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CICLO XXXVI

Learning to ignore emotional distractors: repetition, affective context and long-term effects

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ABSTRACT

It is well known that prolonged experience with certain stimuli modulates their significance in the priority map and leads to a diminished allocation of our attention to them. The present thesis aims to explore the extent to which repetition of the same set of stimuli is effective in supporting a learning process that shapes the attentional filter and allows us to ignore distractors, through the process known as habituation. The primary focus is on understanding how the exposure to repeated task-irrelevant stimuli, particularly emotional ones (both pleasant and unpleasant) might influence the way attention is captured by these images. Additionally, the goal is to determine which stage of emotional processing is affected by this experience, through both behavioral and cortical measures. Finally, we have explored how the habituation mechanisms are influenced by the introduction of a change in the context of experience disrupting its stability, as well as by the lack of exposure to the stimuli themselves for a certain period.

To test this, in Experiment 1, the impact of the repetition of distractors was examined by content (i.e., pleasant, unpleasant, and neutral), showing that emotional interference completely habituated with repetition and promptly recovered with novelty. At the cortical level, the enhanced LPP for emotional pictures was attenuated by repetitions, and stimulus novelty only affected emotional, but not neutral distractors in both the RTs and LPP. Alpha-ERD was similarly reduced for repeated emotional and neutral distractors.

To better understand how flexible the habituation mechanisms are in novel emotional contexts, in Experiment 2 novel distractors (pleasant or unpleasant or neutral) were

introduced among repeated pictures. This prompted a dishabituation response at the behavioral level (i.e., recovery of the response after the habituation) which was more evident in the unpleasant context. Moreover, when novel pictures depicted pleasant contents (i.e., erotica), the dishabituation to unpleasant distractors was attenuated. The LPP and the Alpha-ERD were highly modulated by distractor emotional contents (i.e., trial type), and this modulation persisted across repetitions. Both cortical responses were strongly enhanced when novel pictures were introduced after the habituation phase.

Experiment 3 aims to measure the persistence of the habituation over time, that is, the effect of a lack of exposure to the stimulus on habituation. The same set of stimuli were repeated in a habituation phase and, after a day of rest, a test phase. Behavioral interference for emotional stimuli was still reduced by the habituation in the test phase and recovered by the subsequent introduction of new stimuli.

The different responses observed at the behavioral and cortical levels correspond to different stages of the elaboration of the stimuli. This suggests that the initial stages of evaluation, where we assess and categorize stimuli, are crucial and supported by the engagement with our motivational systems. This engagement is sustained, and it is reflected in the affective modulation of the Late Positive Potential (LPP).

The human brain has the ability to selectively disregard emotionally irrelevant stimuli once the initial evaluation has taken place. This adaptive capability, to overcome the tendency for emotional stimuli to capture our attention, does not occur spontaneously but it is developed through the experience with distracting events. Essentially, it is a learned response originated as a result of the strategy to ignore the distractors and the implicit learning that certain emotional cues hold no significant consequence.

In general, this mechanism of inhibition is also sensitive to specific contextual perturbation, like the introduction of novel emotional stimuli and the temporary lack of stimulation, which modulate the response to the already habituated stimuli.

In summary, this suggest that cognitive mechanisms enable us to prioritize and filter out emotional distractors after evaluating their significance, emphasizing the importance of implicit learning and context of experience in shaping our response to emotional stimuli.

Acknowledgements

“Someone is sitting in the shade today because someone planted a tree a long time ago.” — W. B.

Questo elaborato sigilla un percorso che non si limita agli anni di dottorato, ed è iniziato con un incontro: quello tra me e la prof.ssa Vera Ferrari. Ringrazio Vera sinceramente, per avermi appassionata da subito ai quesiti e ai metodi della Psicofisiologia e delle Scienze Cognitive, per avermi accolta in questa storia che è iniziata ben prima che io ne conoscessi l’esistenza, per la fiducia con cui da subito, e nei momenti più difficili, mi ha incoraggiata affinché potessi tirare fuori il meglio da questo percorso di formazione e da questo segmento della mia vita.

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Acknowledgement: One of the works described in this thesis has been published and it has been documented in the relevant Chapters (2) with acknowledgement.

Chapter 1

1.1 Introduction

While we carry out our daily activities, we are constantly exposed to a large number of stimuli. Completing tasks, achieving goals and being productive is possible because we have the ability to ignore distractions and focus resources on information relevant to us. Imagine a student focusing on a text in a bustling library, despite the noise of people talking and moving around; a driver focusing on relevant traffic signs and ignoring phone calls, other drivers behaving erratically, billboards to reach his destination; employees in a busy office maintaining concentration on their main task despite phone calls, emails, or conversations among colleagues; a basketball player shooting free throws while inhibiting distractions from the crowd or opponents' attempts to disrupt focus. In each of these scenarios, selective prioritization and inhibition of information are two complementary mechanisms that support the accomplishment of a goal through attention, which, in turn, acts like a spotlight to enhance the processing of relevant sensory information and its aware elaboration.

It is also possible to learn through experience to ignore information that is not necessary for our purposes, as will be described in this dissertation. The focal point revolves around understanding the involuntary capture of attention by emotional occurrences that distract us from our goals, and whether an observer's familiarity with these stimuli modulates this capture. The research presented in this work shows that repetition of the same stimuli is effective in reducing susceptibility to emotional distractions, as evidenced by the behavioral interference effect.

In the second chapter, we describe three consequential studies. The first one (Ferrari, Canturi & Codispoti, 2022) showed the habituation for emotional stimuli in a predictable context with only repeated pictures. In this context, we can observe a powerful novelty effect at the behavioral level with the introduction of all new pictures, but this effect is present only for the emotional distractors and not for the neutral ones. We discuss possible explanation of this phenomenon, mainly attributable to a filter that is set on the emotional content of the stimuli, so that the neutral ones are not significant. To better explore the role of context and its influence on the attentional capture for emotional repeated stimuli, the second experiment shows the effect of the introduction of new stimuli among the repeated and habituated ones. We observe different responses at the behavioral vs the cortical level, and different responses depending on the emotional content of the stimuli involved.

However, despite the level of exposure to distracting stimuli, the assessment processes and motivational systems are persistently engaged, as indicated by the prolonged affective modulation of the LPP. Even though in the first experiment the LPP modulation for unpleasant distractors was consistently attenuated by repetition, and the introduction of novel emotional pictures (both pleasant and unpleasant) prompted a more pronounced response of the LPP, in the second experiment the emotional modulation for repeated stimuli in the LPP window is still present at the end of the habituation phase. Thus, while evaluating emotional stimuli is deemed necessary, there exist top-down mechanisms that diminish or hinder further attention allocation toward evidently inconsequential emotional stimuli. Consequently, these mechanisms can aid in preventing counterproductive and repetitive emotional distractions.

The third experiment focused on behavioral measures to explore the stability of habituation mechanisms over time, in particular after a one-day break in which the experience with repeated stimuli is suspended. We have observed that habituation is robust at a behavioral level, and that it is sensitive to novelty.

The project of this dissertation is part of a specific line of research, which has as its objective to better understand how implicit learning influences the way our attention is either drawn towards emotional stimuli or it can ignore them. In order to introduce the theoretical background from which these data take on meaning, in the first chapter I will briefly recall some significant works on the state of the art.

1.2 The attentional capture debate: goal-driven, stimulus-driven, and history-driven accounts

Since attention is a capacity-limited system (e.g., Broadbent, 1957; Kahneman, 1973; Luck & Vecera, 2002), in contexts as complex as those just described in the introduction's examples, in which we must ignore some of the information that reaches us in order to facilitate others, selective attention is crucial for processing and interpreting information efficiently. In this way, the organism is able to enact the most advantageous behavior and respond to stimuli based on the context in which it finds itself (Luck, Hillyard, Mouloua, & Hawkins, 1996; Posner & Petersen, 1990; Theeuwes, 1989; Theeuwes & Van der Burg, 2007).

The leading models that explain the processes governing the control of attention allocation (e.g., Posner, 1980; Desimone & Duncan, 1995; Yantis, 2000; Corbetta & Shulman, 2002; Theeuwes, 2010) call into question the *stimulus-driven account* (or bottom-up) according to which attention is guided by the perceptually salient, motivationally significant, or novel events (Jonides & Yantis, 1988; Theeuwes, 1993) regardless of observer's goal. This is the case of the *additional singleton paradigm* (Figure 1.1, Theeuwes 1992), where participants are typically instructed to search for a distinct shape (circle) among uniform shapes (diamonds). To test the competition between stimuli, in some trials one of the non-target shapes (distractors) appears as a singleton in a different dimension (e.g., red diamond item among green diamonds). This distractor singleton feature isn't relevant for the task, but it is implicitly favored by the attentional set (*singleton detection mode*) and leads to a slower search time for the target, that is called *distractor interference effect*.

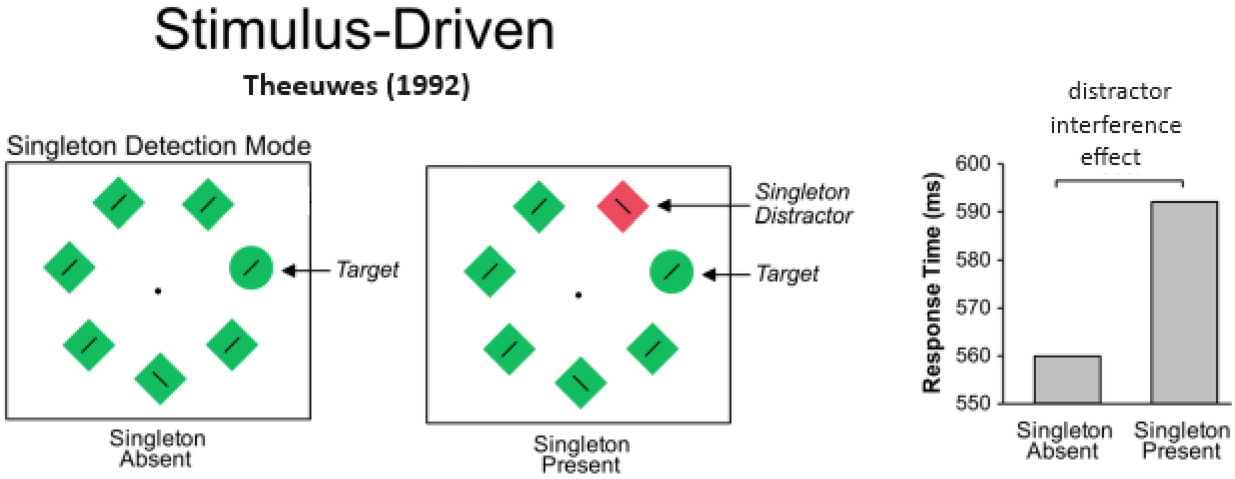

Figure 1.1 The target circle among diamond distractors, leading to a distractor interference effect (modified from Gaspelin and Luck, 2018).

However, the distractor interference effect can be reversed by introducing various shapes (target feature) into the display, forcing participants to search for the specific shape defining the target (*feature search mode*) rather than its distinctive characteristic relative to the other stimuli (Figure 1.2, Bacon & Egeth, 1994; Leber & Egeth, 2006a). From this prospective, called contingent *involuntary orienting hypothesis* (Folk, Remington & Johnston, 1992), the attentional capture relies on the observer's strategy to reach the goals, and stimuli can involuntarily capture attention only when they align with these goals, not solely based on their perceptual salience.

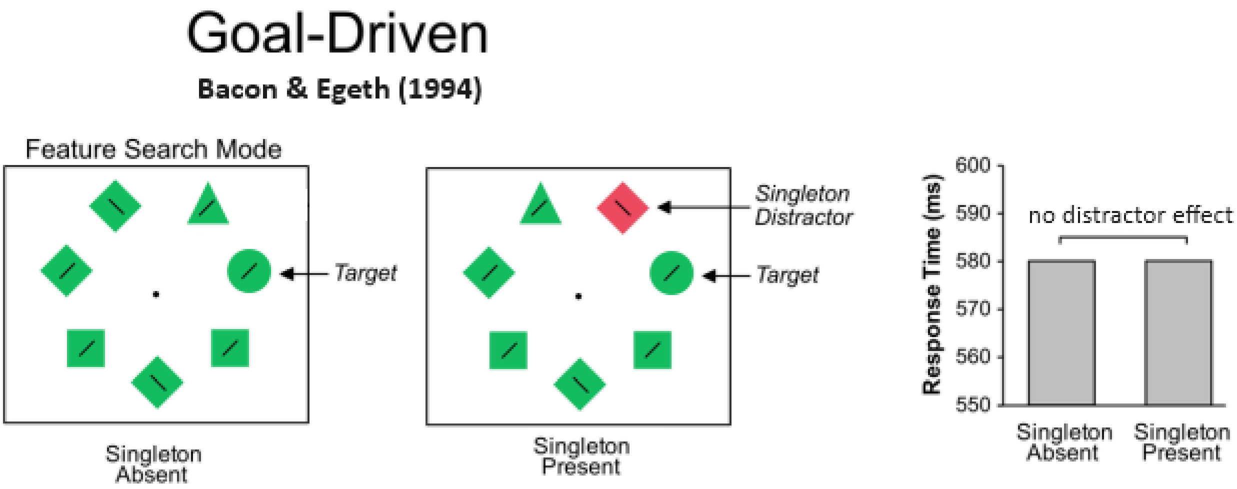

Figure 1.2 A circle target appears among heterogeneous distractors, leading to no singleton distractor interference effect (modified from Gaspelin and Luck, 2018).

Recently, the attentional capture debate pointed out that selection is not only a result of the explicit goal of the observer nor of the sensory features of the stimulus, but also previous experience with the stimulus can prompt selection biases (e.g., Awh, Belopolsky & Theeuwes, 2012; Theeuwes, 2018). In this case, labeled *selection history*, events can be prioritized even when they are not salient concerning the perceptual feature nor irrelevant for the ongoing task. Several previous experiences can influence attentional capture, as reward or punishment associated with a neutral stimulus, priming or statistical regularities. In the first mentioned paradigm, the successful selection of the target is rewarded (Anderson, Laurent & Yantis, 2011) or a certain neutral stimulus is associated with a shock (Kim, Lee, Grindell &

Anderson, 2022) during a training phase. During the subsequent test phase, participants search for a different target and no reward or shock are delivered, while previous reward/shock associated stimuli are presented as distractors, interfering with the search of the target. Another category that continues to efficiently capture attention is a stimulus or a feature that has been attended in the past, establishing a phenomenon called priming (e.g., Maljkovic & Nakayama, 1994). Importantly, it was recently demonstrated that participants can learn statistical regularities of the target, that is selected faster in known configurations (e.g., Chun & Jiang, 1999), and also distractor regularities (location) reducing his distractor effect (e.g., Wang & Thueewes, 2018).

1.3 Behaviorally urgent stimuli

History driven selection is a special case of behaviorally significant events that have been acknowledged for their capacity to capture attention irrespective of top-down control. In an *evolutionary framework*, these categories include stimuli such as abrupt onset (Jonides & Yantis, 1988), biological motion (Pratt, Radulescu, Guo & Abrams, 2010), rare and unexpected stimuli (e.g., Turatto & Pascucci, 2016; Neo & Chua, 2006; Horstmann, 2002), stimuli associated with a reward or a punishment (Awh et al., 2012; Anderson, 2018) and emotional stimuli (Öhman & Wiens, 2003; Vuilleumier, Armony, & Dolan, 2004; Lang and Bradley, 2010). These stimuli are considered capable of eliciting mandatory attention, operating independently of the observer's goal, since they may need an immediate behavioral reaction which requires the attentional system to be particularly efficient in detecting them and allowing rapid evaluation. The ability to process and respond directly to so-called *behaviorally urgent* stimuli promotes the survival of the organism, because these stimuli can signal an opportunity to acquire resources or to avoid a threat (Anderson, 2021). On the other hand, distracting can also be costly for the ongoing activities in which the observer is involved, in a learning setting (Taneja, Fiore, & Fischer, 2015), as well as in the workplace (e.g., Namian, Albert & Feng, 2018), and in motor vehicle crashes (e.g., Strayer & Drew, 2004). In fact, there is growing interest in understanding how the involuntary allocation of the attention by distractors can be attenuated and under what conditions the observer can ignore a stimulus that he has no reason to attend to.

1.4 Learning to ignore distarctors

Attentional mechanisms have evolved not only to respond quickly to behaviorally relevant stimuli, but also to minimize the costs of attentional capture by irrelevant stimuli (Chelazzi, Marini, Pascucci, & Turatto, 2019; Anderson, 2021). It is well established that the attentional template is shaped by implicit learning, that is below the threshold of awareness, and requires less voluntary engagement. This mechanism is based on learned associations (Kim and Anderson, 2019) or statistical information extracted during a previous experience with the stimulus (Li & Theeuwes, 2020; Zhao, Al-Aidroos & Turk-Browne, 2013). At the same time, stimuli that initially capture attention are efficiently ignored due to habituation when they are frequently encountered (Turatto & Pascucci, 2016) showing that the attention allocation system adjusts by learning to disregard stimuli that are still perceptually salient, but based on the current priority of the observers, are deemed irrelevant. The process known as *habituation* is the reduction of the interference effect on a main task with the repetition of the same stimulus, and it is observed at different levels of stimulation (Thompson, 2009; Rankin et al., 2009).

