & Hillyard, 1991). Of note, effects of predictability have been reported on the N1, with decreased (i.e., less negative) amplitude to expected (e.g., standard) tones corresponding to an increase in the sensory predictability of a stimulus (e.g., Bendixen, SanMiguel, & Schröger, 2012; Knolle, Schröger, & Kotz, 2013; Timm, Schonwiesner, Schroger, & SanMiguel, 2015). The N1 amplitude was also found to be reduced in response to standard compared to deviant stimuli which were not in the focus of attention (Kühnis, Elmer, & J & ncke, 2014; Sepp & nen, H & m & l & inen, Pesonen, & Tervaniemi, 2012). The P2 seems to be associated with stimulus evaluation and classification (e.g., Crowley & Colrain, 2004; Reinke, He, Wang, & Alain, 2003), and with enhanced activation of information from sensory traces available in short-term memory (e.g., Atienza, Cantero, & Dominguez-Marin, 2002). The P2 is also sensitive to stimulus predictability: it is increased in response to correctly predicted stimuli (Knolle et al., 2013). It is therefore not surprising that studies that probed auditory processing with passive oddball paradigms found increased (i.e., more positive) P2 for standard relative to deviant sounds (Lanting, Briley, Sumner, & Krumbholz, 2013).

1.1. Effects of emotional variables on the MMN

More recent studies suggest that the MMN represents a more complex mechanism than initially thought. For example, this component is also sensitive to the emotional category of the sounds. Those studies that manipulated the perceived valence of unattended auditory stimuli provided compelling evidence that emotionally salient stimuli are more easily detected at a preattentive level: earlier peak latency or enhanced amplitude MMN effects were observed for emotional compared to neutral stimuli (Chen, Lee, & Cheng, 2014; Schirmer, Striano, & Friederici, 2005).

Importantly, even though there have been many attempts to characterize the modulatory influence of stimulus affective properties on how the brain forms predictions and detects changes in an unattended auditory input (e.g., Schirmer, Escoffier, Cheng, Feng, & Penney, 2016; Schirmer et al., 2005), few studies have systematically examined the effects of emotional contexts on auditory prediction mechanisms, the focus of the current study. These studies indicate that visually presented emotional stimuli affect the way unattended auditory stimuli are perceived (De Pascalis, Arwari, Matteucci, & Mazzocco, 2005; Gulotta, Sadia, & Sussman, 2013; Sugimoto, Nittono, & Hori, 2007; Surakka, Tenhunen-Eskelinen, Hietanen, & Sams, 1998; Tartar et al., 2012). However, they also present a mixed picture. Some studies suggest that emotional contexts disrupt either the extraction and representation of the regular features in an unattended auditory environment (reflected in reduced P2 to standard tones – Sugimoto et al., 2007), or the detection of a prediction error (reflected in reduced MMN – Surakka, Tenhunen-Eskelinen, Hietanen, & Sams, 1998). Others demonstrate that the registration of unpredicted changes in the auditory environment is facilitated in an emotional context (reflected in increased MMN – De Pascalis, Arwari, Matteucci, & Mazzocco, 2005). Furthermore, positive *vs.* negative contexts were found to produce qualitative and quantitative differences in their impact on auditory predictive processing. Reduced MMN amplitude was observed in the context of positive pictures compared to both negative and neutral pictures (Sugimoto et al., 2007; Surakka et al., 1998), whereas in other studies the MMN was reduced in both neutral and positive contexts compared to negative ones (De Pascalis et al., 2005). Differential effects of context valence were also observed on the generation of auditory predictions, demonstrated by the ERP response to standard tones: the extraction of regular auditory features was found to be impaired in a negative context (reduced N1 to standard tones following negative *vs.* neutral pictures – Tartar et al., 2012), in a positive context (reduced P2 to standard tones after positive *vs.* both neutral and negative pictures – Sugimoto et al., 2007), or in both (reduced P2 for standard tones presented in the context of positive and negative video clips, compared to neutral video clips – Gulotta et al., 2013). Methodological differences may account for these discrepant results, such as differences in arousal ratings between positive and negative pictures, random *vs.* blocked presentation of visual stimuli as a function of emotional category, insufficient methodological control regarding the content of the pictures (e.g., human *vs.* animal scenes), or lack of a positive emotional condition (see Supplementary Table 1). Taken together, it is not generally agreed upon whether emotional contexts result in facilitated or disrupted predictive processing of unattended sounds.

Despite the methodological issues raised above, it is plausible that the observed effects of an emotional context on auditory predictive processes reflect transient changes in mood, here understood as a slow change in an affective state elicited by a stimulus, event or situation, and that is less intense than an event-triggered emotion such as disgust or anger (e.g., Forgas, 1995; Scherer, 2005). Mood changes associated with emotionally salient stimuli, such as pictures, sounds or movies, were found to affect distinct cognitive processes including attention (e.g., Grol, Koster, Bruyneel, & De Raedt, 2014; Vanlessen, Rossi, De Raedt, & Pourtois, 2014; Wadlinger & Isaacowitz, 2006), executive functioning (e.g., Richards, French, Johnson, Naparstek, & Williams, 1992), memory (e.g., Bower, 1981; Clark & Teasdale, 1985; Kliegel et al., 2005), language (e.g., Bolte, Goschke, & Kuhl, 2003; Federmeier, Kirson, Moreno, & Kutas, 2001; Pinheiro, del Re et al., 2013; Van Berkum, De Goede, Van Alphen, Mulder, & Kerstholt, 2013; Vissers, Chwilla, Egger, & Chwilla, 2013), or probabilistic learning (Bakic, De Raedt, Jepma, & Pourtois, 2015; Bakic, Jepma, De Raedt, & Pourtois, 2014). Evidence for the effects of mood on the MMN has been provided by clinical studies with patients with major depressive disorder, for example, which report reduced (i.e., less negative) MMN amplitude to deviant sounds in patients compared to healthy control subjects (e.g., Takei et al., 2009).

