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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

* 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,