Novelty of a stimulus is a characteristic that determines a strong attention capture (Jonides & Yantis, 1988) and can be defined with different meanings, referring to a stimulus that has never been seen before, or appears in an unexpected context or frequency. The basic idea is that presentation of a stimulus characterized in this way constitutes a change in the scene that no longer reflects the observer's expectations, triggering an orienting (OR) response toward the new stimulus (Sokolov, 1963). However, the orienting response involves a certain energy consumption since it determines autonomic and cortical changes, which would become disadvantageous for the organism. Therefore, repeated stimuli that do not pose a subsequent threat or advantage to the organism can be incorporated into the neural model and inhibit the orienting reflex (Pavlov, 1927). According to the *Stimulus-Model Comparator Theory* (Sokolov, 1963) any new stimulation is compared with a cortical model that represents the environment, and fails to match it, prompting an orienting response. The repeated exposure to the same stimulus built a representation including the repeated stimulus, inhibiting the response to it, and leading to the habituation of the OR.

1.5 Habituation of emotional scenes: LPP, Alpha-ERD and behavioral interference

The habituation mechanism is effective in inhibiting the response not only for simple stimuli, but also for emotional complex scenes, that are a special category of stimuli capable of attentional capture (Lang, Bradley & Cuthbert, 1997). The elaboration of emotional stimuli is supported by the engagement of the cortico-limbic circuits to facilitate the perception and evaluation of the stimulus, and also to prepare the organism for the needed action through a series of physiological changes (Anderson, Laurent & Yantis, 2011; Hickey, Chelazzi &

Theeuwes, 2010; Lang & Bradley, 2010, 2013; Lang, Bradley & Cuthbert, 1997; Le Doux, 2012; Bradley & Lang, 2007; Sabatinelli et al, 2011; Sambuco et al., 2019). Consistent with the *motivational hypothesis*, the involvement of these systems is reflected in the stimulus significance, which is composed by valence (indicating which system is activated, defensive or appetitive) and arousal (indicating the intensity of the physiological activation). These two dimensions define a cartesian space where the ratings for the images of the *International Affective Picture System* (IAPS; Lang, Bradley, & Cuthbert, 2005) are placed (Figure 1.3).

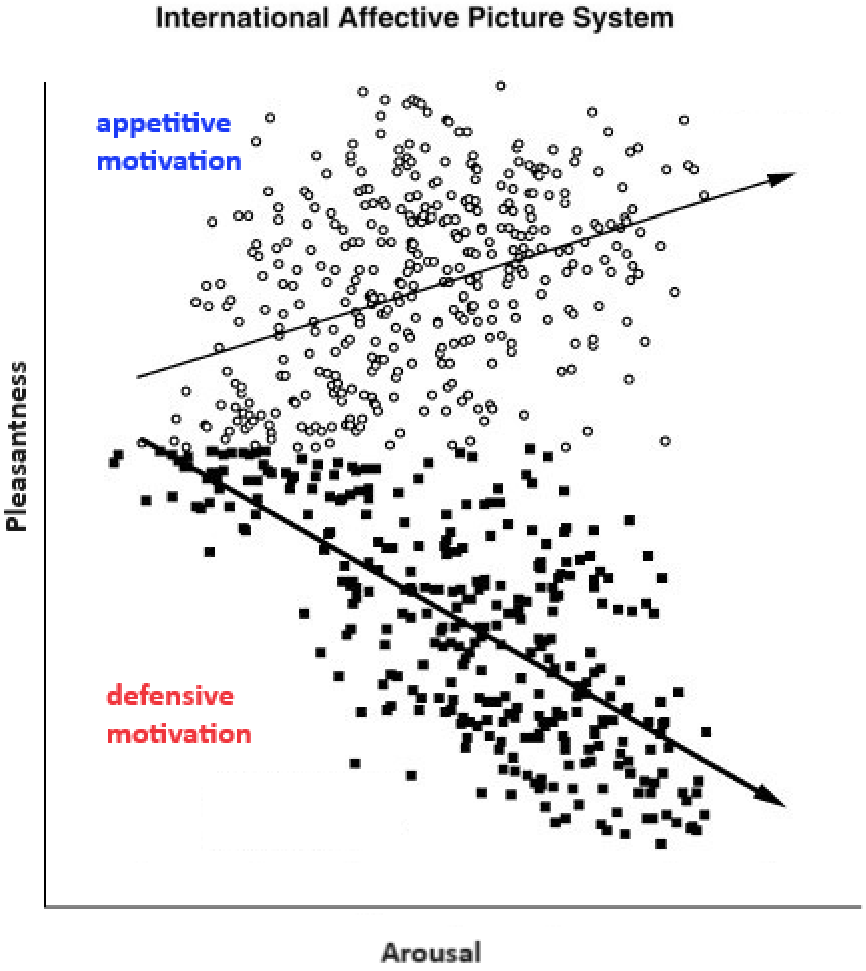

Figure 1.3 Affective space defined by ratings in valence and arousal for natural scenes in the Affective Picture System (modified from Bradley, Codispoti, Cuthbert, & Lang, 2001).

The activation of the motivational system reflected in the arousal is visible through different neural, physiological, and motor responses, including Electroencephalogram activity (EEG). Particularly, during a free picture view, the emotional content of visual stimuli modulates the amplitude of a specific late positive potential called Late Positive Potential (LPP). The LPP component is described by the comparison between emotional stimuli (both unpleasant and pleasant) and neutral stimuli, such as an increase in positivity at the level of the central-parietal sensors, which begins around 300-400 ms from the stimulus onset. Furthermore, the amplitude of the LPP is greater for high arousing images (Cuthbert, et al., 2000; Schupp et al., 2000; 2006), while it does not change based on the perceptual characteristics of the image as size, color, and complexity (De Cesarei & Codispoti, 2006, 2008; 2011; 2012; Bradley, 2007) suggesting that the modulation of LPP reflect semantic elaboration of stimuli and not perceptual factors. It has been shown in several studies that the repeated presentation of stimuli in free viewing and central to the visual field only slightly affects the emotional modulation of the LPP (Figure 1.4). It suggests that, in the absence of a competing task, mere repetition is not sufficient to inhibit the impact of these stimuli (Codispoti, Ferrari, & Bradley, 2006, 2007; Ferrari, Bradley, Codispoti, & Lang, 2011; Mastria, Ferrari, & Codispoti, 2017; Ferrari, Mastria, Codispoti, 2020).

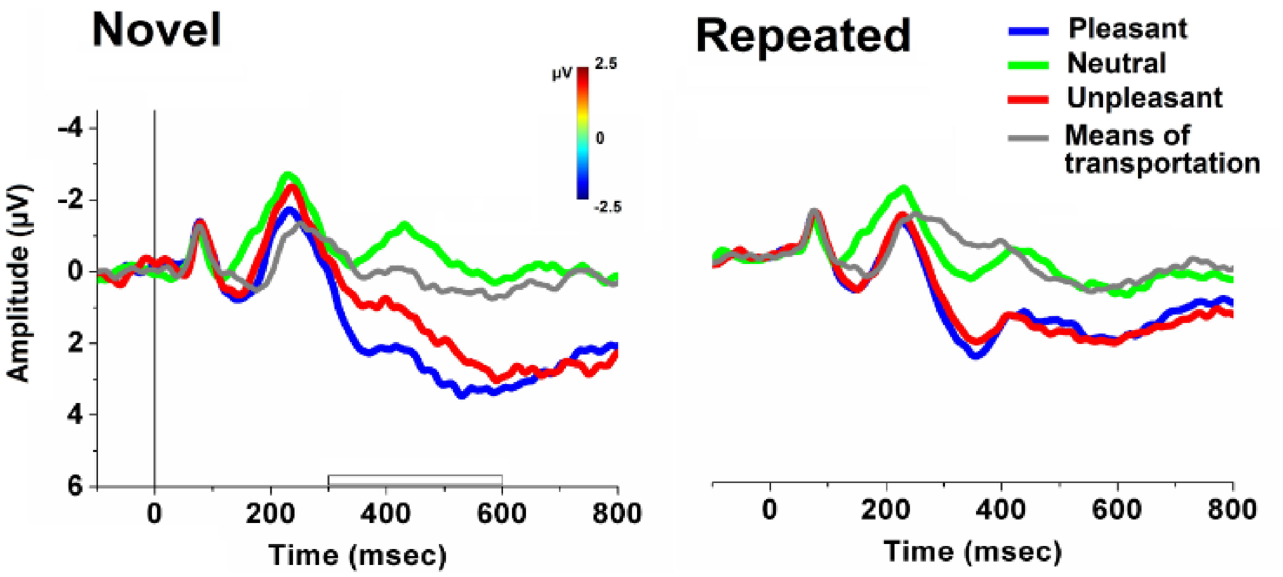

Figure 1.4 Cortical response over centro-parietal sensors elicited by viewing novel and repeated pictures in free-viewing, showing a visible difference between emotional and neutral in the LPP window (300-600 ms) preserved after receptions. (modified from Mastria et al., 2017).

Only few studies have investigated the effects of repetition of stimuli on emotional distractors through LPP during a task. An explicit categorization paradigm asking to indicate the category of the shown pictures based on a specific feature, showed an enhanced LPP after few repetitions of the pictures, which did not differ from the free viewing condition (Mastria et al., 2017). During a parity judgment task, with the emotional stimulus in the center of the screen, the behavioral interference effect gradually diminished with stimulus repetitions, while the LPP enhancement for emotional compared to neutral pictures wasn’t affected by the repetition (Figure 1.5, Codispoti, De Cesarei, Biondi & Ferrari, 2016).

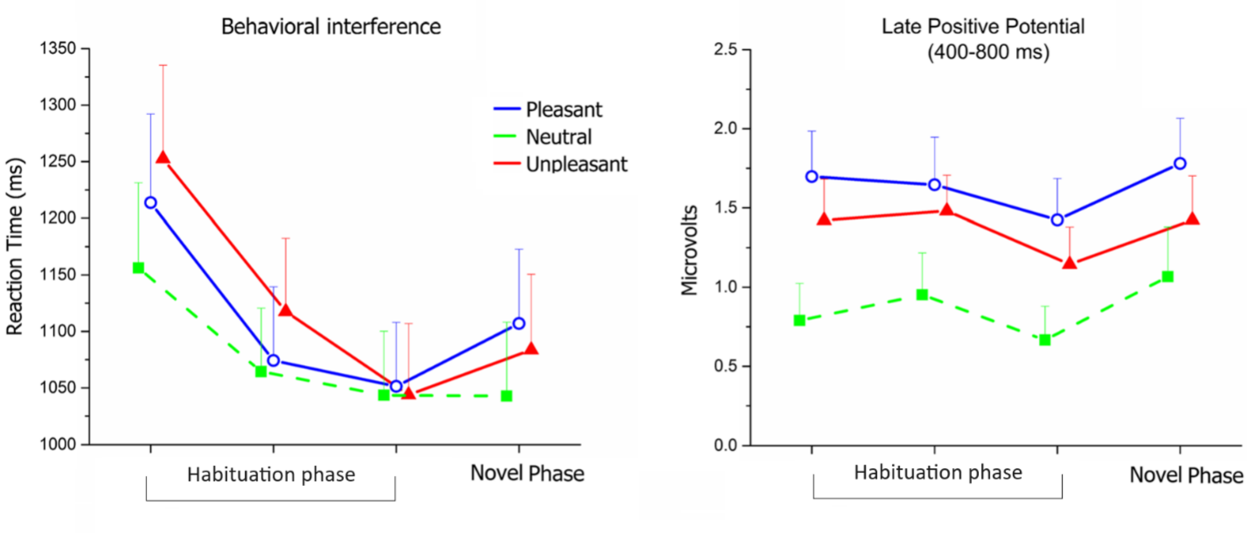

Figure 1.5 Stimulus repetition effect on the behavioral interference and on the affective modulation of the LPP during a parity judgment task. Modified from Codispoti et al. 2016.

The findings suggested that the emotional modulation of the LPP reflect an earlier and mandatory stage of the emotional process, at the service of the evaluation of the stimulus and the engagement of the motivational system; once the stimulus has been categorized and recognized as an event without consequences on the basis of previous experience, it does not require further attentional resources or preparation for action, therefore we can observe a reduction in the interference on behavioral performance.

The analysis of ERPs is informative concerning the evolution over time of the cortical response, that can also be analyzed in the time-frequency domain in order to study oscillatory activity. The alpha wave is a rhythmic oscillation of the EEG in the frequency range from 8 to 12 Hz. Alpha desynchronization is an enhancement of the decrease in power of alpha activity compared to a baseline, and it thought to index a higher activation of visual processing areas possibly associated with perceptual enhancement; decreased alpha-band activity has been interpreted as representing an electrophysiological correlate of cortical activation or enhanced cortical excitability and engagement in stimulus processing. Typically, the onset of a visual stimulus results in alpha band enhancement (Alpha-ERD) over occipital areas (Berger, 1929).

Recently, it has been reported that the enhanced Alpha-ERD over posterior sensors is a consistent response indicating emotional processing compared with neutral condition (for a review see Codispoti, De Cesarei, Ferrari, 2023). In the passive-view condition, it has been shown an enhancement of Alpha-ERD for emotional compared to neutral stimuli (Ferrari, Bradley, Codispoti, & Lang, 2015; Ferrari et al., 2020; Schubring & Schupp, 2019). The enhancement of Alpha-ERD for emotional compared to neutral pictures seems to be independent of task (De Cesarei and Codisposti, 2011; Schubring & Schupp, 2019) and repetition (Ferrari et al., 2015; Schubring & Schupp, 2021). Interestingly, in a two sessions study with a one-day break in stimulus repetitions, the alpha desynchronization was observed for new emotional stimuli compared to neutral ones, although little evidence of a repetition effect was observed (Figure 1.6, Ferrari et al., 2020).

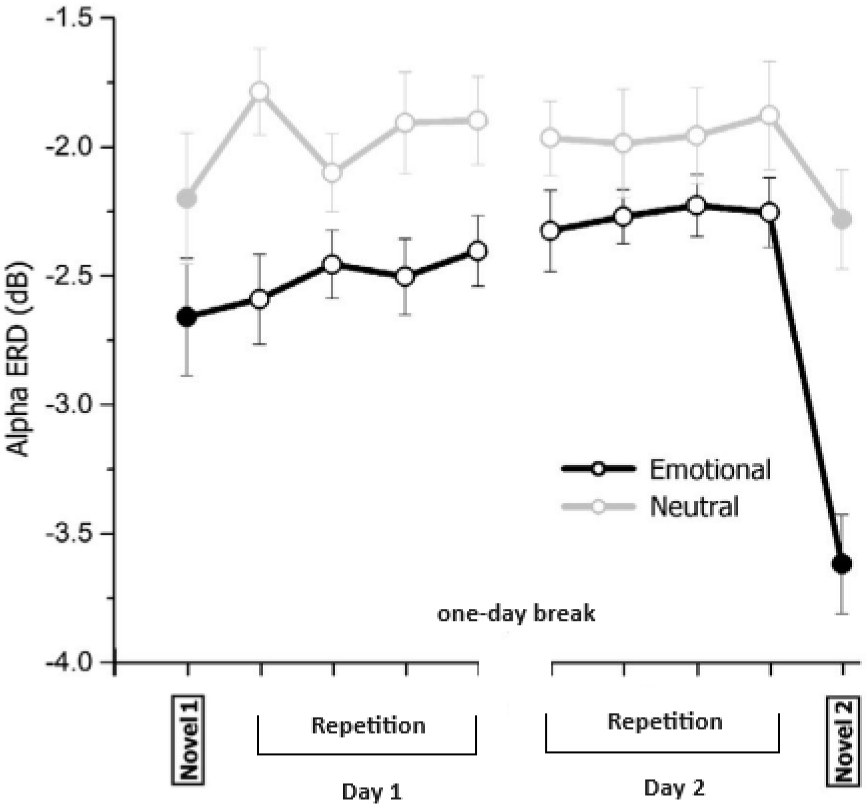

Figure 1.6 Mean Alpha-ERD for emotional and neutral pictures across blocks of novel and repeated pictures. In the second day session, it shows a novelty effect for emotional pictures. (modified from Ferrari et al., 2020).

At the behavioral level, it is well known that emotional stimuli have the ability to involuntarily capture attention (as distractor) more reliably than neutral stimuli, and this can result in a disruption of performance (i.e., reaction times or accuracy) in the current task (Bradley, Cuthbert, & Lang, 1996; Calvo, Gutiérrez-García, & Del Libano, 2015; De Cesarei & Codispoti, 2008; Ihssen, Heim, & Keil, 2007; Micucci, Ferrari, De Cesarei, & Codispoti, 2019; Weinberg & Hajcak, 2011). Importantly, emotional complex scenes are effective in prompting an interference effect on the main task also when the low-level perceptual features were paired with neutral and in the peripheral view (Calvo et al., 2015).

This supports that the attentional capture by emotional pictures rely on the semantic emotional content rather than perceptual factors. The emotional interference is affected by stimulus repetitions, as indicated in different studies using emotional words as well as emotional picture, in which the initial attentional captures decrease after few repetitions (Harris & Pashler, 2004; Codispoti, et al., 2016). However, only one previous study measured the inhibition of emotional interference by pictures over repetitions introducing a competing parity judgment task (figure 1.7, Codispoti et al., 2016). It is important to note that the emotional interference recovered with the introduction of new pictures, indicating a stimulus specific habituation rather than a general inhibition of task irrelevant distractors.