1.2. The current study and hypotheses

Here we explore how the emotional quality of task-relevant visual stimuli affects auditory prediction and change detection. In a carefully controlled experimental design, we asked participants to look at pictures presented in three different blocks (neutral, positive and negative valence), and matched on content. Importantly, the arousal of emotional pictures (positive and negative) did not differ as assessed with normative ratings (Lang, Bradley, & Cuthbert, 2008). Pictures of the same valence were presented in the same experimental block. Participants were instructed to ignore the sounds, and were asked questions about the pictures at the end of the experiment. Since the eliciting stimuli were identical in the three picture blocks, ERP differences can be interpreted as reflecting the effects of visual emotion on automatic auditory change detection. The MMN was the main focus of our analyses. In addition, we also analyzed the N1 and P2 response to standard and deviant sounds to clarify the effects of an emotional context on the extraction and representation of regularities (standard-related ERP responses), as well as on the sensory registration of unexpected changes in unattended sounds (deviant-related ERP responses).

An additional motivation for clarifying the effects of an emotional context on processes of automatic change detection indexed by the MMN has a methodological focus. As in a typical MMN paradigm subjects are instructed to pay attention to visual stimuli, such as movies, while ignoring the sounds, there are strong reasons to believe that the pleasantness or unpleasantness of the task-relevant stimuli may influence how the brain forms regularity representations of the auditory input and how it detects changes that violate those representations.

As the comparison process underlying the MMN may differ as a function of the specific acoustic features that deviate from the neural representation of the standard (e.g., Mathiak et al., 2002), a relevant question is whether the MMN to specific auditory features is differently affected by an emotional context. For example, there is evidence that the detection of change in specific acoustic features is carried out by different neural populations of the human auditory cortex (Escera, Corral, & Yago, 2002; Giard et al., 1995). Specifically, intensity and duration were found to have separate neural representations in sensory memory, reflected in different MMN neural generators within the supratemporal auditory cortex (Giard et al., 1995), different MMN scalp topography (Escera et al., 2002; Giard et al., 1995), and increased MMN for duration relative to intensity deviants (Escera et al., 2002). Along the same lines, the expectation of temporal (*when*) *vs.* spectral (*what*) features was found to operate in a distinct manner at the brain level (Hsu, H&m&l&inen, & Waszak, 2013), which suggests that predictive mechanisms may be differently modulated by specific acoustic properties of a sound. Based on these findings, duration and intensity deviants were presented in the current study to examine whether prediction of temporal *vs.* spectral features was more strongly affected by an emotional context.

As emotionally charged pictures modulate sensory and cognitive processes (De Pascalis et al., 2005; Surakka et al., 1998), we hypothesized ERP amplitude differences in response to auditory change occurring in an emotional *vs.* neutral context. If an emotional context disrupts predictive mechanisms underlying automatic auditory change detection, this would be reflected in reduced MMN, as well as increased N1 and reduced P2 responses to standards, in emotional relative to neutral contexts. Alternatively, if an emotional context facilitates predictive processing underlying automatic auditory change detection, an increase in the MMN amplitude, as well as the P2 (accompanied by a decrease in the N1) response to standards, should be observed in emotional relative to neutral contexts. If context has a more prominent role in automatic detection of changes in spectral *vs.* temporal auditory stimulation, then this would be reflected in enhanced (i.e., facilitated predictive processing) or reduced (i.e., impaired predictive processing) MMN to temporal *vs.* intensity deviance.

Considering that mood changes have been reported after the presentation of sequences of emotional pictures (e.g., Federmeier et al., 2001; Pinheiro, del Re et al., 2013; Pinheiro, Liu et al., 2013), we expected ERP differences between neutral and emotional contexts to be related to transient mood changes in response to emotional pictures viewing. In turn, transient mood changes would be reflected in changes in self-reported mood before and after the presentation of the pictures. Specifically, given the fact that negative mood elicited by the visualization of negative pictures had disruptive effects on predictive processes (indirect evidence from language studies − e.g., Pinheiro, del Re et al., 2013; and also clinical studies − e.g., Takei et al., 2009), we hypothesized reduced MMN, and P2 response to standards, in a negative context compared to both neutral and positive contexts, as well as an association between decreased MMN response and increased self-reported negative mood.

2. Method

2.1. Participants

Twenty college students (10 female; mean age = 22.70 ± 4.23 years) participated in the study. The inclusion criteria were: being right handed (Oldfield, 1971); no history of neurological illness; no present medication for medical disorders that could have deleterious effects on electroencephalogram (EEG) morphology, as well as neurological, and/or cognitive functioning consequences. All participants had normal hearing and normal or corrected-to-normal vision. In compliance with the Declaration of Helsinki, participants were provided a clear explanation of the study procedure before the experiment, and provided written informed consent for the experimental protocol approved by the Ethics Committee of the University of Minho (Braga, Portugal). They were given course credit for their participation in the study.

Before the ERP experiment, the participants completed a short clinical questionnaire (Brief Symptom Inventory − Canavarro, 1999) to rule out the presence of psychopathological symptoms. None of the participants had scores that indicated the presence of clinical symptoms (M = 1.20 ± 0.16).