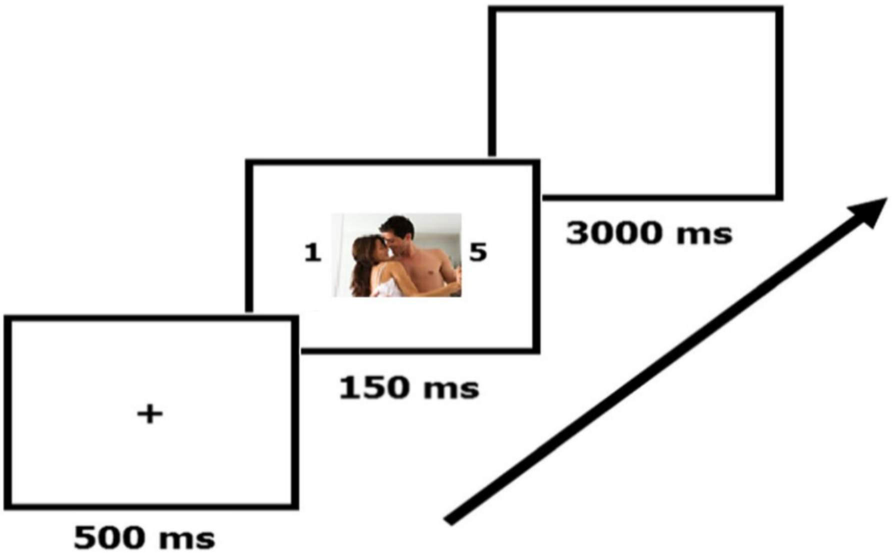

Figure 1.7 showing the parity judgment task: a picture, flanked by two numbers, is presented for 150 ms, followed by a blank screen during which behavioral responses are collected. Participants are instructed to ignore the picture, and to indicate whether the two numbers are both odds or both even (parity) or not (one odd and one even) (modified from Codispoti et al., 2016).

In summary, the attentional system is efficient in detecting emotional stimuli that can represent cues of advantageous or disadvantageous situations. The resources necessary to process emotional stimuli, when they are in the condition of distractors, fall back on the task in performance, reducing efficiency. However, the attentional system has also evolved to adapt to situations in which emotional stimuli are no longer carriers of information, such as repeated stimuli that are not followed by consequences of value. The system can ignore these stimuli, which are still processed at an early stage, allowing to concentrate resources on the main task.

The studies presented in the following section aim to investigate which factors influence the habituation mechanisms. We measured the habituation of emotional stimuli presented as distractors, in the periphery of the visual field, and in competition with a task, to analyze the response at a behavioral and cortical level.

Chapter 2

2.1 Experiment 1: Stimulus novelty and emotionality interact in the processing of emotional distractors

Acknowledgements: Ferrari, V., Canturi, F., & Codispoti, M. (2022). Stimulus novelty and emotionality interact in the processing of visual distractors. Biological Psychology, 167, 108238. https://doi.org/10.1016/j.biopsycho.2021.108238

The goal of Experiment 1 was to investigate the processing of repeated distractor stimuli, as reflected in both behavioral interference (i.e., Reaction time, RT) and cortical activity (i.e., Late Positive Potential, LPP; Alpha desynchronization, Alpha-ERD), in order to understand at which stage of processing repeated emotional distractors can be ignored. The stimuli were distractors, as they were task-irrelevant for participants instructed to indicate the orientation of a central Gabor patch stimulus (vertical or horizontal). Specifically, the distractors were pictures varying in emotional content (i.e., pleasant, neutral or unpleasant).

The emotional interference is observable as slower RT for emotional compared to neutral stimuli, and it decreases in response to repeated stimuli, indicating that the attentional allocation system learns to ignore emotional stimuli over time, and hence attentional capture by emotional stimuli is modulated by the observer's experience (e.g., Harris and Pashler, 2004; Codispoti, De Cesarei, Biondi & Ferrari, 2016). At the same time, the persistence of the affective modulation of the LPP regardless of stimulus repetition and in the presence of a task has been interpreted as evidence that the initial evaluation processes, which reflect the engagement of motivational systems, occur mandatorily (e.g., Codispoti, Ferrari, & Bradley, 2006, 2007; Ferrari, Bradley, Codispoti, & Lang, 2011; Codispoti et al., 2016; Ferrari, Codispoti, Cardinale, & Bradley, 2008; Mastria, Ferrari, & Codispoti, 2017).

Experiment 1 addresses the following three issues.

First, if the attentional system is sensitive to specific perceptual features of the repeated stimulus, the habituation process could already be evident at an early stage, that is, before the distractor content is evaluated and the attentional system has been engaged; alternatively, distractor filtering may only be effective once the stimulus has been evaluated in terms of its motivational relevance, resulting in the LPP modulation, but preventing further information gathering when the stimulus is highly familiar, with no interference effect on the performance of tasks.

Second, at the end of the habituation phase, the introduction of wholly novel distractors helped to assess the hypothesis that the reduction of emotional interference with stimulus repetition could be mediated by a specific spatial inhibition of any sensory stimulus appearing in the distractor location. If distractor novelty is effective in prompting a recovery of attentional capture, we may argue that the filtering mechanism is basically tuned on the specific features of the repeated stimuli, instead of on spatial filtering. At the same time, the sensitivity to stimulus change may be different for emotional and neutral pictures. In a previous repetition study, in which affective habituation was measured in a free viewing context, the introduction of novel stimuli after an extensive habituation phase prompted a response recovery in the LPP only for emotional but not for neutral pictures (Ferrari et al., 2020). If a similar pattern is also evident for behavioral interference, this would be further evidence that novelty is not sufficient per se to prompt an orienting response, and that other factors related to motivational significance of the stimulus (or of the context, Reisenzein, Horstmann, & Schützwohl, 2017) may play a crucial role.

Third, in the literature on brain oscillations, emotional scenes prompt enhanced alpha event-related desynchronization (Alpha-ERD; Schubring & Schupp, 2019); moreover, alpha increase has been shown to reflect a gating process tuned to inhibit distractor processing (e.g., Geng, 2014; Wöstmann, Alavash, & Obleser, 2019). Although previous habituation studies found little evidence of repetition effects on the Alpha-ERD enhancement for emotional pictures (Ferrari et al., 2020; Schubring & Schupp, 2021), here pictures are the distractor stimuli, which may activate a gating process, with an increased Alpha ipsilaterally to the distractors, that develops across repetitions and to a greater extent for emotional distractors.

Method

Participants

The participants were 25 university students (12 females; mean age = 24.64 years, SD = 4.8; 22 right-handed). All participants had normal or corrected-to-normal visual acuity. The experimental protocol conformed to the Declaration of Helsinki.

Material

The visual stimuli were 132 pictures of natural scenes selected from various sources, including the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005), and public domain pictures available on the Internet. Of these pictures, 44 depicted pleasant contents (heterosexual erotic couples), 44 showed unpleasant contents (mutilated bodies), and the remaining 44 were neutral pictures depicting a variety of images of people in daily contexts. All images (14.3◦ h × 10.8◦) were equated in brightness and contrast, using a MATLAB-based toolbox (SHINE; Willenbockel et al., 2010). Pictures of natural scenes served as distractor stimuli and were positioned either to the left or the right of a central Gabor patch (sinusoidal gratings with a Gaussian envelope). The distance between the inner edge of the distractor image and the center of the Gabor patch was 4◦. The Gabor patch subtended a 5.3◦ × 5.3◦ visual angle and it could be horizontally or vertically oriented. Gabor patches were generated using custom MATLAB software by overlapping two distinct Gabor patches with the same frequencies but a different orientation (0.94 and 9.4 cycles per degree of visual angle, respectively). Stimuli were displayed on a gray background. Stimuli were presented on a 16-in. monitor at 1024 × 768 resolution and at a refresh rate of 120 Hz. Stimulus presentation and data collection were performed using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002).

Procedure

In the experimental session, upon arrival at the laboratory, participants signed an informed consent form. Then the participant was seated in a recliner in a small, sound-attenuated, dimly lit room, and the EEG sensor net was attached.

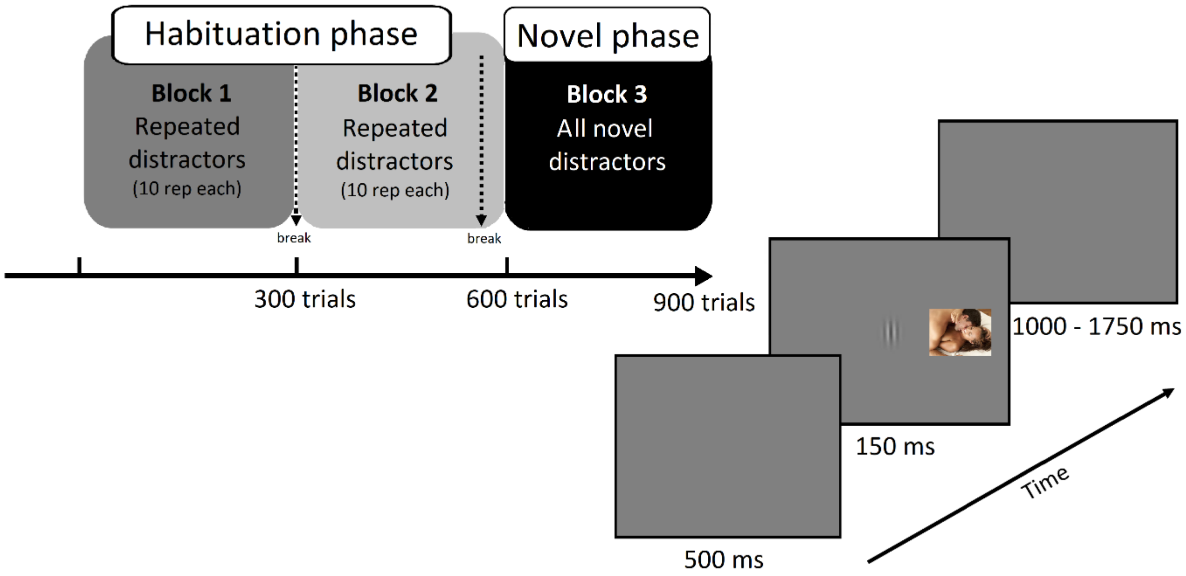

Figure 2.1 showing the sequence of events of the experimental paradigm. Two blocks of repeated distractors (habituation phase) were followed by one block consisting wholly of novel distractors (novel phase). In each trial, an initial dark-grey screen appeared for 500 ms followed by a Gabor patch presented in the center of the screen for 150 ms. The participant's task was to determine, as quickly and accurately as possible, whether the Gabor patch was vertical or horizontal, and respond accordingly by pressing the corresponding key with the index finger of the dominant hand. The intertrial interval was variable (1000, 1550, or 1750 ms) and consisted of a gray screen. During this period, behavioral responses to the orientation task were collected. In distractor-present trials, a distractor picture (either pleasant, unpleasant, or neutral) was presented simultaneously with the Gabor patch, appearing equally often in the left or right visual field. Participants were explicitly informed that there would be a distractor in some trials and that it should be ignored. The gabor patch was always present, whereas distractors appeared in 40% of the trials.

The experimental session consisted of three blocks of 300 trials each: the first two blocks belonged to the habituation phase, as a small set of 12 pictures (4 pleasant, 4 neutral, and 4 unpleasant) were continuously repeated (10 repetitions for each picture exemplar in each block, i.e., 4 × 10). The third and last block of the experiment was the novel phase, where only new pictures that had never been presented before were revealed (40 pleasant, 40 neutral, 40 unpleasant). Two brief breaks were introduced across blocks. To make the novel distractors more unexpected, the second break was introduced 30 trials before the end of the habituation phase. Using the same 132 pictures, four presentation orders were constructed that varied, across participants, the specific pictures presented in the habituation and novel phases. Before the beginning of the experiment, each participant performed a practice block of 30 trials in which a neutral distractor appeared in 40% of the trials. This picture exemplar was exclusively presented in the practice trials.

EEG recording and processing

Electroencephalogram (EEG) was recorded at a sampling rate of 1000 Hz using a 59 channel Electro-Cap connected to a SA Instrument CO (San Diego, CA) UF-64/72BA amplifier and in-house developed software. Impedance of each sensor was kept below 10 kΩ. Eye movements were recorded at a sampling rate of 1000 Hz from two bipolar couples of electrodes, placed respectively 1 cm above and below the right eye and 1 cm left and right to the side of the eyes. Both EEG and ocular signal were on-line filtered from 0.01 to 100 Hz. Off-line analysis was performed using Emegs (Peyk, De Cesarei, & Junghöfer, 2011). First, eye movements were subtracted from the EEG on a trial-by-trial basis, based on the data from the monopolar horizontal and vertical EOG, and using a regressive procedure (Gratton, Coles, & Donchin, 1983). Then, raw data were low-pass filtered at 30 Hz. ERP averages were computed with a 200-ms baseline and a 1000-ms time window. Trials and sensors containing artifacts were detected through a statistical procedure (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). In each trial, if a high number of neighboring bad sensors was present, then the whole trial was discarded; for the remaining trials, sensors containing artifacts were replaced by interpolating the nearest good sensors. The percentage of good trials was 85%, and this percentage did not significantly change across blocks or conditions. Finally, data were re-referenced to the average of all channels. The average of the 200 ms pre-stimulus baseline was subtracted from the waveform obtained. Processed data were averaged for each Block of 300 trials (Block 1, Block 2, Block 3) and Trial type (distractor absent; pleasant, neutral, and unpleasant distractors). ROI and time interval of interest were identified by both visual inspection and previous studies (Micucci et al., 2020). The LPP was scored as the average of the ERP waveform in the time window between 450 and 900 msec after stimulus onset at the centro-parietal sensor group (CPZ, CP1, CP2, CP3, CP4, PZ, P1, P2, P3, P4, P5, P6, POZ, PO3, PO4, PO5, PO6, PO7, PO8, OZ, O1, O2, see inset in Fig. 2.3). For time-frequency analysis, no low-pass filtering was applied on the row EEG signal, but the correction of eye movements, as well as the artifact detection and sensor interpolation, was similar to the ERP analysis. Data were convolved using complex Morlet's wavelet varying in time and frequency with a Gaussian shape. The time frequency analysis was performed on single trial data using FieldTrip software through EMEGS (Peyk et al., 2011). The Morlet wavelet has a Gaussian shape, where the f/SD(f) ratio was set to 7, and the number of wavelet cycles was set to 5 (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997). The range of analysis was from 4 to 80 Hz and analysis was performed in time windows from 1000-ms before picture onset to 1500 ms after picture onset in steps of 10 ms. As frequency resolution is maximal for low frequencies and minimal for high frequencies (Roach & Mathalon, 2008), the step between successive frequencies varied linearly from 0.5 Hz for the lowest frequencies to 5 Hz for the highest frequencies. All data were baseline corrected, by subtracting the average alpha power of the prestimulus baseline (- 300 to - 100 ms) from each data point. The baseline was calculated slightly earlier than stimulus onset to avoid the burst of oscillatory activity that starts before the onset of the stimulation, due to the artifact of the filter algorithm (Herrmann, Grigutsch, & Busch, 2005). The resulting event-related change in total power values (relative to baseline) are in decibels (dB) (Delorme & Makeig, 2004). For Alpha-ERD (8–14 Hz), statistical analyses were performed on the mean value of bilateral occipito-temporal sensor groups (P3, P4, P5, P6, P7, P8, PO3, PO4, PO5, PO6, PO7, PO8, O1, O2, see inset in Fig. 2.4) over the same temporal window of the LPP (450–900 ms).

Data analysis

RT and EEG analyses were performed only on accurate trials, that is, when the orientation of the central gabor was correctly detected. For each participant, block, and trial type, RTs above or below 3 SDs from the mean were discarded as outliers. These criteria removed 4.6 % of the data. For RT and the LPP, a repeated-measures ANOVA was performed with the two within-participant factors of Block (3: Block 1, Block 2, and Block 3) and Trial type (4: distractor absent, pleasant, neutral, unpleasant). Considering that Alpha-ERD showed an occipital bilateral topography that was highly sensitive to distractor spatial position, the statistical design also included the Position factor: contralateral vs. ipsilateral hemisphere relative to distractor visual hemifield. Thus, a first analysis focused on the emotional content of distractor pictures, with the following design: distractor Position (2: Contro, Ipsi) × Block (3) × distractor Valence (3: pleasant, neutral, unpleasant). A second analysis assessed the overall Alpha-ERD during trials with distractors (contralateral and ipsilateral) versus distractor-absent trials as a function of blocks: distractor Position (3: Contro, Ipsi, Absent,) × Block (3). Greenhouse-Geisser corrections were applied where relevant. For each ANOVA test, we reported the partial η^2 squared statistic (η^{2}p), indicating the proportion of variance that is explained by experimental conditions over the total variance.

Results

Behavioral data

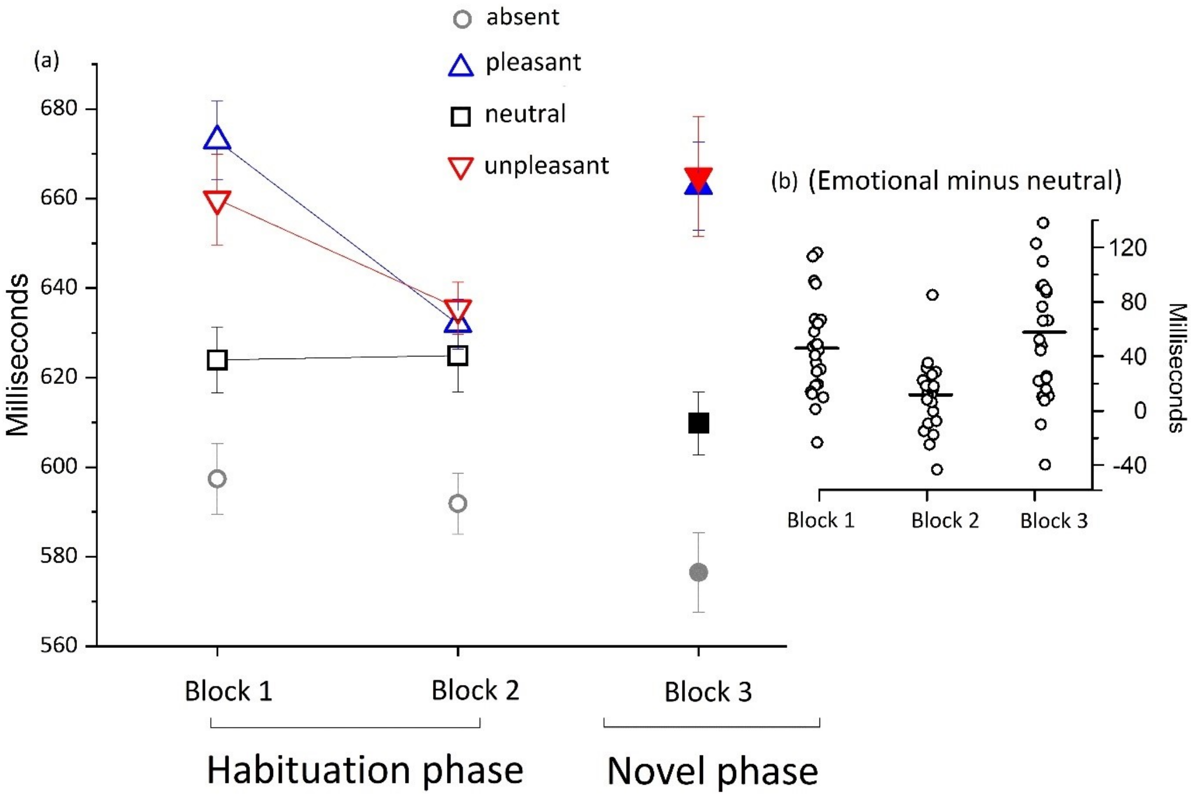

Figure 2.2 (a) showing the interference effects of distractors on the response times (RTs) to the gabor discrimination task. Behavioral interference is plotted as a function of block: all types of pictures prompted an evident RT slowdown, compared to distractor-absent trials. The emotional content of distractors, either pleasant or unpleasant, was more effective in capturing attention and interfering with the task, but this affective interference was very sensitive to picture repetition, showing an evident decrease throughout the habituation phase, followed by a full recovery with novel distractors. Error bars show ± 1 SEM calculated within participants using the method of O'Brien and Cousineau (2014).

(b) Single subject plot of the RT difference between emotional (average of pleasant and unpleasant) and neutral distractors (i.e., affective modulation). Line represents the mean.

Statistical analysis of RTs revealed a main effect of trial type ($F_{3,72} = 34.6$, $p < .001$, $\eta^2p = .59$), with slower RTs for distractor-present trials, compared to distractor-absent trials ($Fs_{1,24} = 44, 30.89, 43.79$, $ps < 0.001$, $\eta^2p > 0.56$, respectively, for pleasant, neutral, and unpleasant distractor types). The emotional picture content prompted an additional modulatory effect on RTs, with slower responses during the occurrence of both pleasant and unpleasant distractors, compared to neutral pictures ($Fs_{1,24} > 20.89$, $ps < 0.001$, $\eta^2p > 0.47$). RTs for pleasant and unpleasant distractors were similarly modulated. The Block (3) × trial types (4) interaction ($F_{6,144} = 6.896$, $p < .001$, $\eta^2p =.223$) indicated that behavioral interference changed over trials as a function of distractor repetitions, but only for emotional pictures (distractor-present vs. distractor-absent (2) x 3 blocks: for pleasant, $F_{2,48} = 13.116$, $p < .001$, $\eta^2p = .353$ and unpleasant, $F_{2,48} = 5.435$, $p = .016$, $\eta^2p = .185$), and not for neutral distractors ($F_{2,48} < 1$, $p = .594$, $\eta^2p = .020$). More specifically, compared to distractor-absent trials, both pleasant and unpleasant pictures decreased their interference from block 1 to block 2 of the habituation phase (distractor-present vs. distractor-absent (2) × 2 blocks for pleasant, $F_{1,24} = 22.17$, $p < .001$, $\eta^2p = .480$; unpleasant, $F_{1,24} = 4.984$, $p = .035$, $\eta^2p = .172$), such that the affective modulatory pattern found in block 1 (pleasant and unpleasant vs. neutral, $Fs_{1,24} > 18.259$, $ps < 0.001$, $\eta^2p > 0.432$) was no longer evident at the end of the habituation phase (block 2: pleasant and unpleasant vs. neutral, $Fs_{1,24} > 1.85$, $ps > 0.082$, $\eta^2p > 0.072$).

The introduction of novel pictures prompted a full recovery of emotional interference (pleasant and unpleasant vs. neutral in the novel block, $Fs_{1,24} > 15.371$, $ps < 0.001$, $\eta^2p > 0.39$), that was similar to that observed in the first block of the habituation phase (block1,3 × trial

Type $_{pl,neu,unpl}$, $p = .054$). In all these conditions, RTs behaved similarly for pleasant and unpleasant distractors.

Overall accuracy was high ($M = 96.5\%$), indicating that the discrimination task was perceptually easy (low-load perceptual task). The ANOVA did not reveal any significant effects involving trial type, block, or their interactions.

Late Positive Potential (LPP)

Statistical analysis of the LPP revealed a main effect of trial Type, ($F_{3,72} = 31.167$, $p < .001$, $\eta^2p = .565$), showing the largest positivity for pleasant distractors, compared to all other trial types, including unpleasant distractors ($F_{1,24} = 10.165$, $p = .004$, $\eta^2p = .298$), which in turn were more positive than neutral distractors ($F_{1,24} = 31.726$, $p < .001$, $\eta^2p = .569$). Interestingly, the LPP amplitude did not differ between neutral distractor and distractor-absent trials ($F_{1,24} = 0.64$, $p = .43$, $\eta^2p = .026$). A main effect of Block ($F_{2,48} = 6.528$, $p = .003$, $\eta^2p = .214$) indicated that the LPP changed as a function of distractor repetitions, with a smaller amplitude in block 2 compared to block 1, ($F_{1,24} = 12.478$, $p = .002$, $\eta^2p = .342$) as well as compared to block 3 (novel), $F_{1,24} = 6.466$, $p = .018$, $\eta^2p = .212$. The Block x trial Types interaction ($F_{6,144} = 4.133$, $p = .001$, $\eta^2p = .147$) revealed that the effect of repetition impacted only emotional distractors (pleasant over blocks, $F_{2,48} = 7.672$, $p = .001$, $\eta^2p = .242$, unpleasant over blocks, $F_{2,48} = 6.53$, $p = .003$, $\eta^2p = .214$) but not neutral distractors $F_{2,48} = 1.199$, $p = .307$, $\eta^2p = .048$. Indeed, similarly to RT results, the LPP to neutral distractors was not attenuated by repetition, and novel neutral pictures did not prompt any hint of LPP enhancement compared to repeated neutral distractors (Block 2 vs. Novel, $F = 0.376$, $p = .546$). The affective modulation was highly significant in block 1 ($F_{2,48} = 14.962$, $p < .001$, $\eta^2p = .384$) with both pleasant and unpleasant being more positive than neutral pictures ($F_{1,24} =$

32.998, $p < .001$, $\eta^2p = .50$; $F_{1,24} = 17.276$, $p < .001$, $\eta^2p = .419$, respectively), but similar to each other.

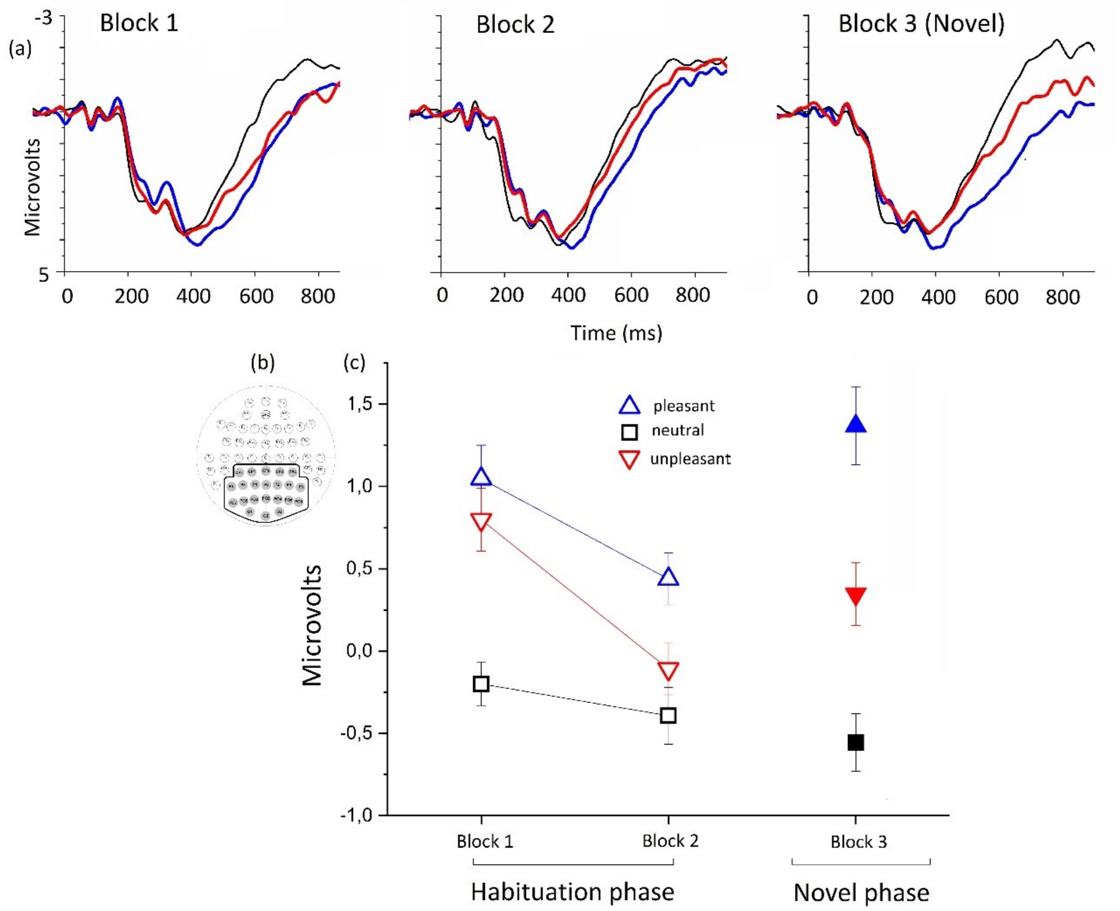

Figure 2.3 showing the effects of distractor repetition on the LPP amplitude. (a) Grand-averaged ERP waveforms (average across the sensor cluster) for pleasant, neutral, and unpleasant distractors across the two blocks of the habituation phase and the final novel block. The LPP enhancement for pleasant and unpleasant distractors, compared to neutral distractors, decreased throughout the habituation phase, and then recovered with the introduction of novel distractors. (b) The sensor cluster used for statistical analyses is reported on the sensor map (gray dots). (c) The line graph shows the mean of the LPP amplitude (window 450–900 ms) for distractor-absent, pleasant, neutral, and unpleasant distractors as a function of block.

Unlike reaction times, in block 2 the affective modulation of the LPP was still significant, ($F_{2,48} = 6.293$, $p = .004$, $\eta^2p = .208$), but this modulatory effect was mostly driven by pleasant distractors, that, if compared to neutral distractors, did not show a significant habituation pattern across repetitions ($\text{Block}_{1,2}$ × trial $\text{Type}_{pl, neu}$, $F_{1,24} = 2.184$, $p = .152$, $\eta^2p = .083$). Unpleasant distractors, on the other hand, were significantly affected by repetitions ($\text{Block}_{1, 2}$ × trial $\text{Type}_{unpl, neu}$, $F_{1,24} = 4.885$, $p = .037$, $\eta^2p = .169$), such that in block 2 there was no LPP difference between unpleasant and neutral distractors ($F_{1,24} = 1.119$, $p = .301$, $\eta^2p = .045$).

In the novel phase the LPP was again larger for both pleasant and unpleasant distractors compared to neutral ones $Fs_{1,24} > 15.522$, $ps < 0.001$, $\eta^2p > .393$, although novel unpleasant distractors continued to prompt a smaller LPP compared to pleasant stimuli $F_{1,24} = 8.882$, $p = .007$, $\eta^2p = .270$.

Alpha Event Related Desynchronization (alpha-ERD)

Distractor position (2) × block (3) × distractor valence (3)

Alpha-ERD was significantly modulated by distractor valence ($F_{2,48} = 26.859$, $p < .001$, $\eta^2p = .528$) with stronger desynchronization for both pleasant, $F1,24 = 43.991$, $p < .001$, $\eta^2p = .647$, and unpleasant ($F_{1,24} = 21.216$, $p < .001$, $\eta^2p = .469$) compared to neutral pictures, and for pleasant, compared to unpleasant pictures ($F_{1,24} = 11.015$, $p = .003$, $\eta^2p = .315$). The amount of affective modulation of Alpha was not affected by distractor spatial position (distractor Position × Valence, $F_{2,48} = 2.091$, $p = .138$, $\eta^2p = .080$), and did not show a consistent repetition effect (Block × Valence, $F_{4,96} = 2.526$, $p = .058$, $\eta^2p = .095$), as was, however, the case for the RTs and the LPPs.

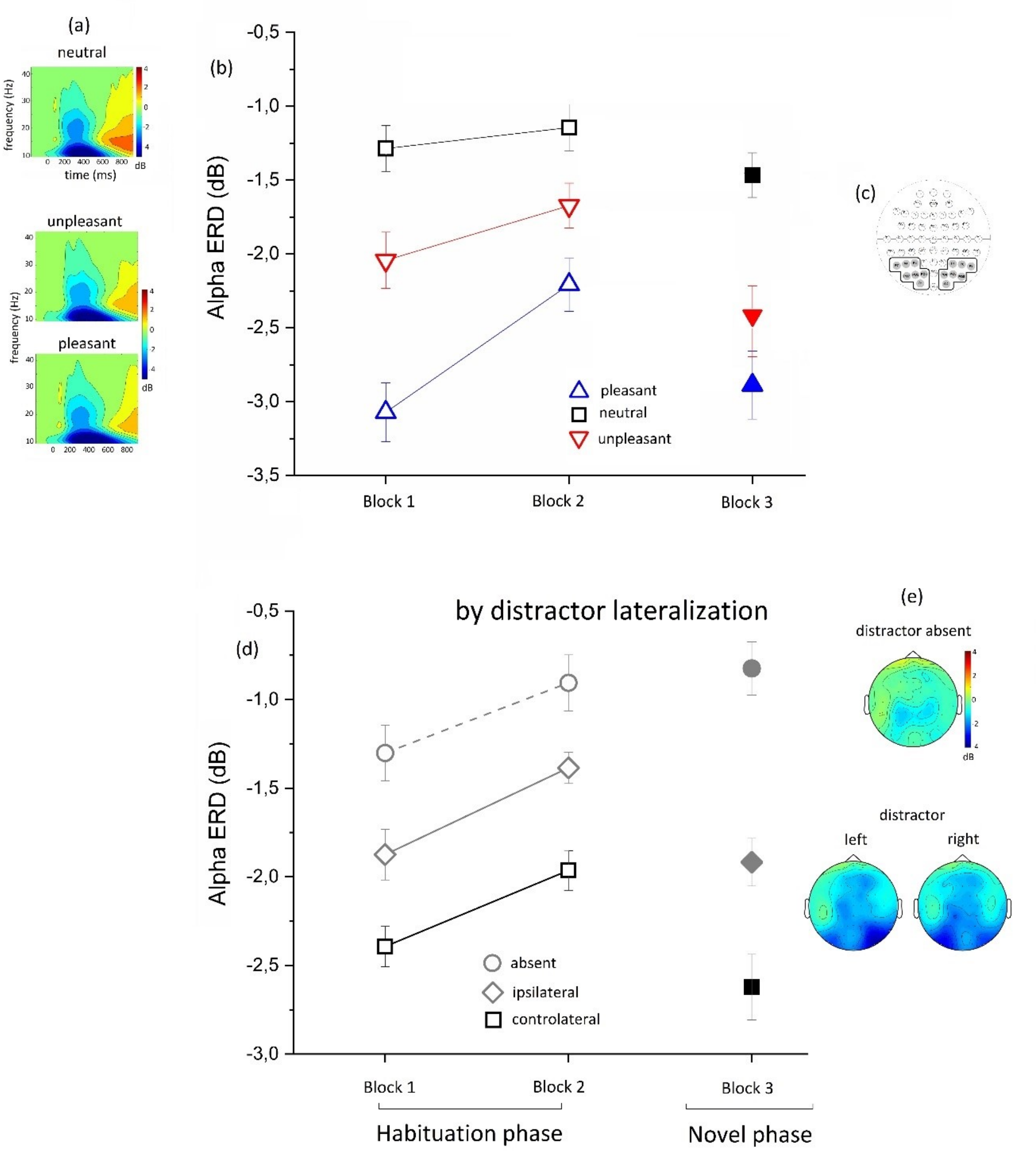

Figure 2.4 The effects of distractor repetition on the alpha-ERD. (a) Time-frequency plot for neutral, unpleasant, and pleasant distractors (average over blocks). (b) The line graph illustrates the mean of alpha-ERD (8–14 Hz) in the window 450–900 ms after stimulus onset for distractor-absent, pleasant, unpleasant, and neutral pictures as a function of block. The overall alpha-ERD was enhanced for emotional (both pleasant and unpleasant) compared to neutral distractors, and this affective modulation was preserved over blocks. (c) The sensor cluster used for statistical analyses is reported on the sensor map (gray dots). (d) The line graph illustrates the mean alpha-ERD for distractor-absent trials, and for contralateral and ipsilateral distractors (averaged across picture content) as a function

of block. (e) Scalp topography of alpha-ERD for distractor-absent trials, and for trials with distractors (averaged across picture contents) as a function of distractor lateralization (to the left or right of the central gabor). Alpha-ERD was clearly lateralized as a function of distractor position, with a more evident desynchronization in the contralateral, compared to the ipsilateral, hemisphere. Enhanced alpha-ERD was shown in both the contralateral and the ipsilateral hemisphere to distractor occurrence compared to in distractor-absent trials, and this desynchronization decreased across repetitions to then recover with novel distractors.