2.2. Stimuli

Experimental stimuli were 159 pictures selected from the International Affective Picture System (IAPS; Lang et al., 2008) and were divided into three blocks of 53 each (neutral, positive and negative valence).[1] Images were matched on arousal and overall

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[1] The IAPS pictures selected were: A) *Neutral*: 1313, 1616, 1640, 2025, 2037, 2038, 2102, 2104, 2107, 2200, 2210, 2214, 2215, 2240, 2250, 2270, 2280, 2305, 2308, 2377, 2383, 2435, 2440, 2441, 2480, 2484, 2512, 2514, 2518, 2521, 2570, 2575, 2579, 2595, 2630, 2870, 2880, 4605, 5455, 5531, 5950, 6570.2, 7042, 7077, 7300, 7495, 7506, 7550, 7600, 7830, 8050, 8312, 9070; B) *Positive:* 1340, 1630, 1710, 1812, 2035, 2040, 2045, 2058, 2071, 2150, 2158, 2208, 2209, 2222, 2224, 2274, 2304, 2306, 2311, 2341, 2345, 2347, 2352, 2360, 2373, 2391, 2501, 2510, 2550, 2655, 4603, 4610, 4612, 4616, 4619, 4622, 4625, 4626, 4628, 4641, 5199, 5220, 5390, 7330, 7350, 7430, 7475, 7487, 7508, 8120, 8497, 8500, 8502; C) *Negative:* 1280, 1945, 2095, 2115, 2120, 2141, 2276, 2278, 2279, 2301, 2375.1, 2399, 2455, 2456, 2457, 2490, 2491, 2700, 2716, 2718, 2720, 2722, 2750, 2900, 3180, 3181, 3215, 3220, 3230, 3280, 6010, 6562, 6610, 6800, 7046, 8231, 9001, 9008, 9041, 9042, 9101, 9171, 9182, 9220, 9290, 9330, 9331, 9390, 9421, 9435, 9582, 9584, 9635.2.

Table 1
Affective Ratings of the IAPS Pictures used in each Experimental block.

	Affective Ratings	
Picture Type	Valence	Arousal
Neutral	5.36 (1.41)	3.77 (2.01)
Positive	7.20 (1.58)	4.69 (2.26)
Negative	3.24 (1.61)	4.66 (2.12)

Note: Mean (SD) values are shown. IAPS picture rating norms as published by Lang et al. (2008).

content (Lang et al., 2008): all included a similar proportion of human characters, animals, landscapes, food, and everyday objects. The IAPS norms for valence (1–9 corresponding to unpleasant-to-pleasant range) and arousal (1–9 corresponding to low arousal-to-high arousal range) are presented in Table 1. Positive and negative pictures did not differ in arousal ($p > 0.05$), but neutral pictures were less arousing than both positive ($p < 0.001$) and negative ($p < 0.001$) pictures.

Three tones were used in the auditory oddball paradigm. Each auditory sequence included 1050 standard tones (50 ms, 1000 Hz, 80 dB sound pressure level [SPL]) and 100 deviant tones (50 stimuli differing in duration − 125 ms; 50 stimuli differing in intensity[2] − 90 dB SPL, following Todd et al., 2008).[3] Two types of deviants were selected to allow an acceptable number of deviants per experimental condition, and to prevent adaptation effects.

2.3. Procedure

The experiment was conducted in a dimly lit, sound-attenuated and electrically shielded room. Participants were seated in a comfortable chair at 100 cm distance from a liquid-crystal display (LCD) screen (LG ACPI x86). The presentation and timing of pictures and sounds were controlled through Presentation software (version 16.3; Neurobehavioral Systems, Inc., Albany, NY, USA).

The experiment was divided in three blocks, each composed of neutral (Neutral Block), positive (Positive Block) or negative (Negative Block) IAPS pictures. Neutral pictures were always presented as the second block to avoid that the effects of an emotional block were carried on to the subsequent block. The order of the positive and negative blocks was counterbalanced across participants (i.e., for half of the participants the Positive Block was presented first, for the other half the Negative Block was presented first). An additional short block (not included in the analysis), composed of 53 neutral pictures, was presented before the neutral block. This short block aimed to ensure that emotional effects of the first block were not carried on to the subsequent block.

Each trial started with the presentation of one picture that remained on the screen until the end of the trial (see Fig. 1). At 200 ms after picture onset, a tone (standard or deviant) was presented, followed by another tone with a 500 ms inter-stimulus interval (ISI). The picture remained on the screen for further 300 ms. Thus, each picture belonging to a specific valence block (neutral, positive or negative) was presented for 1000 ms, with no ISI between pictures. Moreover, no sound was presented either at the exact beginning or end of a picture to avoid picture on and offset confounding effects. The proportion of deviants occurring in first and second position during picture presentation was comparable across deviant types and picture blocks. Each block was composed of 1050 ($P = 0.90$) standard tones and 100 deviant tones ($P = 0.05$ for each deviant type) presented in a pseudo-random order, with a minimum of 6 standards occurring between each deviant. For each block, pictures of the same valence were also presented in a pseudo-random order. Each block lasted for about 19 min, and each picture was repeated 10 times within a block due to the high number of trials.[4] The acoustic stimuli were delivered binaurally through Sennheiser CX 300-II earphones. Participants were instructed to pay attention to the pictures and to ignore the sounds to the best of their abilities. At the end of the experiment, they were asked questions about the pictures that were presented (e.g., global evaluation of the pleasantness *vs.* unpleasantness of the pictures; description of the content of the pictures).

Before the ERP session and after each picture block, participants' mood was assessed using the Portuguese adaptation of the *Positive and Negative Affect Schedule* (PANAS; Galinha & Pais-Ribeiro, 2005; Watson & Clark, 1994), which includes 20 items describing negative ("afraid", "scared", "nervous", "jittery", "irritable", "hostile", "guilty", "ashamed", "upset", and "distressed") and positive affect ("active", "alert", "attentive", "determined", "enthusiastic", "excited", "inspired", "interested", "proud", and "strong").

2.4. EEG data acquisition and analysis

Electroencephalographic (EEG) data were recorded using a 64-channel Active Two Biosemi system (Biosemi, Amsterdam, The Netherlands), in a continuous mode at a digitization rate of 512 Hz, and stored on disk for later analysis. Eye blinks and movements were monitored through electrodes placed on both temples (horizontal electrooculogram) and another one below the left eye (vertical electrooculogram).