Distractor position (3) × block (3)

The scalp topography and modulation of alpha desynchronization was clearly affected by the occurrence of a peripheral distractor (distractor Position, $F_{2,48} = 32.142$, $p < .001$, $\eta^2p = .573$), prompting a larger occipital alpha decrease in both the contralateral and ipsilateral hemispheres ($Fs_{1,24} > 18.154$, $ps < 0.001$, $\eta^2p > 0.431$), compared to distractor-absent trials where Alpha-ERD was elicited by the mere presence of the central gabor, showing a bilateral desynchronization.

Alpha-ERD to distractors was even more pronounced in the contralateral, compared with the ipsilateral, hemisphere to the distractor visual hemifield ($F_{1,24} = 47.5$, $p < .001$, $\eta^2p = .664$). Alpha oscillations changed across blocks ($F_{2,48} = 6.18$, $p = .005$, $\eta^2p = .202$) and the distractor Position × Block interaction ($F_{4,96} = 8.657$, $p < .001$, $\eta^2p = .265$) revealed that for distractor-absent trials alpha-ERD decreased linearly over the three blocks ($F_{1,24} = 8.261$, $p = .008$, $\eta^2p = .256$) whereas for distractor-present trials alpha-ERD decreased across repetitions (block 1 vs. block 2, $F_{1,24} = 9.822$, $p = .005$, $\eta^2p = .290$), and then strongly recovered in the novel phase, with a similar pattern in both the contralateral and ipsilateral hemispheres ($Fs1,24 > 9.2$, $ps < 0.001$ $\eta^2p > 0.277$).

Discussion

The present study investigated whether attentional capture by high-arousing emotional distractors can be attenuated through a nonstrategic learning mechanism induced by mere stimulus repetition. The results revealed that behavioral interference of emotional distractors strongly decreased across repetitions, showing a complete habituation by the end of the repetition phase. When repeated distractors were replaced with novel exemplars, the emotional interference fully recovered, with slower reaction times for both pleasant and unpleasant pictures compared to neutral distractors. This indicates that the filtering mechanism was finely tuned regarding the specific stimulus used throughout the habituation phase and did not apply to similar emotional exemplars, like those presented in the novel phase. However, unlike emotional stimuli, novel neutral distractors were not effective at prompting attentional capture.

In terms of cortical reactivity, the enhancement of the LPP for unpleasant distractors was strongly attenuated by repetition, and the introduction of novel pictures prompted a clear and consistent response recovery of the LPP affective modulation. Again, stimulus novelty was effective at prompting a response recovery only for emotional distractors.

Thus, neither at the behavioral nor at the neural level, do we observe an impact of stimulus change for neutral distractors, suggesting that the inner model leading the predictive coding was tuned to detect a change to emotional cues specifically, whereas neutral scenes were all treated as irrelevant distractors, regardless of stimulus novelty.

We would further highlight three main results of Experiment 1.

First, an unexpected finding concerns the clear habituation of the LPP for unpleasant distractors, which prompted an LPP similar to that of neutral distractors by the end of the habituation phase. Compared to other measures of affective processing, the LPP has always proved to be the most resistant to habituation, even in the face of a high number of repetitions (e.g., Codispoti et al., 2006, 2007; Ferrari et al., 2011). However, whereas in previous repetition studies the impact of picture repetition was investigated in a free-viewing context (no task), and with emotional pictures always presented in central vision, here emotional pictures were distractor stimuli presented in the periphery during a concurrent perceptual task in the center (i.e., gabor discrimination). A competing task was introduced only in one previous study on habituation (Codispoti et al., 2016), but, again, pictures were presented in the center, and the LPP enhancement for both pleasant and unpleasant pictures was fully preserved despite repetitions. The present findings help us to understand the obligatory nature of the affective modulation of the LPP, suggesting that in particular circumstances, such as when emotional pictures are task-irrelevant stimuli and are processed in peripheral vision, the habituation process also occurs for the LPP affective modulation and is even stronger for unpleasant compared to pleasant distractors. Although it is well established that complex natural scenes depicting a variety of semantic categories (e.g., faces, means of transportation, animals) can also be highly processed in peripheral vision when they are task-relevant (Rousselet, Thorpe, & Fabre-Thorpe, 2004; VanRullen & Thorpe, 2001) as well as when they are distractors (Micucci et al., 2020) as in the case of the present study, we may hypothesize that the affective habituation could be facilitated for peripheral stimuli, compared to stimuli processed in foveal vision which may prompt a mandatory emotional categorization. Future repetition studies may address this hypothesis with a direct comparison of repetition effects for task-irrelevant pictures presented centrally (foveal or parafoveal vision) or displaced in space compared to the target. One hypothesis explaining why the LPP for pleasant pictures (i.e., erotic couples) resists habituation may have to do with the fact that in many studies erotic scenes prompted a stronger physiological reactivity compared to other emotional contents (e.g., threat and mutilations). Evidence comes from pupil dilation data (e.g., Bradley & Lang, 2015; Bradley, Sapigao, & Lang, 2017) and several brain responses, such as the early posterior negativity (EPN, e.g. De Cesarei & Codispoti, 2006; Farkas, Oliver, & Sabatinelli, 2020; Schupp & Kirmse, 2021), the Late Positive Potential (LPP, e.g., Ferrari, Codispoti, Cardinale, & Bradley, 2008; Ferrari et al., 2020; Mastria et al., 2017; Schupp et al., 2004), and the Alpha desynchronization (Ferrari et al., 2020; Schubring & Schupp, 2019). However, it is worth noting that pleasant and unpleasant distractors did not differ in the first block, suggesting that the difference in valence between blocks has to do with a different impact of picture repetition, which could be attenuated for salient stimuli that are easier to process, as in the case of erotic cues.

Second, the results of Experiment 1 suggest that the detection of a stimulus change goes through a further evaluation in terms of motivational relevance, and only when novel stimuli belong to high arousing categories is a novelty response triggered. The disappearance of distractor interference across trials could also reflect a spatial filtering that selectively cuts out everything that appears outside the attentional focus of the target. The current experimental context, with central targets (i.e., gabor stimulus) and peripheral distractors (pictures) presented simultaneously, may encourage the observer to adopt a top-down attentional set that is accurately tuned to the specific target-defining features or position (Leber and Egeth, 2006a). Hence, in this scenario, distractor filtering could be the consequence of the adoption of a well-specified target template (Leber & Egeth, 2006b), instead of a well-defined memory trace of the distractor. If this were the case, we would have no response recovery for novel emotional distractors presented after the habituation phase. However, we observed a prompt recovery of orienting in both RT and LPP responses as soon as repeated pictures were replaced with novel exemplars. Moreover, the LPP to pleasant pictures, although attenuated across repetitions, continued to be enhanced compared to neutral distractors until the end of the habituation phase, indicating that peripheral distractors were still partially processed, and excluding the hypothesis that the reduction of interference was due to a narrowing of attention around the central target.

Third, Alpha oscillations were highly sensitive to distractor occurrence, showing an enhanced posterior desynchronization at sensors that were contralateral to the distractor position, which was highly modulated by distractor emotionality. Previous studies have shown Alpha-ERD for emotional pictures, both pleasant and unpleasant, compared to neutral pictures during a passive viewing condition (Ferrari, Bradley, Codispoti, & Lang, 2015; Ferrari et al., 2020; Schubring & Schupp, 2019), as well as while carrying out an explicit task on the pictures (De Cesarei & Codispoti, 2011; Schubring & Schupp, 2019). The present study showed Alpha desynchronization for task-irrelevant emotional pictures that were briefly presented in the peripheral visual field. Moreover, although the overall Alpha-ERD decreased with stimulus repetition and increased with novelty, the emotional modulation remained unaffected across blocks, consistent with previous studies (Ferrari et al., 2020; Schubring & Schupp, 2021) with central pictures in a passive viewing condition. Unlike the LPP, that is highly sensitive to the specific novelty of emotional stimuli, Alpha-ERD is characterized by a similar habituation pattern for emotional and neutral distractors, which may reflect a sensitivity to the detection of novelty at a perceptual level (i.e., low-level properties of the visual scene), in the service of an increase in visual processing for any kind of distractor change, regardless of its motivational significance. Furthermore, the hypothesis that an ipsilateral increase in Alpha power may reflect functional inhibition of distractors is not supported by the present findings, since the Alpha power was greater, overall, in distractor-absent compared to distractor-present trials, and this difference was maintained over repetitions, while distractor interference (i.e., RTs) habituated. The filtering mechanism based on ipsilateral increase in alpha power may be more easily engaged in a proactive control context, where the occurrence of the distractor is somehow anticipated, and not in an unpredictable context such as the present one (Vissers, van Driel, & Slagter, 2016).

2.2 Experiment 2: The impact of the affective context on the habituation process

The behavioral interference of peripheral emotional distractors decreases with repetitions of the same exemplars and immediately recovers when repeated stimuli are replaced by new exemplars. Previous studies investigated the emotional habituation in a relatively predictable context (Codispoti et al., 2016; Ferrari et al., 2022), where only the same set of repeated distractors is continuously presented across the habituation phase, demonstrating a complete habituation after few repetitions. However, when familiar distractors are substituted with new examples, emotional interference rebounds entirely, resulting in slower reaction times for both pleasant and unpleasant images compared to neutral distractors. This indicates that the filtering mechanism is specific for the stimuli repeated during the habituation phase and does not concern similar emotional examples introduced in the novel phase.

Experiment 2 addresses the following three issues.

First, Experiment 2 investigates whether a variable context (i.e., novel pictures among repeated ones) can prompt a recovery of the habituated response, that is, a dishabituation process for the repeated stimuli. On one hand, we know that the filter mechanism is based on the features of the specific repeated stimulus with which the experience is made (Ferrari et al., 2022), but we also know that frequent distractors can reduce the interference of emotional stimuli (Micucci et al, 2019). This suggests that the habituation of emotional interference not only relies on the experience with the specific stimulus, but also integrates top-down contextual factors like the amount of certainty in which the brain needs to compute the relative saliency of the stimulus and tune the filter mechanism. In this scenario, the repeated and therefore no longer prioritized images could regain salience and induce a renewed response.

Second, for neutral distractors, Experiment 1 revealed no visible impact of stimulus changes, neither in behavior nor at the cortical level. This suggests that the filter is specifically attuned to detect changes in emotional contents, while neutral scenes are consistently treated as irrelevant distractors, irrespective of stimulus novelty. We can consider this result as an effect of the emotional context experienced, and we expect that the introduction of novelty is effective in prompting a recovery of the response for repeated stimuli as a function of the valence of novel stimuli. In this case, we will observe a dishabituation only in the emotional context, not in the neutral one.

Third, the effect of stimulus repetition is more evident on the behavioral interference than on the cortical response (Codispoti, et al. 2006, 2007, 2016; Ferrari et al., 2008; 2011; 2020; Mastria et al., 2017), and it is therefore not obvious to replicate the modulation of the LPP for repeated stimuli that we observed in the Experiment 2. Furthermore, in a more unpredictable context with novel and repeated stimuli, one can expect that the cortical response does not detect a modulation due to the repetition of the stimuli but reflects a sustained processing also of the emotional stimuli repeated in emotional contexts.

Method

Participants

The participants were 45 university students (24 females; mean age = 24.15 years, SD = 3.11). All participants had normal or corrected-to-normal visual acuity. They had no previous experience with the materials used in this experiment. The experimental protocol conformed to the Declaration of Helsinki.

Material

The visual stimuli were 57 natural scenes selected from various sources, including the International Affective Picture System (IAPS; Lang et al. 2008), and public domain pictures available on the Internet. Of these pictures, 18 depicted pleasant contents (heterosexual erotic couples), 18 showed unpleasant contents (mutilated bodies), and the remaining 21 were neutral pictures depicting people in daily outside and inside contexts. All images (14.3° h x 10.8°) were equated in brightness and contrast, using a MATLAB-based toolbox (SHINE; Willenbockel et al., 2010). Pictures of natural scenes served as distractor stimuli and were positioned either to the left or the right of a central Gabor patch (sinusoidal gratings with a Gaussian envelope). The distance between the inner edge of the distractor image and the centre of the Gabor patch was 4°. The Gabor patch subtended a 5.3° x 5.3° visual angle, and it could be horizontally or vertically oriented. Gabor patches were generated using custom MATLAB software by overlapping two distinct Gabor patches with the same frequencies but a different orientation (0.94 and 9.4 cycles per degree of visual angle, respectively). Stimuli were displayed on a grey background and presented on a 22-inch monitor at 1024 x 768 resolution and at a refresh rate of 120 Hz. Stimulus presentation and data collection were performed using E-Prime software (Schneider et al., 2002).

Procedure

The experiment was composed of two different phases (Figure 2.5): the habituation phase with only repeated stimuli and a novel phase in which a minor number of novel stimuli were presented mixed within the repeated ones. Moreover, each novel block contains only one valence of novel stimuli (i.e., pleasant, neutral, or unpleasant) and the order of the novel phases was counterbalanced by valence between subjects. In the experimental session, after the informed consent form signature, participants were seated in a sound-attenuated, dimly lit room. The task instructions were to look at the centre of the screen, and to press the key correspondent with the vertical or horizontal orientation of the gabor, while ignoring the pictures in the peripheral fields.

The experimental session began with two blocks of 100 trials each (habituation phase), in which the same set of 12 pictures (3 pleasant, 6 neutral, 3 unpleasant) were repeated 5 times in each block, for a total of 10 repetitions of the same picture exemplar by the end of the habituation phase. After the habituation phase, three novel blocks were presented alternating with three habituation blocks (Figure 2.5). The novel blocks were composed of a minor number of novel stimuli (15) intermixed with the repeated pictures (3 out of 6 neutral pictures of the habituation blocks were replaced by the novel pictures). The novel blocks were characterized by the valence of novel stimuli, with one valence per block: 15 pleasant or 15 neutral or 15 unpleasant. The order of blocks was counterbalanced between subjects. Between the blocks, a brief break was introduced. The order of picture presentation was pseudo-randomized with the restriction that a picture of the same content occurred no more than two times consecutively. The specific set of 57 pictures serving as novel or repeated varied across participants, such that the specific pictures were presented in both the repeated and novel condition.

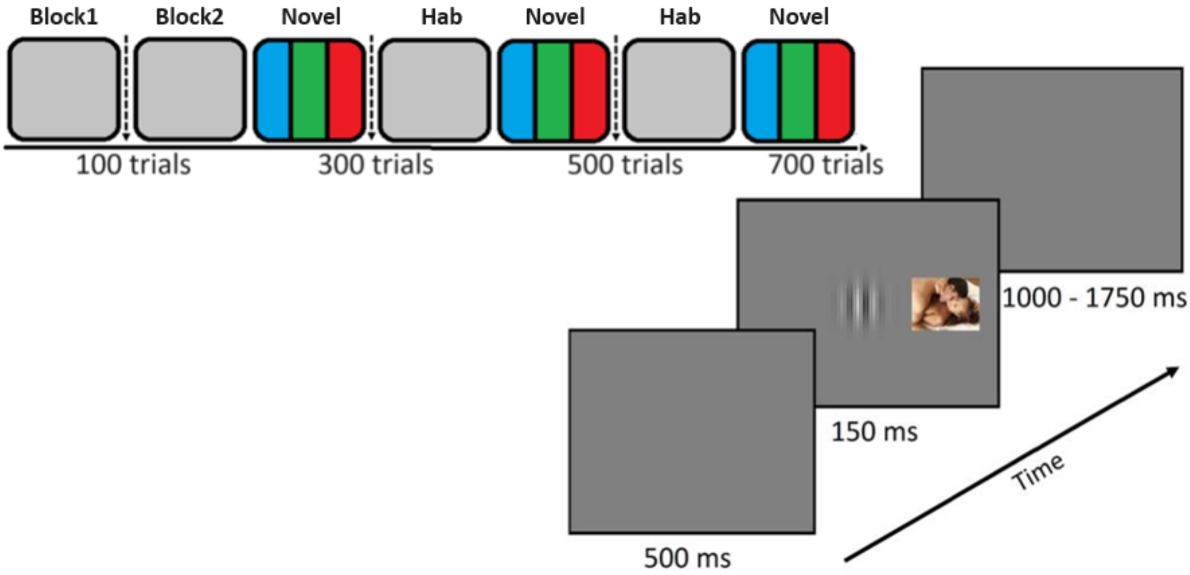

Fig. 2.5 shows the sequence of events of the experimental paradigm. In each trial, a Gabor patch appeared in the center of the screen for 150 ms. The participant's task was to determine, as quickly and accurately as possible, whether the Gabor patch was vertical or horizontal, and respond accordingly by pressing the corresponding key with the index finger of the dominant hand. The intertrial interval was variable (1000, 1550, or 1750 ms) and consisted of a gray screen. During this period, behavioral responses to the orientation task were collected. In distractor-present trials, a distractor picture (either pleasant, unpleasant, or neutral) was presented simultaneously with the Gabor patch, appearing equally often in the left or right visual field. Participants were explicitly informed that there would be a distractor in some trials and that it should be ignored. The gabor patch was always present, whereas distractors appeared in 60% of the trials (40% of trials were without distractors).

Before the beginning of the experiment, each participant performed a practice block of 30 trials in which a neutral distractor appeared in 40% of the trials. This picture exemplars were exclusively presented in the practice trials.

EEG recording and processing

Electroencephalogram (EEG) was recorded at a sampling rate of 1000 Hz using a 59 channel Electro-Cap connected to a SA Instrument CO (San Diego, CA) UF-64/72BA amplifier and in-house developed software. Impedance of each sensor was kept below 10 kΩ. Eye movements were recorded at a sampling rate of 1000 Hz from two bipolar couples of electrodes, placed respectively 1 cm above and below the right eye and 1 cm left and right to the side of the eyes. Both EEG and ocular signal were on-line filtered from 0.01 to 100 Hz. Off-line analysis was performed using Emegs (Peyk, De Cesarei, & Junghöfer, 2011). First, eye movements were subtracted from the EEG on a trial-by-trial basis, based on the data from the monopolar horizontal and vertical EOG, and using a regressive procedure (Gratton, Coles, & Donchin, 1983). Then, raw data were low-pass filtered at 30 Hz. ERP averages were computed with a 200-ms baseline and a 1000-ms time window. Trials and sensors containing artifacts were detected through a statistical procedure (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). In each trial, if a high number of neighbouring bad sensors was present, then the whole trial was discarded; for the remaining trials, sensors containing artifacts were replaced by interpolating the nearest good sensors. The percentage of good trials was 85%, and this percentage did not significantly change across blocks or conditions. Finally, data were re-referenced to the average of all channels. The average of the 200 ms pre-stimulus baseline was subtracted from the waveform obtained. Processed data were averaged for each Block of 100 trials (Block 1 to 5) and Trial type (distractor absent; pleasant, neutral, unpleasant, filler in habituation/new in novel blocks distractors). ROI and time interval of interest were identified by both visual inspection and previous studies (Ferrari et al., 2022). The LPP was scored as the average of the ERP waveform in the time window between 450 and 900 msec after stimulus onset at the centro-parietal sensor group (CPZ, CP1, CP2, CP3, CP4, PZ, P1, P2, P3, P4, P5, P6,

POZ, PO3, PO4, PO5, PO6, PO7, PO8, OZ, O1, O2, see inset in Fig. 2.7). For time-frequency analysis, no low-pass filtering was applied on the row EEG signal, but the correction of eye movements, as well as the artifact detection and sensor interpolation, was similar to the ERP analysis. Data were convolved using complex Morlet's wavelet varying in time and frequency with a Gaussian shape. The time frequency analysis was performed on single trial data using FieldTrip software through EMEGS (Peyk et al., 2011). The Morlet wavelet has a Gaussian shape, where the f/SD(f) ratio was set to 7, and the number of wavelet cycles was set to 5 (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997). The range of analysis was from 4 to 80 Hz and analysis was performed in time windows from 1000-ms before picture onset to 1500 ms after picture onset in steps of 10 ms. As frequency resolution is maximal for low frequencies and minimal for high frequencies (Roach & Mathalon, 2008), the step between successive frequencies varied linearly from 0.5 Hz for the lowest frequencies to 5 Hz for the highest frequencies. All data were baseline corrected, by subtracting the average Alpha power of the prestimulus baseline (- 300 to - 100 ms) from each data point. The baseline was calculated slightly earlier than stimulus onset to avoid the burst of oscillatory activity that starts before the onset of the stimulation, due to the artifact of the filter algorithm (Herrmann, Grigutsch, & Busch, 2005). The resulting event-related change in total power values (relative to baseline) are in decibels (dB) (Delorme & Makeig, 2004). For alpha-ERD (8–14 Hz), statistical analyses were performed on the mean value of bilateral occipito-temporal sensor groups (P3, P4, P5, P6, P7, P8, PO3, PO4, PO5, PO6, PO7, PO8, O1, O2, see inset in Fig. 2.8) over the same temporal window of the LPP (450–900 ms).

Data Analysis

Since every participant was exposed to the three new contexts, we analyzed the data collapsing together the novel blocks by the valence of novel stimuli (context), independently from the order of presentation during the experiment. This configuration allows us to observe, after the habituation process, the modulation of the response to novel distractors by their valence, and eventually the rebound effect on the habituation of repeated distractors.

RT and EEG analyses were performed only on accurate trials, that is, when the orientation of the central gabor was correctly detected. For each participant, block, and trial type, RTs above or below 3 SDs from the mean were discarded as outliers. These criteria removed 3.81 % of the data.

For all the measures (RT, LPP, alpha-ERD), a repeated-measures ANOVA was performed with the two within-participant factors of Block (5) and Trial type (3: pleasant, neutral, unpleasant). Greenhouse-Geisser corrections were applied where relevant. For each ANOVA test, we reported the partial *η2* squared statistic (*η2p*), indicating the proportion of variance that is explained by experimental conditions over the total variance.

Results

Behavioral data

Statistical analysis of RTs revealed a main effect of Valence ($F_{2,88} = 18.54$, $p < .001$, $\eta^2 p = .29$; quadratic, $F_{1,44} = 32.08$, $p < .001$, $\eta^2 p = .42$), with slower responses during the occurrence of pleasant ($Fs_{1,44} = 39.66$, $ps < .001$, $\eta^2 p = .47$) and unpleasant distractors ($Fs_{1,44} = 11.37$, $ps = .002$, $\eta^2 p = .20$), compared to neutral pictures. RTs for pleasant were also slower compared to unpleasant distractors ($Fs_{1,44} = 6.86$, $ps = .012$, $\eta^2 p = .13$).

The significant Block (5) x Valence (3) interaction ($F_{8,37}$ = 2.8, *p* = .015, η^2p = .37) indicated that the emotional interference changed over blocks of repeated pictures, with a decrease from Block1 to Block2 (2 x 3, $F_{2,88}$ = 3.75 , p = .030, η^2p = .07; quadratic, $F_{1,44}$ = 9.712, p = .003, η2p = .18), such that the affective modulation found in Block1 ($F_{2,43}$ = 10.78 p < .001, η^2p = .33; quadratic, $F_{1,44}$ = 21.175, p < .001, η^2p = .325) was attenuated at the end of the habituation phase (Block2, $F_{2,43}$ = 2.574 p = .088, η^2p = .107; quadratic, $F_{1,44}$ = 4.143, p = .048, η2p = .08).

The introduction of novel distractors among repeated pictures prompted a dishabituation of the emotional modulation for repeated stimuli in the unpleasant context (2 Block2vsBl$_{unpl}$ x 3, Valence, $F_{2,43}$ = 4.24, p =.021, η^2p = .16); in fact, the interference of repeated emotional distractors returned to be highly significant (quadratic of Valence, $F_{1,44}$ = 21.06, p < .001, η^2p = .32). In the neutral context, the dishabituation was weaker (2 Block Block2vsBl$_{neu}$ x 3 Valence, $F_{2,43}$ = 1.98, p = .16, η^2p = .08), but the valence effect reached the significant threshold (quadratic of Valence, $F_{1,44}$ = 13.95, p < .001, η^2p = .24). Novel pleasant pictures clearly did not prompt a significant recovery of emotional interference for repeated pictures (2 Block2vsBl$_{pleasant}$ x 3, Valence, $F_{2,43}$ < 1, quadratic of Valence, $F_{1,44}$ = 1.24, p =.271, η^2p = .02).

New pictures prompted a reliable emotional interference (Valence 3, $F_{2,43}$ = 4.01, p = .025, η2p = .157 quadratic, $F_{1,44}$ = 8.12, p =.007, η^2p = .15), but only the response to novel pleasant pictures differed from repeated pleasant ($F_{1,44}$ = 4.858 p = .033, η^2p = .09).

Overall accuracy was high (M = 96%) and remained stable over trials, indicating that the discrimination task was perceptually easy (low-load perceptual task). The ANOVA did not reveal any significant effect involving trial type, block or their interaction.

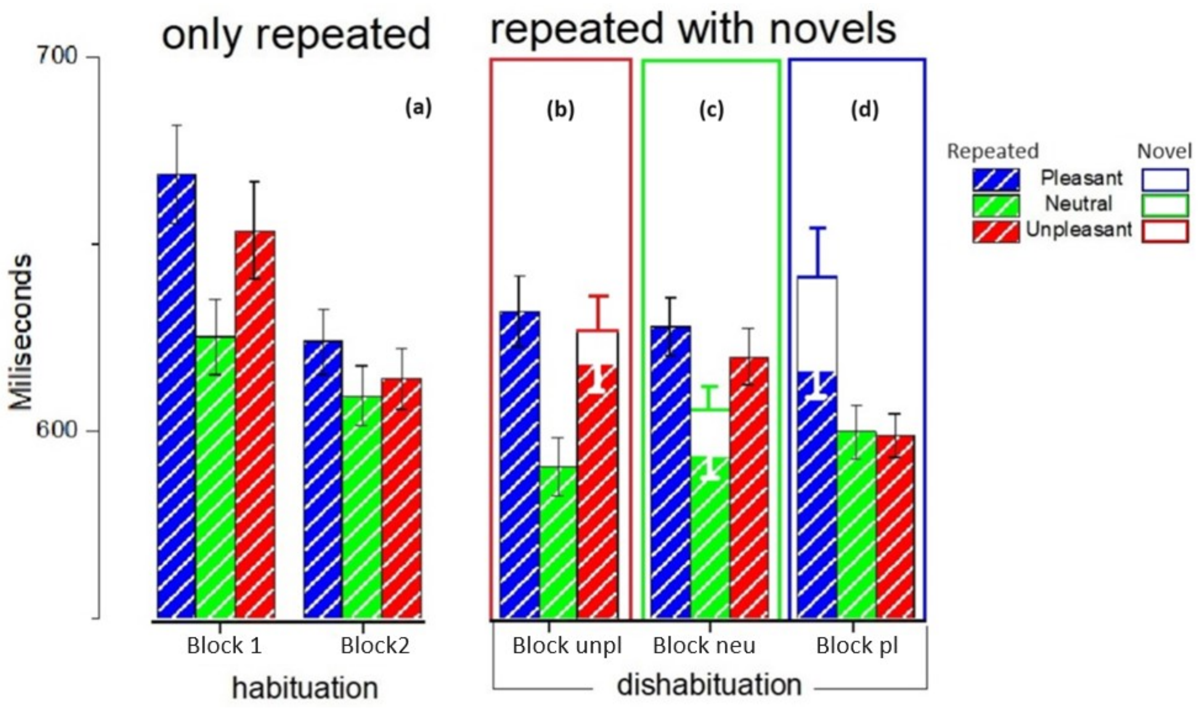

Figure 2.6 shows the interference effects of distractors on the response times (RTs) to the gabor discrimination task. (a) Behavioral interference is plotted as a function of block, showing that emotional pictures prompted an evident RT slowdown in the first block, compared to neutral. The emotional content of distractors, either pleasant or unpleasant, was more effective in capturing attention and interfering with the task, but this affective interference was very sensitive to picture repetition, showing an evident decrease throughout the habituation phase. (b) in the unpleasant and neutral context (c) the introduction of new pictures prompted a recovery of the emotional interference (difference between emotional and neutral), while in the pleasant context there is a stronger inhibition for unpleasant repeated stimuli (d). Error bars show ± 1 SEM calculated within participants using the method of O'Brien and Cousineau (2014).

Late Positive Potential (LPP)

Statistical analysis 5 x 3 of the LPP revealed a main effect of Valence was present ($F_{2,88}$= 27,61 p<.001, η^2p =.386; quadratic, $F_{1,44}$ = 50.84, p < .001, η^2p = .53), and it was enhanced for pleasant ($F_{s1,44}$ = 40.64, ps < .001, η^2p = .48) and unpleasant ($F_{s1,44}$ = 37.25 , ps < .001, η^2p = .45) compared to neutral, but not for pleasant compared to unpleasant ($F_{s1,44}$ = 3.23 , ps = .075, η^2p = .06). The emotional modulation did not decrease during the habituation phase (2 Block x 3 Valence, $F_{2, 88}$= 1.14, p =.322, η^2p = .02) and the interaction 5 x 3 ($F_{8,37}$ = .590, p = .780, η^2p = .11) was not significant.

The introduction of novel distractors among repeated pictures does not affect the modulation for the repeated pictures in any context (p > .05) compared to the habituation phase. However, the LPP modulation for new pictures was enhanced compared to the repeated stimuli of the same valence in pleasant condition ($F_{1,44}$ = 12.254, p = .001, η^2p = .22), unpleasant ($F_{1,44}$ = 5.096, p =.029, η^2p = .10) and neutral ($F_{1,44}$ = 8.611, p =.005, η^2p =.16).

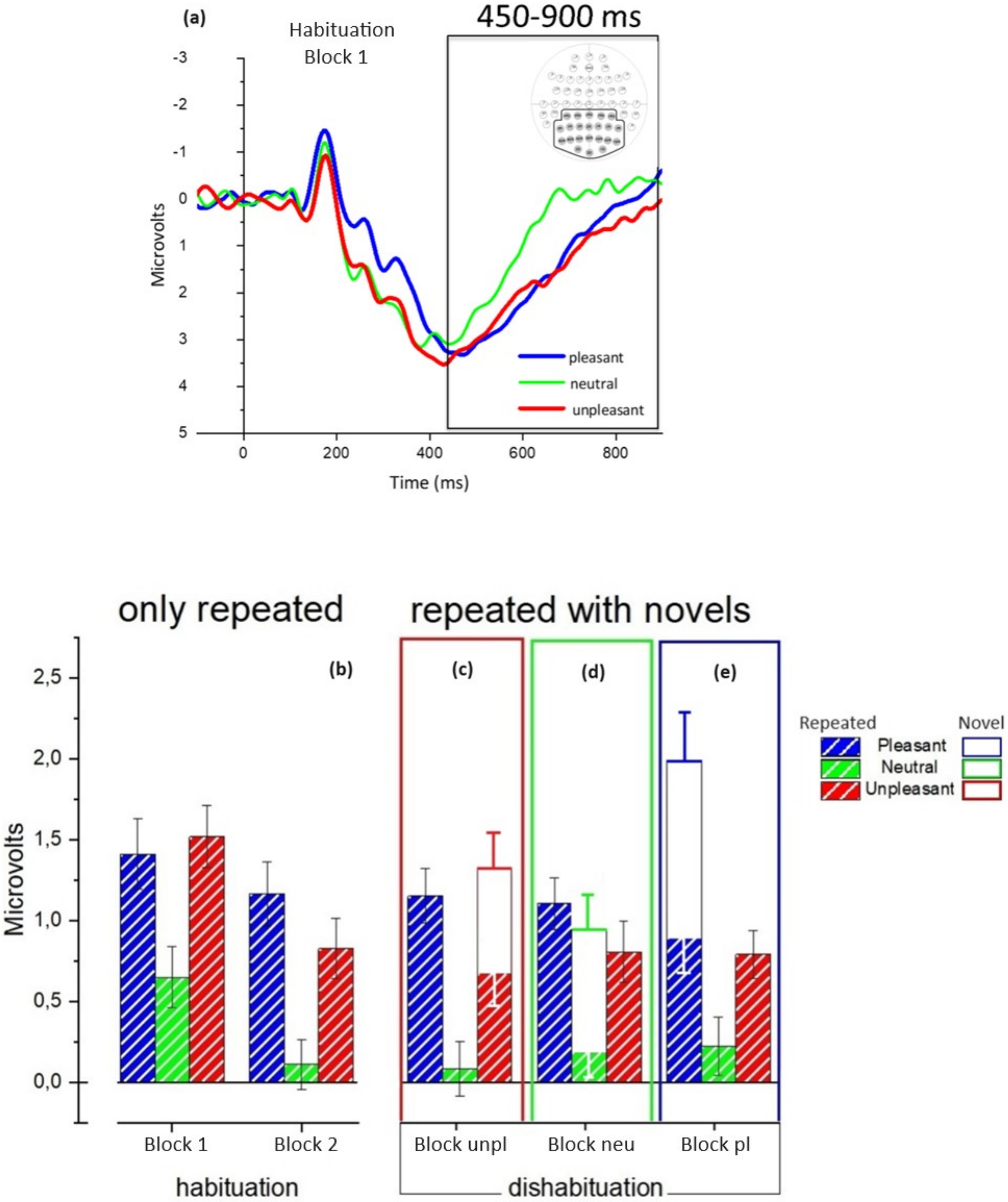

Fig. 2.7 illustrates the effects of distractor repetition on the LPP amplitude. (a) Grand-averaged ERP waveforms (average across the sensor cluster, for pleasant, neutral, and unpleasant distractors) across the two blocks of the habituation phase and the final novel block. The line graph shows the mean of the LPP amplitude (window 450–900 ms) for pleasant, neutral and unpleasant distractors as a function of block, showing an emotional modulation in the habituation phase (b) as well as in the unpleasant (c), neutral (d) and pleasant (e) contexts.