EEG data were analyzed using EEGLAB 13.1.1b software (Delorme & Makeig, 2004). Data were referenced offline to the average of the left and right mastoids and filtered with a 4th order Butterworth high-pass filter with a cutoff of 0.1 Hz. Individual ERP epochs were created for each stimulus type (standard, duration deviant, intensity deviant) in each context (neutral, positive, negative), with −200 ms pre-stimulus baseline and 700 ms post-stimulus epoch. Standard tones following deviant sounds were excluded from the analysis.[5] The EEG was baseline corrected using the −200 to 0 ms pre-stimulus interval. The vertical electrooculogram (EOG) was derived by subtracting the activity measured at an electrode positioned below the left eye from an electrode positioned above it. The horizontal EOG was derived by subtracting the activity measured between electrodes placed at the outer canthi of the eyes. The EEG channels were corrected for vertical and horizontal eye movements using the method of Gratton et al. (1983). Segments were also semi-automatically screened for eye movements, muscle artifacts, electrode drifting and amplifier blocking. EEG epochs exceeding ± 100 microvolts were not included in individual ERP averages. After artifact rejection, at least 75% of the epochs per experimental condition per subject entered the analyses. Conditions did not differ in the number of non-rejected epochs ($p > 0.05$).

Difference waveforms were obtained by subtracting the standard from each deviant ERP waveform. The peak latency of each component was computed for intensity and duration deviant types at frontal, frontocentral, central, centroparietal, and parietal electrodes: the MMN peak latency was 180 ms (intensity deviant) and 220 ms (duration deviant). Based on those latency values and on visual inspection of the grand average waveforms, the following latency intervals were selected

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[2] An intensity deviant was chosen as an exemplar of spectral change, since previous studies demonstrated that sound intensity is less vulnerable to task requirements than frequency (e.g., Muller-Gass, Stelmack, & Campbell, 2005).

[3] In this study, Todd and collaborators selected values of intensity change that produced MMN amplitudes comparable to that produced by duration changes, based on a review of previous MMN studies.

[4] However, the repeated presentation of IAPS emotional pictures does not seem to prompt habituation of the affective response (Schupp et al., 2006; Smith, Bradley, & Lang, 2005).

[5] Since there is evidence that the standard stimulus that immediately follows a single deviant also elicits a small MMN (Sams, Alho, & Naatanen, 1984).

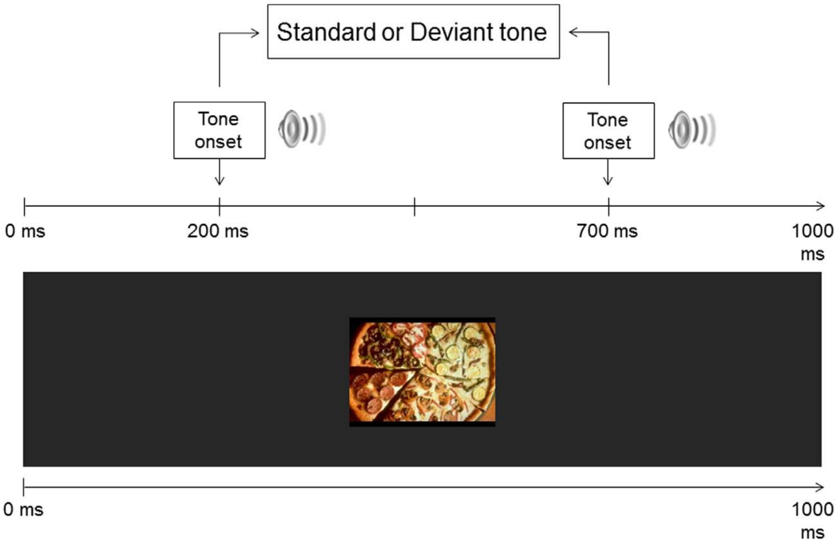

Fig. 1. Schematic Illustration of an Experimental Trial.

for MMN mean amplitude measurements: 160–220 ms (intensity deviants), and 190–250 ms (duration deviants).[6]

Furthermore, in order to explore whether the emotional context produced differential effects on the processing of standard and deviant sounds, we measured the N1 and P2 amplitude for standard and deviant sounds separately in the three picture contexts, in the following latency windows: 50–90 ms (N1); 91–130 ms (P2).

2.5. *Statistical analyses*

The SPSS statistical software package (Version 22.0, SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. Only significant results are presented (alpha level was set at 0.05). Effect sizes for significant effects are reported using the partial η-square method ($\eta_p{}^2$).

2.5.1. *Behavioral data*

Paired-sample *t*-tests were performed to probe differences between self-reported mood ratings immediately before and after each experimental block (neutral, positive and negative valence).

2.5.2. *ERP Data*

Repeated-measures analyses of variance (ANOVAs) were conducted to probe the effects of context on MMN mean amplitude, as well as on the N1 and P2 responses to standard and deviant sounds separately. The following procedure was adopted. First, context (neutral, positive, negative) and ROI (frontal − F3, Fz, F4; frontocentral − FC3, FCz, FC4; central − C3, Cz, C4; centroparietal − CP3, CPz, CP4; parietal − P3, Pz, P4) were included as within-subject factors. Subsequently, we probed the effects of hemisphere, testing the within-subject factors of context and hemisphere (left − F3, FC3, C3, CP3, P3; right − F4, FC4, C4, CP4, P4). For the MMN, an additional factor of deviant type (duration, intensity) was used in both ROI and hemisphere analyses.

Analyses were corrected for non-sphericity using the Greenhouse–Geisser method (the original *df* is reported). Significant interactions were followed with pairwise *t*-tests, using the Sidak adjustment for multiple comparisons (see Supplementary Tables 2 and 3).