Alpha- desynchronization (Alpha-ERD)

Alpha-ERD was significantly modulated by distractor valence ($F_{2,88}$= 21.798, p<.001, η^2p =.34; quadratic, $F_{1,44}$ = 32.48, p < .001, η^2p = .43). It was enhanced for emotional distractors (pleasant, $F_{s1,44}$ = 38.18, ps < .001, η^2p = .47; unpleasant, $F_{s1,44}$ = 14.62, ps < .001, η^2p = .24) compared to neutral, and also for pleasant compared to unpleasant ($F_{s1,44}$ = 10.54, ps = .002, η^2p = .20). It did not show a repetition effect (2 Block x 3 Valence, $F_{2,\ 88}$= .611, p =.545, η^2p = .01).

The interaction 5 x 3 was not significant ($F_{8,35}$ = .234, p=.982, η^2p =.05) showing a stable Alpha desynchronization across repetition, regardless of the presence of novel pictures.

Interestingly, Alpha-ERD affective modulation was strongly enhanced in response to novel emotional pictures presented among repeated stimuli (novel vs repeated: pleasant, $F_{1,44}$ = 14.974 p < .001, η^2p = .254; unpleasant, $F_{1,44}$ = 8.459 p = .006, η^2p = .161), but did not change in the neutral context (neutral, $F_{1,44}$=.094, p=.760, η^2p = .002).

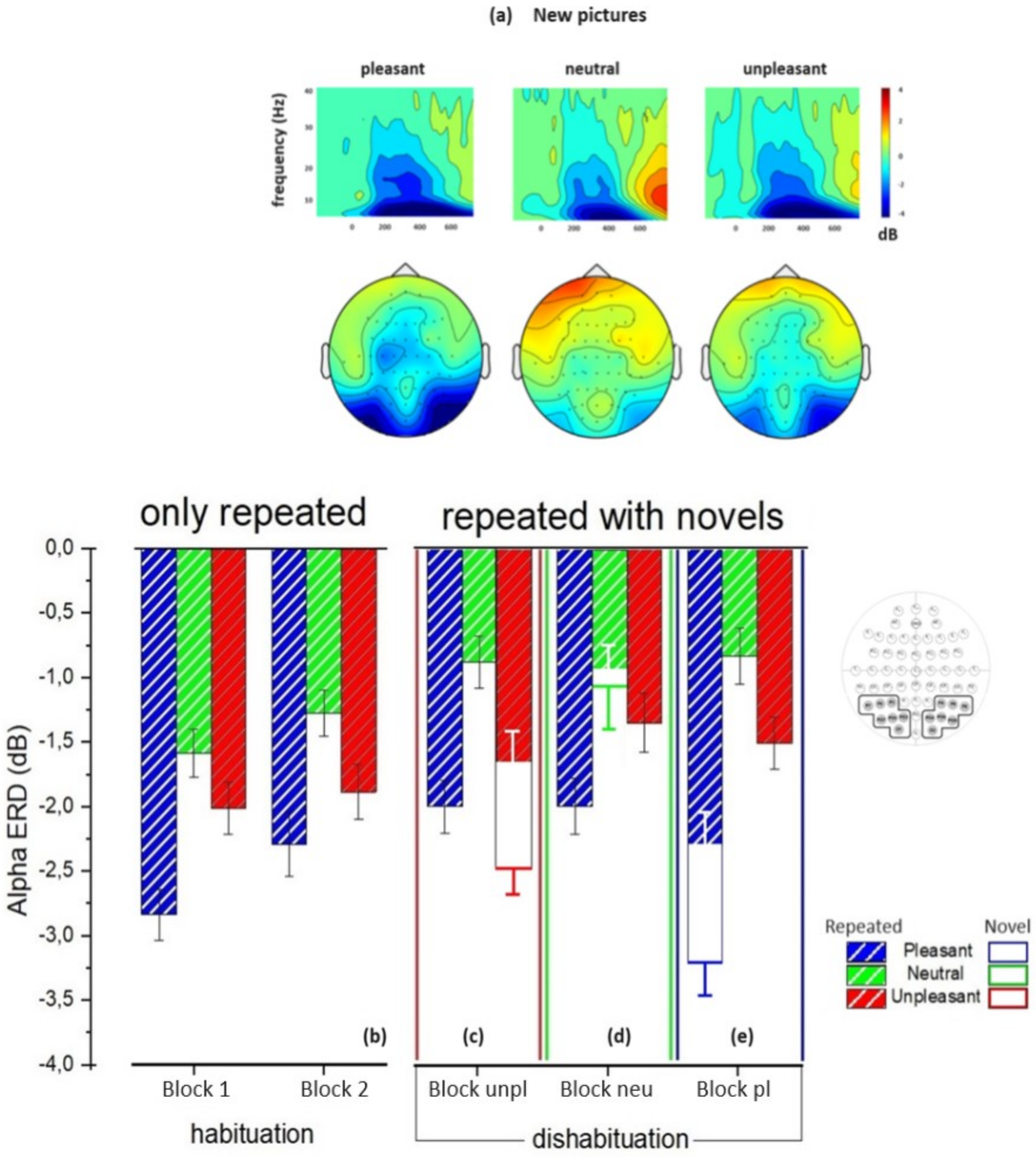

Fig. 2.8 The effects of distractor repetition on the Alpha-ERD. (a) Time-frequency plot and scalp topography for novel neutral, unpleasant, and pleasant distractors (average over blocks). The line graph illustrates the mean of alpha-ERD (8–14 Hz) in the window 450–900 ms after stimulus onset for pleasant, neutral and unpleasant pictures as a function of block. (b)The overall alpha-ERD was strongly enhanced for emotional (both pleasant and unpleasant) compared to neutral distractors, and this affective modulation was preserved over blocks. Alpha-ERD showed a more evident desynchronization for the new distractor in the unpleasant (c) and pleasant (e) contexts but not in the neutral one (d).

Discussion

Consistent with previous studies (Codispoti et al., 2016; Ferrari et al., 2022) the response slowdown for pleasant and unpleasant distractors was strongly attenuated by the repetition of the same stimulus exemplar.

We would further highlight three main results of Experiment 2.

First, the introduction of novel pictures among the repeated ones causes a disruption of the context, thereby reducing its predictability and affecting the habituation process of the behavioral interference. In fact, we can observe a recovery of emotional habituated response at the behavioral level (dishabituation), which was more evident in the unpleasant context, suggesting that a more variable context with novel unpleasant cues increases the alert system, making the filtering of distractors less effective.

Second, this recovery of the emotional response with the introduction of novel stimuli shows a different pattern depending on the valence of the new stimuli. We observe a clear recovery of the behavioral interference in the unpleasant context, with an emotional modulation of pleasant and unpleasant compared to neutral repeated, and a weaker effect in the neutral context. Interestingly, the emotional modulation for the repeated stimuli recovers despite neither the modulation for the unpleasant nor for the new neutrals being significantly different from the response for the same repeated category. This could indicate that the filter is more tolerant towards even repeated emotional images. Moreover, when novel pictures depicted pleasant contents, the dishabituation to unpleasant pictures was attenuated. This valence effect could reflect a more selective attentional mode prompted by pleasant novelty, which reduces the impact of negative stimuli.

Third, in all contexts, both cortical markers (LPP and Alpha-ERD) were mostly unaffected by stimulus repetition (habituation phase) and the response to repeated pictures was not affected by the presence of novel stimuli. Interestingly, despite the absence of habituation across repetitions, the presentation of novel stimuli among repeated ones prompted an evident novelty effect: for the Alpha-ERD this novelty effect was specific for emotional stimuli, both pleasant and unpleasant, whereas no cortical change was found for novel neutral pictures compared to the repeated ones. A similar result was obtained in a free viewing experiment (Ferrari et al., 2020); there, the substantial rebound observed for emotional images, particularly for erotica, in the novel block after the habituation phase implies that the memory trace proved effective for those specific instances and did not extend to dissimilar new examples introduced in the novel phase, which indicates a limited generalization of the memory trace, and an efficient detection of novel stimuli.

These findings suggest that the behavioral emotional interference relies on both the specific experience with stimulus repetition and on top-down contextual factors related to novelty expectation and its motivational relevance.

2.3 Experiment 3: Long-term effect of emotional distractor repetition on the behavioral interference

In the previous studies (Experiments 1 and 2) a complete habituation of emotional interference (i.e., RT) was observed due to the repetition of the stimuli in the periphery of the visual field. Habituation of the response to emotional stimuli has been confirmed to be reachable at the behavioral level, while at a cortical level the initial processing of stimuli seems to be preserved (Codispoti, et al. 2006, 2007, 2016; Ferrari et al., 2008, 2011, 2020; Mastria et al., 2017).

The attentional filter, visible on the behavioral level, is sensitive to the characteristics of specific repeated stimuli and therefore not generalizable to new stimuli (Experiment 1). At the same time, it also relies on top-down contextual factors, such as the predictability of the images, which decides the priority of the image relative to other stimuli (Experiment 2). These findings arise from investigations conducted within a single experimental session, which precludes the differentiation between short-term and long-term habituation effects. The current study aimed to discern whether affective habituation implies a transient learning process or a more enduring alteration involving long-term memory. Participants underwent an initial habituation phase involving 20 repetitions of the same set of emotional (pleasant and unpleasant) and neutral pictures, during which the reaction times to a gabor patch orientation discrimination task was measured (Session 1). Then, after a 1-day interval, the same participants were exposed to a second habituation phase using the same stimuli previously encountered. Results from a previous study (Ferrari et al., 2020), which recorded the cortical response in free-view, revealed that the attenuation of the Late Positive Potential (LPP) affective modulation observed during repetitions in Session 1 remained unaltered after the 1-day interval, suggesting that the decrease of the LPP affective modulation is not a transient learning process, but rather signifies a strengthened long-term memory representation of specific repeated stimuli. In the current study, we are interested in the long-term effect of repetition on the behavioral interference, since previous experiments suggest that we can clearly obtain the habituation of the behavioral interference after 20 repetitions, while the modulation of the LPP is still present. Once we reach the habituation in the first experimental session, we can measure the modulation of the response after a break where the subject does not have experience with the stimuli. If the habituation is a transitory effect, mainly linked to a recent stimulation of the memory trace with stimuli, then the detailed trace of the distracting stimulus can be kept active as long as the stimulus is present. In this scenario, the second session will show a spontaneous recovery of the emotional interference for the repeated stimuli (dishabituation) due to the absence of recent presentations. It is therefore possible that the habituation is determined by a learning mechanism with long-term effects, and we will observe an inhibition of emotional interference similar to the previous day. Some studies show a long-term effect of habituation to perceptually salient stimuli on automatic orienting of the attention and oculomotor capture (Chelazzi, Marini, Pascucci & Turatto, 2019; Turatto, Bonetti, Pascucci, 2018; Turatto & Pascucci, 2016). Furthermore, in the last draft of the characteristics of habituation, the long-term effects were taken into account (Rankin et al., 2009). However, emotional stimuli are a particular type of stimuli with an evolutionary significance that makes them more resistant to inhibition (Folk, 2015), supporting a less stable habituation.

Method

Participants

The participants were 48 university students (22 females; mean age = 23.45 years, SD = 2,74). All participants had normal or corrected-to-normal visual acuity. They had no previous experience with the materials used in this experiment. The experimental protocol conformed to the Declaration of Helsinki and was approved by the Ethical Committee of the Department of Psychology at the University of Bologna.

Material

The visual stimuli were 72 natural scenes selected from various sources, including the International Affective Picture System (IAPS; Lang et al. 2008), and public domain pictures available on the Internet. Of these pictures, 24 depicted pleasant contents (heterosexual erotic couples), 24 showed unpleasant contents (mutilated bodies), and the remaining 24 were neutral pictures depicting people in daily outside and inside contexts. All images (14.3° h x 10.8°) were equated in brightness and contrast, using a MATLAB-based toolbox (SHINE; Willenbockel et al., 2010). Pictures of natural scenes served as distractor stimuli and were positioned either to the left or the right of a central Gabor patch (sinusoidal gratings with a Gaussian envelope). The distance between the inner edge of the distractor image and the centre of the Gabor patch was 4°. The Gabor patch subtended a 5.3° x 5.3° visual angle, and it could be horizontally or vertically oriented. Gabor patches were generated using custom MATLAB software by overlapping two distinct Gabor patches with the same frequencies but a different orientation (0.94 and 9.4 cycles per degree of visual angle, respectively). Stimuli were displayed on a grey background and presented on a 34-in monitor at 1024 x 768 resolution and at a refresh rate of 60 Hz. Stimulus presentation and data collection were performed using E-Prime software (Schneider et al., 2002).

Procedure

The experiment was composed by two different sessions developed with a similar procedure (Fig. 2.9).

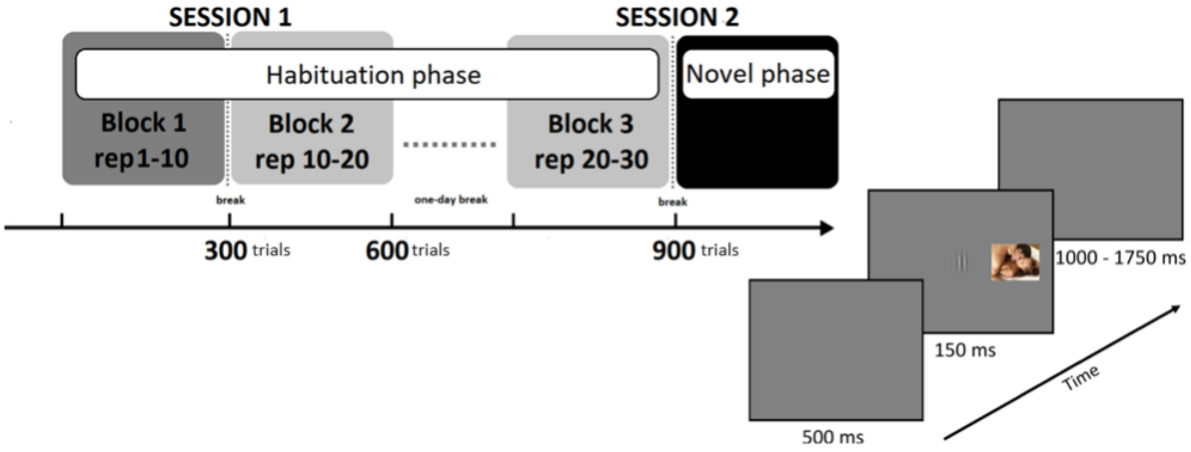

Figure 2.9 Schematic drawing explaining the experimental paradigm. Two blocks with the same set of repeated distractors (habituation phase) are presented in Session 1; after a one-day break, the same set of pictures were again repeated across an additional block, followed by one block of all novel distractors (novel phase). In each trial, a Gabor patch appeared in the centre of the screen for 150 msec. In distractor-present trials, a distractor picture (either pleasant, unpleasant, or neutral) was presented simultaneously with the Gabor patch in the left or right visual field. The participant's task was to determine, as quickly and accurately as possible, whether the Gabor patch was vertical or horizontal, and press the corresponding key while ignoring the distracting scenes. The intertrial interval was variable (1000, 1550, or 1750 msec) and consisted of a grey screen. During this period, behavioral responses to the orientation task were collected. The gabor patch was always present, whereas distractors appeared in 40% of the trials.

In Session 1, after the informed consent form signature, the participant was seated in a sound-attenuated, dimly lit room. The task instructions were to look at the centre of the screen, and to press the key corresponding to the vertical or horizontal orientation of the gabor, while ignoring the pictures in the peripheral fields. Session 1 began with two blocks of 300 trials each (habituation phase), in which the same set of 12 pictures (4 pleasant, 4 neutral, and 4 unpleasant) were repeated 10 times in each block, for a total of 20 repetitions of the same picture exemplar by the end of Session 1. Session 2, one day apart, started with the habituation phase, where the same set of pictures that had been repeatedly presented the day before were again repeated across an additional block (10 more repetitions). After the habituation phase, one block of all novel pictures was presented (10 pleasant, 10 neutral, 10 unpleasant) by the end of Session 2. Between the two blocks in both sessions, a brief break was introduced. The order of picture presentation was pseudo-randomized with the restriction that no more than two times consecutively a picture of the same content occurred. The specific set of 72 pictures serving as novel or repeated varied across participants, such that the specific pictures were presented in the habituation and novel phases.

Before the beginning of the experiment, each participant performed a practice block of 30 trials in which a neutral distractor appeared in 40% of the trials. This picture exemplar was exclusively presented in the practice trials.

Data Analysis

RT analyses were performed only on accurate trials, that is, when the orientation of the central gabor was correctly detected. For each participant, block, and trial type, RTs above or below 3 SDs from the mean were discarded as outliers. These criteria removed 3.16 % of the data. For RT, a repeated-measures ANOVA was performed with the two within-participant factors of Block (4: Block 1, Block 2, Block 3, Block 4) and Trial type (4: distractor absent, pleasant, neutral, unpleasant). Greenhouse-Geisser corrections were applied where relevant. For each ANOVA test, we reported the partial $\eta2$ squared statistic ($\eta2p$), indicating the proportion of variance that is explained by experimental conditions over the total variance.

Results

Behavioral results

Statistical analysis of RTs revealed a main effect of Trial type ($F_{3,141} = 71.66$, $p < .001$, $\eta^2p = .604$), with slower RTs for distractor-present trials, compared to distractor-absent trials (4 Blocks x 2 Trial Type, Trial Type: $Fs_{1,47} = 90.49, 42.68, 110.6$, $ps < .001$, $\eta^2p > .476$, respectively, for pleasant, neutral, and unpleasant distractor types). The emotional picture content prompted an additional modulatory effect on RTs, with slower responses during the occurrence of both pleasant and unpleasant distractors, compared to neutral pictures (4 Blocks x 2 Trial Type, Trial Type: $Fs_{1,47} > 63.49, 63.69$ $ps < .001$, $\eta^2p = .575$).

The Block (4) x trial Type (4) interaction ($F_{9,423} = 6.13$, $p < .001$, $\eta^2p = .115$) indicated that behavioral interference changed over trials as a function of distractor repetitions.

More specifically, compared to distractor-absent trials, both pleasant and unpleasant pictures decreased their interference from Block 1 to Block 2 in Session 1 (distractor-present vs. distractor-absent (2) x 2 Blocks for pleasant, $F_{1,47} = 18.88$, $p < .001$, $\eta^2p = .287$; unpleasant, $F_{1,47} = 6.45$, $p = .014$, $\eta^2p = .121$), such that the affective modulatory pattern found in Block 1 ($Fs_{1,47} = 43.49, 27.36$ $ps < .001$, $\eta^2p > .368$ for pleasant and unpleasant compared to neutral) was still evident at the end of the first Session (Block2: $Fs_{1,47} = 18.91, 8.28$ $ps > .006$, $\eta^2p >$

.150) but different from the beginning (Block$_{1,2}$ x Trial Type $_{pl,neu,unpl}$: F2,94= 9.31, p<.001, η^2p = .165).

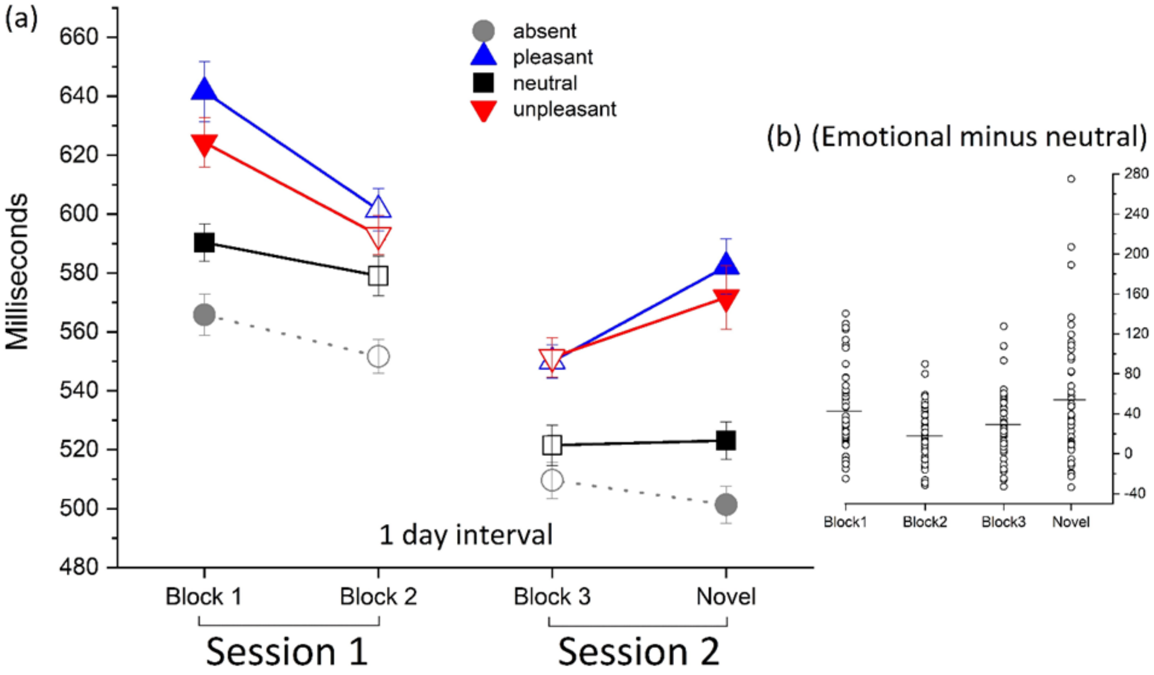

Figure 2.10 (a) Diagram showing the interference effects of distracting scenes on the response times (RTs) in the orientation discrimination task. All types of distractors (pleasant, neutral, unpleasant) initially prompted an evident RT slowdown, compared to distractor-absent trials. Emotional distractors (pleasant or unpleasant) resulted in a greater interference with the task, but this affective interference decreased throughout the habituation phase, weakly persisting after a one-day interval, and increased again with novel distractors. Error bars show ± 1 SEM calculated within participants using the method of O'Brien and Cousineau (2014). (b) Single subject plot of the RT difference between emotional (average of pleasant and unpleasant) and neutral distractors (i.e., affective modulation). Line represents the mean.

After a one-day interval, we observed a general slowdown in the reaction times (Block$_{2,3}$ x trial Type $_{abs,pl,neu,unp}$: F3,141 = 3.39, p = .025, η^2p = .067). Although the difference in the modulatory pattern between the end of Session 1 and the beginning of

Session 2 was on the threshold ($\text{Block}_{2,3}$ x trial Type $_{pl,neu,unpl}$: $F2,94 = 3.09$, $p = .52$, $\eta^2p = .062$) and the affective modulation continued to be highly reliable ($Fs_{1,47} = 30.13, 31.95$ $ps < .001$, $\eta^2p > .391$), the modulation differs from the first Block ($\text{Block}_{1,3}$ x trial Type $_{pl,neu,unp}$: $F_{2,94} = 4.68$, $p = .012$, $\eta^2p = .061$) suggesting that the emotional interference for repeated stimuli is still negatively modulated by the habituation effect after the one-day break.

The introduction of novel pictures prompted an increase of emotional interference ($\text{Block}_{3,4}$ x trial Type $_{pl,neu,unpl}$: $F_{2,94} = 5.01$, $p = .011$, $\eta^2p = .096$) that was similar to that observed in the first block of the habituation phase (Block $_{1,4}$ x trial Type $_{pl,neu,unpl}$, $p = .343$). The novelty effect confirms that novel stimuli prompt a stronger interference compared to the repeated stimuli in the second experimental session.

Overall accuracy was high (M = 96%) and remained stable over trials of both sessions, indicating that the discrimination task was perceptually easy (low-load perceptual task). The ANOVA reveals a significant effect involving trial type ($F_{2,94} = 6.43$, $p < .001$, $\eta^2p = .120$) driven by the difference between the absent condition and both pleasant and unpleasant ($p<.001$).

Discussion

The present study investigated the long-lasting effect of habituation to repeated emotional stimuli, by measuring emotional interference after a one-day break. Participants had to discriminate the orientation of a gabor patch in the centre of the screen, while distracting pictures (pleasant, neutral and unpleasant) were shown in the periphery of the visual field. The reaction time to the task showed that, after few repetitions, the initial interference of emotional stimuli significantly decreased. Based on previous studies (Codispoti et al., 2016; Ferrari et al., 2022) we expected to reach a complete habituation of the emotional interference by the end of the first session (i.e., the absence of difference in reaction times between emotional and neutral stimuli), while in the present study, we observed a significant reduction in the emotional interference (emotional vs. neutral) compared to the beginning of the task. After a one-day break, in which the participants were no longer exposed to the distractors, a new presentation of the same distractors prompted a response that was still modulated by the habituation. Although the effect of habituation seemed to be weakened by the pause, the response to emotional stimuli is still significantly reduced compared to the beginning of the experiment, indicating an inhibition of the interference, which then becomes strong again with the introduction of the new stimuli. Consistent with previous studies (Experiment 1 and 2), response inhibition is finely tuned regarding the specific stimulus used throughout the habituation phase and did not apply to similar emotional exemplars, showing a novel effect only for emotional stimuli and not for neutral new ones. The result of this experiment suggests that the habituation is still present after a one-day break, in which there is no longer experience with the stimulus.

The long-term nature of habituation is well known for perceptually salient stimuli (Chelazzi, et al., 2019; Turatto et al., 2018; Turatto & Pascucci, 2016), while the emotional nature of the stimuli seems to promote a spontaneous recovery of the attentional capture that can influence the response in the second session (Folk, 2015). However, a previous study observed a significant habituation of the LPP emotional enhancement, which is an earlier stage of processing, after a one-day break, with a higher number of repetitions of each stimulus (80 repetitions; Ferrari et al., 2020). Future studies should investigate the habituation effect after a more extended habituation phase on the first session, and with longer breaks, such as a month, or after subsequent short-term break periods.

An interesting effect is the general learning between the two sessions, which we can see as a reduction in RT for all stimulus categories, including the absent condition in which the stimulus is not presented. This result indicates that, regardless of the presence or type of distractor, the pause supported an improvement in carrying out the task that is consistent with the literature and suggests that a break (and micro-breaks) improves the performance in easy task, as our perceptual task, due to the recovery of resources (Globerson, S., Levin, N., & Shtub, A., 1989; Lim, J., & Kwok, K., 2016; Hunter, E. M., & Wu, C., 2016; Albulescu, et al., 2022).

Chapter 3

General discussion

The present project sought to better understand the effect of involuntary learning through repetition in modulating the allocation of attention to high-arousing stimuli by measuring behavioral interference (response time) in a main task. We further study the elaboration of said stimuli at the cortical level (LPP and Alpha-ERD).

For this purpose, in Experiment 1 (Ferrari et al., 2022) we presented the same set of stimuli a few times, reaching a complete habituation of the emotional interference (i.e., no difference in RT between emotional and neutral) before presenting new stimuli belonging to the same categories. The results clearly showed that the repetition of the emotional stimuli in the periphery of the visual field was effective in decreasing the interference caused by the emotional stimuli irrelevant for the task. Importantly, compared to previous habituation studies (Codispoti et al., 2006, 2007; Ferrari et al, 2011; Mastria et al., 2017), the introduction of a task allowed us to evaluate the impact of stimulus repetition on the emotional elaboration when it is in competition with a main task. Furthermore, this experimental setup, with central targets (gabor stimulus) and peripheral distractors (pictures) presented simultaneously, may favour a top-down attentional template that privileges target-specific features or position (Leber and Egeth, 2006a, 2006b) instead of a specific memory trace of the distractor. In this case, we would have no response recovery for novel emotional distractors presented after the habituation phase, because the position would be completely ignored. In Experiment 1, however, the introduction of novel stimuli of the same category prompted a clear novel effect, suggesting that the filter is tuned to the specific features of the single repeated stimulus (instead of the position) and does not generalize to similar stimuli. Importantly, only emotional novel stimuli induced a recovery of the response, while novel neutral distractors were not effective in prompting a recovery of the response, as we observed at the cortical level.

Concerning the cortical response, repetition strongly attenuated the enhancement of the LPP, especially for unpleasant stimuli, that consistently recovered with novel emotional stimuli. Also, at the cortical level, novel neutral distractors did not prompt a recovery of the LPP enhancement. The lack of impact for novel neutral stimuli at the behavioral and cortical level suggests that the filter is tuned to detecting the emotional content of the stimuli, and the novelty per se is not relevant. This also means that the emotional context of repetition influences the relevance of the stimuli in the priority map.

Among several cognitive mechanisms for filtering distractors, the most fitting interpretation of these results aligns with the "Comparator theories" of habituation (Öhman, 1992; Ramaswami, 2014; Siddle, 1991), which evolved from the original "neural model" concept of the orienting reflex (OR) proposed by Sokolov (1960, 1963). Key features of the OR included the responses to stimulus changes and the habituation of orienting with stimulus repetition. The main challenge to this seemingly straightforward model argued that, if stimulus novelty alone can trigger an Orienting Reflex (OR), orienting might be maladaptive, disrupting the organism's ongoing behavior anytime it confronts novel but non-important stimuli. The protracted debate (Maltzman, 1979; O'Gorman, 1979) regarding the definition of the OR as a measure of novelty or significance led to the idea that mere recognition of a stimulus change is not a sufficient condition for the appearance of an OR unless the change holds consequences for the organism. A revision of the traditional OR theory introduced a two-stage process, where novelty is initially assessed based on the degree of match with a neural model, followed by an evaluation of stimulus significance. Maltzman (1979) proposed a conception of a neural model as a detector of stimulus change that is determined by a specific state of the organism, considering ontogeny, phylogeny, past learning experiences, and the immediate stimulus context. These determinant factors influence the degree of unexpectedness (Reichardt et al., 2020) that can be visualized has a threshold that must be overcome to evoke the orienting response (Reisenzein et al., 2017). This idea is in line with the current predictive coding framework (Friston, 2005) and highlights the unexpectedness as a fundamental property of the event, relating it with the particular state of the organism at the time of stimulation. According to this view, the findings of Experiment 1 provide evidence that stimulus novelty per se is not sufficient to overcome the threshold required to trigger an orienting of attention, as this occurred only for novel emotional distractors, but not for those that were emotionally neutral.

To better define which factors influence the filter threshold for emotional stimuli in the distractor condition, the main question that guided Experiment 2 was to what extent the attentional system is sensitive to emotional contextual information (as well as the detailed characteristics of the single repeated stimulus) in ignoring irrelevant habituated stimuli. In fact, in the Experiment 1, we observed a novel effect only for emotional stimuli and not for neutral. Furthermore, we know that a high occurrence of distractors prompts an attenuation of emotional interference, compared to a context with rare distractors (Micucci et al., 2019), meaning that attenuation is sensitive to the contextual factor in which the experience is made. To test the effect of emotional context on the elaboration of the emotional distractors that were already habituated through repetition, we presented new stimuli mixed with the repeated ones. The results showed that the behavioral interference of the emotional stimuli recovered, especially in the unpleasant context compared to the neutral and pleasant ones, indicating that in a more variable context (novel mixed with repeated ones) the filtering for repeated distractors is affected by a contextual novelty, and it is more tolerant towards repeated stimuli. Interestingly, the pleasant new picture attenuated the dishabituation to the unpleasant pictures, suggesting a more selective filter mode, specifically tuned on the pleasantness of the pictures.

Regarding the cortical elaboration of the stimuli, unlike in Experiment 1, in Experiment 2 we did not observe a modulation of the LPP enhancement with repetition, while it was enhanced for new pictures. The alpha-ERD modulation, however, is consistent with previous experiments (Ferrari et al., 2020; Ferrari et al., 2022), showing greater desynchronization with novelty, although it is not affected by the repetition. These results (Experiment 1 and 2) confirm that the alpha-ERD is highly sensitive to distractors' occurrence and emotionality, efficient in detecting novel emotional scenes, and supportive of visual processing from a very early stage.

The dissociation observed between emotional interference at the behavioral level and affective modulation of the LPP enhancement has been shown in previous studies with a massive repetition of the distractor (Codispoti et al., 2006, 2007, 2016; Ferrari et al., 2014) and task-related processes (Ferrari et al., 2008; Mastria et al., 2017), indicating that the semantic processing of emotional stimuli at the early cortical level engages the motivational system, even when the behavioral effect of the stimuli in the main task is inhibited.

These findings address our central question, indicating that the attentional allocation system adapts by ignoring irrelevant emotional stimuli over the course of experience, taking in account not only the specific experience with the distractor, but also the complexity of the context (e.g., repeated intermixed with novel), the degree of unexpectedness of the event (e.g., new stimulus), the motivational relevance and the predictability of the environment.

Experiment 3 was guided by the interest in better defining the stability of the implicit learning effect due to experience with the stimulus. In fact, the behavioral response in previous studies showed a complete habituation in a predictable environment with only repeated stimuli. In this study, a one-day break was introduced modifying the experience with the repeated distractor, whose detailed memory trace is not reinforced for the duration of the pause. In the second session, the same stimuli are presented again to measure their attentional capture and compare it with that of the previous session, in which there was habituation. This paradigm allows us to distinguish between short-term (one session) and long-term effects of repetition, as was shown in previous studies with perceptually salient stimuli (Chelazzi, et al., 2019; Turatto, et al., 2018; Turatto & Pascucci, 2016). The results of Experiment 3 showed that, after the break, the behavioral interference of the repeated and habituated distractors is still modulated by the habituation, and it is different compared to the response to new emotional stimuli. Consistently with the previous studies in this dissertation, Experiment 3 confirms that the attentional filter is influenced by the repetition, is in fact finely tuned to the specific features of the repeated emotional stimuli, and does not extend to the new stimuli. The interruption of the experience with the stimulus for one day does not remove the habituation, showing that the previous experience with the repeated stimulus could induce a long-lasting modulation of the attentional capture.

This set of studies consistently suggest that attentional capture induced by emotional stimuli is a flexible process, influenced by the experience with the stimuli (habituation), and susceptible to contextual factors (predictability and emotionality of pictures). At the same time, this finely tuned process seems to persist even in the absence of an immediate experience with the stimulus (one-day break).

The complex mechanism of emotional stimuli inhibition has different displays at various response levels, involving behavioral interference, LPP and Alpha-ERD. In general, picture repetition and task-related setting dissolve the emotional interference, but the processing displayed in emotional modulation of LPP and Alpha-ERD appears to be resistant to top-down factors. However, there is evidence indicating at least partial habituation of LPP when pictures are placed outside the attentional focus and act as distractors (Ferrari et al., 2022).

Future studies are required to better understand the role of contextual factors, like emotionality, in defining the unexpectedness of the stimulation and modulating the attentional capture for repeated emotional stimuli. That is, to further clarify the extent to which, on the behavioral level, the valence of the context of experience determines the relevance of emotional stimuli with a different modulation for pleasant and unpleasant. It would be also interesting to investigate whether any settings can influence the cortical processing of emotional distractors, which appears resistant to complete habituation, but is at the same time modulated by a prolonged experience with the same stimuli in the periphery of the visual field. A further aspect to be explored concerns the permanence of the inhibition of emotional interference, and whether it could be re-established by a more prolonged break, such as a month, in which the experience with the distractor is suspended.

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