2.5.3. *Correlational Analyses*

Two-tailed Pearson correlation analyses were conducted in an exploratory analysis of the relationship between statistically significant ERP effects and self-reported mood.

3. Results

3.1. *Behavioral data*

3.1.1. *Self-reported mood*

After the presentation of negative pictures, positive mood was decreased, $t(19) = 4.180$, $p = 0.001$, while negative mood was increased, $t(19) = -5.799$, $p < 0.001$, compared to the self-reported affect right before the negative block (see Table 2). No significant mood changes were observed after the presentation of neutral ($p > 0.05$) and positive ($p > 0.05$) pictures.

3.2. *ERP data*

Fig. 2 shows grand-average ERPs elicited by standard and deviant tones in neutral, positive and negative contexts. Fig. 3 illustrates difference waveforms separately in the neutral, positive and negative contexts, as well as the topographical distribution of the MMN effects.

3.2.1. *The effect of context on standards and deviants*

3.2.1.1. Standards. No context effect or interaction involving the context factor were found on the N1 elicited by standard sounds ($p \geq 0.05$). However, context modulated the P2 amplitude to standards ($F(2, 38) = 4.597$, $p = 0.016$, $\eta_p{}^2 = 0.195$): P2 was increased for standards presented in the positive compared to neutral context ($p = 0.029$).

3.2.1.2. Deviants. There were no significant effects of context on the N1 and P2 elicited by duration deviants or intensity deviants ($p \geq 0.05$).

3.2.2. *The effect of context on the difference potentials: Mismatch Negativity*

The repeated-measures ANOVA confirmed the typical fronto-central distribution of the MMN, demonstrated by a significant ROI effect ($F(4, 76) = 42.289$, $p \leq 0.001$, $\eta_p{}^2 = 0.690$; fronto-central ≥ frontal − $p \leq 0.001$; fronto-central ≥ centro-parietal − $p = 0.001$; fronto-central ≥ parietal − p 0.001). A significant effect of deviant type was also observed, $F(1, 19) = 39.637$, $p < 0.001$, $\eta_p{}^2 = 0.676$: MMN was generally more negative for duration relative to intensity deviants.

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[6] As expected, the peak of the MMN effect for duration deviants occurred later than for intensity deviants, since a change in duration can only be judged at its offset (e.g., Parmentier et al., 2010). This supports the notion that the MMN latency varies according to the type of regularity that is violated (e.g., Näätänen et al., 2004).

Table 2
Self-reported Mood (PANAS) Before and After the Neutral, Positive and Negative Experimental Blocks.

		Positive Mood	*Change in Positive Mood*	Negative Mood	*Change in Negative Mood*
Before Experiment		23.95 (5.66)	–	10.85 (1.66)	–
Neutral Block	**Before**	18.95 (7.49)	−0.35	12.90 (3.73)	−1.9
	After	18.6 (8.08)		11 (1.72)	
Positive Block	**Before**	20.60 (6.76)	1.85	10.55 (1.00)	0.25
	After	22.45 (7.60)		10.8 (2.26)	
Negative Block	**Before**	21.95 (8.11)	−5.1 **	11.30 (2.11)	4.4 ***
	After	16.85 (6.30)		15.7 (4.32)	

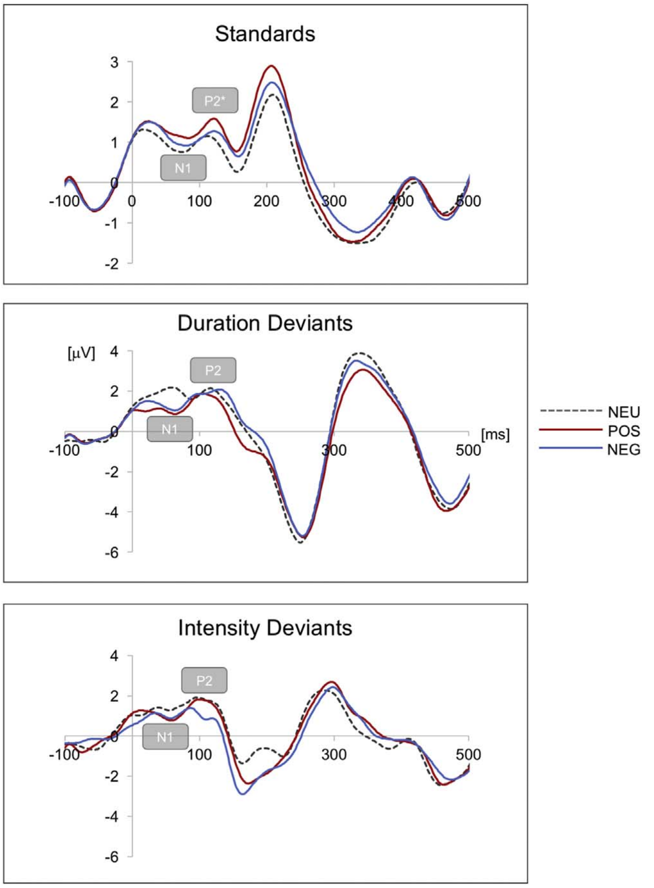

Fig. 2. Grand Average Waveforms (at Cz) illustrating ERPs to standard and deviant sounds presented in the Neutral, Positive and Negative Contexts.

Importantly, context interacted with ROI, $F(8, 152) = 2.172$, $p = 0.033$, $\eta_p^2 = 0.103$, but not with deviant type. This interaction was followed up by testing context effects in each region separately (with the same factors described before except 'ROI'). At frontal sites, the MMN was larger (i.e., more negative) in the positive relative to the negative context (significant effect of context − $F(2, 38) = 3.777$, $p = 0.032$, $\eta_p^2 = 0.166$; positive *vs*. negative − $p = 0.035$).

Subsequently, the ANOVA testing hemisphere effects showed a significant context by hemisphere interaction, $F(2, 38) = 4.483$, $p = 0.018$, $\eta_p^2 = 0.191$. We followed this interaction by running separate ANOVAs in left *vs.* right hemisphere electrodes. The MMN was significantly larger (i.e., more negative) in the neutral relative to the negative context in the left hemisphere (context effect − $F(2, 38) = 3.254$, $p = 0.05$, $\eta_p^2 = 0.146$).

Even though the P3a (a neurophysiological index of attention orienting − Polich, 2007) was not the focus of the current study, we also analyzed the amplitude of this component, measured from 260 to 320 ms (intensity deviants), and 290–350 ms (duration deviants), and using the same statistical model described above. No significant context effect or interaction involving the context factor ($p > 0.05$) were observed.

3.3. *Association between ERPs and self-reported mood*

The correlational analysis indicated a moderate significant association between MMN amplitude in the negative context and self-reported negative mood after the negative pictures block, $r = 0.535$, $p = 0.015$: the higher the negative mood, the less negative the MMN amplitude.

4. Discussion

In a dynamic sensory environment, humans are constantly bombarded by stimuli of different types. Given our limited attentional capacities, a way of optimizing resources is to reduce responsiveness to repetitive events that confirm expectations, while increasing the responsiveness to events that bring new and potentially salient information (e.g., Bendixen et al., 2012; Wacongne et al., 2012). Prediction is, thus, at the core of the cognitive and neural processing of sensory information. In the current study, we investigated how different types of visual contexts (neutral, positive, and negative) affect the ERP response to standard and deviant sounds that are not in the focus of attention. To accomplish this aim, the pictures set was carefully controlled and positive and negative pictures were matched in arousal.

In line with previous studies (e.g., Federmeier et al., 2001; Pinheiro, del Re et al., 2013; Pinheiro, Liu et al., 2013), our findings indicate that viewing emotional pictures resulted in mood changes, i.e., a decrease in positive affect and an increase in negative affect after the presentation of negative pictures.[7] Critically, even though the sound input was the same in the three visual contexts, we demonstrated that early stages of auditory change detection were impacted by context. Specifically, context had a major influence on the P2 response to standards (increased in the positive context), whereas it modulated the N1 response to both intensity and duration changes in a similar manner. Further, the difference between standard and deviant sounds revealed that the MMN was reduced in the negative compared to both positive and neutral contexts. However, context did not affect processes of attention orienting reflected in the P3a. These findings suggest that the emotional valence of concurrent visual stimuli affects the comparison of predicted and perceived sound input, likely as a function of mood changes induced by pictures viewing.

4.1. *Emotional context modulates the capacity to predict auditory input*

EEG activity related to standard *vs.* deviant sounds sheds light on

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[7] The fact that no mood changes were observed after the positive block may be related to the high positive mood of the participants reported at the baseline assessment ($M_{\text{baseline}} = 23.95$). This may be explained by the fact that our sample was composed of college students, with no current psychopathological symptoms. Therefore, considering the high self-reported positive mood at the baseline, a further increase was less likely than an increase in negative mood ($M_{\text{baseline}} = 10.85$).

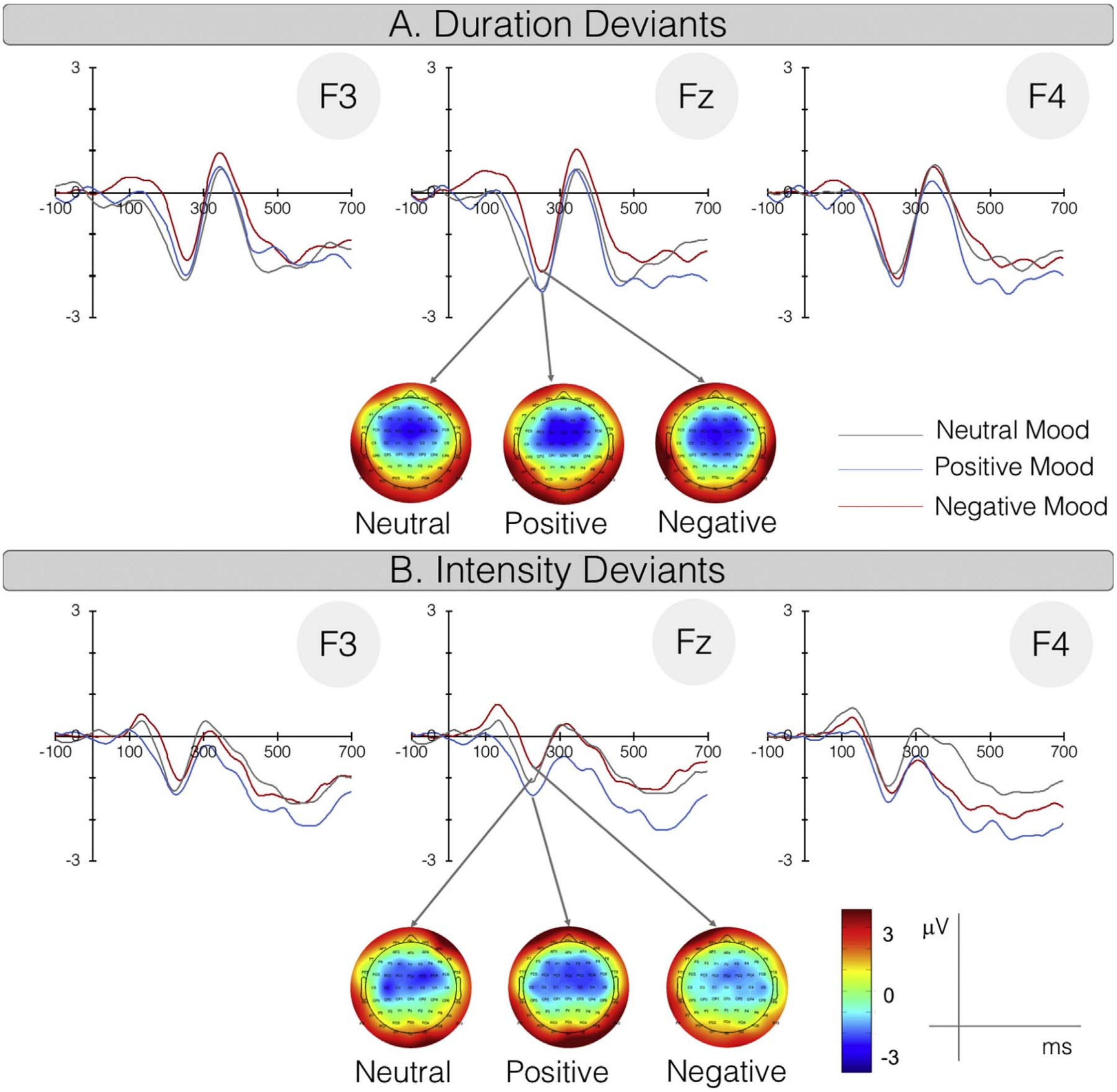

Fig. 3. Grand Average Difference Waveforms illustrating the MMN elicited in the Neutral, Positive and Negative Contexts, and respective Topographical Maps.
The topographical maps showed that the MMN effects were maximal at frontal, frontocentral, and central electrodes corroborating the typical fronto-central scalp distribution of the MMN (e.g., Garrido et al., 2009 for a review).
Note: Grand-averaged waveforms were filtered with a 12-Hz low-pass filter for graphical display only.

different neural processes (e.g., Garrido et al., 2009): whereas standard-related ERP effects inform about how regularities in sound features that appear outside the focus of attention are stored as predictive memory representations, deviant-related ERP effects indicate how changes in these features are automatically detected. We observed that the type of emotional context affected differently the early responses to standard tones: the P2 amplitude was enhanced in a positive context.

Probing ERP effects to standard stimuli is critical to understand how the auditory system builds rules of regular events (standards). These representations determine how rare events (deviants) that do not match the predictions are detected. Specifically, more positive amplitude elicited by standard tones within 250 ms in passive auditory oddball paradigms has been interpreted as suppressed prediction error due to more efficient top-down predictions (Baldeweg, 2007; Costa-Faidella, Baldeweg, Grimm, & Escera, 2011; Haenschel, Vernon, Dwivedi, Gruzelier, & Baldeweg, 2005). These findings agree with reports of increased P2 with increased sound predictability (e.g., Ross & -Tremblay, 2009), and with facilitated preattentive access to perceptual representations (Tong, Melara, & Rao, 2009). The increased P2 for standards in a positive context in the current study suggests that a positive emotional context facilitated the prediction of future auditory events that were not in the focus of attention. This context enhanced the encoding of regular features of the auditory environment (the comparison templates or standard sounds).

4.2. *Automatic deviance detection is impaired in a negative context*

Consistent with the observation that the MMN does not represent an all-or-none response (Wacongne et al., 2012), we observed that the MMN amplitude to unattended sounds was modulated by the emotional valence of the task-relevant visual context. The MMN amplitude was reduced in the negative context relative to the positive and neutral contexts, despite the fact that the sounds were the same in the three different visual contexts. The observed modulation suggests that the emotional quality of the pictures altered the way the brain automatically encoded regularities in the auditory background and compared predictions with incoming sound input.

Note that positive and negative emotional contexts did not differently affect the intensity *vs.* duration MMN. This suggests that context does not have a more prominent role in the automatic detection of changes in spectral *vs.* temporal auditory stimulation. The current findings also support a lateralization of preattentive deviance detection as a function of the type of emotional context. The reduced MMN for negative compared to neutral contexts in the left electrode sites may suggest that the left hemisphere is less dominant or efficient in detecting auditory change when sounds are presented in a negative context. Whereas the right hemisphere was proposed to be dominant for processing emotions with a negative quality or negative affect, the left hemisphere seems to be specialized in the processing of positive (and less arousing – e.g., neutral) stimuli (Borod et al., 1998; Stefanics, Csukly, Komlósi, Czobor, & Czigler, 2012). However, in the absence of source localization analyses, this hypothesis remains speculative and needs to be addressed in future studies.

As a significant increase in negative affect was reported after the presentation of negative IAPS pictures, and the MMN amplitude in the negative context was significantly associated with self-reported negative mood, it seems plausible that negative mood affected how error signals were generated. Previous studies suggest that even mild affective states can produce changes in cognitive processes (e.g., Ashby, Isen, & Turken, 1999; Chwilla, Virgillito, & Vissers, 2011; Pinheiro, del Re et al., 2013; Vissers et al., 2010), and demonstrate qualitative differences in information processing style as a function of mood (happy = global processing style; sad = local processing style). For example, Bolte et al. (2003) reported that the effects of positive mood were reflected in enhanced access to remote associates in semantic memory, while negative mood was associated with restricted spread of activation in the semantic network in a task requiring judgments about the semantic coherence of word triads. The effects of mood were also demonstrated in (semantic) predictive processes. For example in the study of Chwilla et al. (2011), the N400 ERP cloze effect (N400 amplitude difference between the high-cloze and the low-cloze condition), an index of expectancy effects, was reduced in the context of sad relative to happy mood (elicited by presenting emotionally valenced film clips). Mood effects on the N400 modulation occurred together with significant changes in mood ratings. Importantly, a sad mood disrupted how participants predicted forthcoming auditory events, which suggested that “people in a sad mood are less open to accessible cognitions of what usually happens in the world around us” (p. 2412). Similarly, Pinheiro and collaborators (Pinheiro, del Re et al., 2013) demonstrated that mood had an impact on predictive mechanisms associated with language comprehension, reducing the ability to predict the category membership of expected targets. The current findings suggest that a negative mood state may additionally impair the comparison between predicted and perceived auditory input. Consistent with this hypothesis, Ahveninen et al. (2002) reported decreased MMN amplitude in individuals on a dietary challenge that resulted in acute tryptophan depletion that in turn decreased the synthesis of serotonin in the brain and lead to an increase in negative mood. Likewise, smaller MMN amplitude was observed in patients with major depressive disorder (characterized by increased negative affect) when compared with healthy controls (e.g., Qiao et al., 2013; Takei et al., 2009).

An alternative hypothesis for the current findings is that the MMN amplitude reduction in the negative context occurred as a function of sensory competition between the visual stimuli that were in the focus of attention and the task-irrelevant sounds: amplified responses to emotionally relevant pictures might have resulted in reduced attentional processing resources available for non-task-relevant sound processing (e.g., Tartar et al., 2012). In other words, the higher the attentional load of the primary task, the fewer the attentional resources available for the non-task-relevant stimuli. Note that prediction error minimization and bottom-up attention play opposite effects (e.g., attention increases the N1, whereas prediction decreases the N1 amplitude – Kok, Rahnev, Jehee, Lau, & De Lange, 2012). Nonetheless, challenging this hypothesis, some studies observed no significant MMN amplitude difference when comparing MMN elicited in an ignore *vs.* attend condition (e.g., Gomes et al., 2000; Sussman et al., 2004), even though a strong focus of attention to concurrent stimuli may lead to MMN amplitude attenuation (e.g., Alain & Izenberg, 2003). This suggests that the MMN is resistant to manipulations of attention. Whereas attention seems to primarily influence the processing of standard (*predicted*) stimuli, the detection of deviance (*unpredicted* stimuli) seems to represent a more automatic process, regardless of whether the sounds are attended (Sussman, 2007). Critically, if sensory competition was the major reason explaining the MMN differences, we would have also observed a significant difference in MMN amplitude between the neutral and emotional context regardless of valence. However, this was not the case.

Based on the current results, we might expect that, if a person suddenly encounters a bloody accident scene, his/her impaired capacity to notice that a nearby church bell suddenly started ringing may be due to the transient mood changes elicited by that negative visual context.

4.3. The role of emotional context in generating predictions and detecting auditory change: implications

The MMN findings provide support for the impact of task-relevant visual emotional contexts on the way the brain generates prediction and detects task-irrelevant sound changes. Specifically, they corroborate the interaction between bottom-up (driven by stimulus features) and top-down (driven by current mood state) processes during early stages of stimulus processing (e.g., Vanlessen, Rossi, De Raedt, & Pourtois, 2012). As such, these findings add to existing literature that highlights the intricate relationships between mood and cognitive functions such as language (Federmeier et al., 2001; Hinojosa et al., 2010; Pinheiro, del Re et al., 2013), cognitive control (Yuan et al., 2011), error detection (Larson, Perlstein, Stigge-Kaufman, Kelly, & Dotson, 2006), or attention (Wang, LaBar, & McCarthy, 2006).

Our findings also highlight the importance of looking at differences between negative and positive stimuli. Previous studies indicated that positive affect is related to a broadened scope of attention and more global (top-down) information processing style (Ashby et al., 1999; Basso, Schefft, Ris, & Dember, 1996; Fredrickson & Branigan, 2005; Gasper & Clore, 2002; Rowe, Hirsh, & Anderson, 2007; Wadlinger & Isaacowitz, 2006). The current results indicate that positive input may support the capacity to predict sensory information in another modality channel.

Conversely, negative mood has been associated with a narrowed focus of attention that impairs the processing of peripheral details (Gable & Harmon-Jones, 2010), or the generation of contextually-guided predictions (Pinheiro, del Re et al., 2013), resulting in a more detailed (bottom-up) information processing style. This may impair predictions in a concurrent sensory (auditory) modality.

Elucidating the interplay between affective variables and prediction is critical for our understanding of psychiatric disorders. For example, negative affect is a central feature of major depressive disorder, which may lead to altered predictions about upcoming sensory events, with putative cascading effects on cognitive processes (Barrett, Quigley, & Hamilton, 2016).

Since the magnitude of the MMN response was influenced by the valence of the concurrent (and task-relevant) visual stimuli, the current data also have important methodological implications. Specifically, controlling for the valence of the visual stimuli presented in the distracting task (e.g., silent movies), as well as carefully assessing participants’ mood states before and after the task, seems to be a critical step in MMN studies.

4.4. Limitations and future directions

As the current design did not consist of a deviant-standard-reverse oddball paradigm (Jacobsen & Schröger, 2003), physical differences between standard and deviant stimuli might have contributed to the current ERP effects. Hence, we cannot rule out the putative contribution of early feature-selective neural activity to the current findings. Moreover, it is possible that some residual attention-related cross-modal effects might have interfered with the early components. Additionally, given the temporal proximity of the N1 and MMN components, N1 amplitude effects may have contributed to the MMN. Even though, in the current study, the N1 was not impacted by context (and thus unlikely to impact the MMN results), it is still possible that the N1 affected the MMN results in ways that cannot be qualified by the current design. As the current study parameters were not optimized to disentangle these effects, future studies should explore these issues.

4.5. Conclusions

The current study investigated the effects of pictures' valence, and associated mood changes, on preattentive auditory change detection. The results revealed that the automatic detection of changes in unattended auditory channel was reduced when sounds were presented in a negative visual context (reduced MMN) and that this reduction was associated with self-reported negative mood. On the contrary, the detection of regularities in the auditory stream was facilitated in a positive context (increased P2 to standards).

Therefore, they demonstrate that emotion changes auditory prediction and change detection. These results highlight the intricate links between emotion, perception and prediction.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biopsycho.2017.05.007.

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