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Stimulus novelty and emotionality interact in the processing of visual distractors

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Abstract

Novel distractors are prioritized for attentional selection. When distractors also convey emotional content, they divert attention from the primary task more than neutral stimuli do. In the present study, while participants were engaged in a central task, we examined the impact of peripheral distractors that varied for emotional content and novelty. Results showed that emotional interference on reaction times completely habituated with repetition and promptly recovered with novelty. The enhanced LPP for emotional pictures was attenuated by repetitions and, interestingly, 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. Altogether, these findings suggest that the impact of peripheral distractors can be attenuated through a non-strategic learning mechanism mediated by mere stimulus repetition, which is fine-tuned to detect changes in emotional distractors only, supporting the hypothesis that novelty and emotion share the same motivational circuits.

1. Introduction

A long-standing debate in the field of emotion and cognition is whether emotional cues are processed in a mandatory fashion or whether contextual factors can modulate the impact and processing of these stimuli (Öhman & Wiens, 2003; Pessoa, 2017; Pourtois et al., 2013; Schupp et al., 2007; Vuilleumier et al., 2004). When emotional stimuli serve as distractors, their appearance prompts a reliable attentional capture that is reflected in a disruption of performance in the ongoing task (Bradley et al., 1996; Calvo et al., 2015; De Cesarei & Codispoti, 2008; Ihssen et al., 2007; Micucci et al., 2020; Weinberg & Hajcak, 2011). Previous studies (see Chelazzi et al., 2019, for a review) have shown that attentional capture by physically salient distractors (i.e., abrupt onset, color singletons) is a flexible mechanism that is susceptible to modulation by contextual factors, such as the attentional set defined by a given task or implicit learning (e.g., selection history or habituation).

Although there is consistent evidence that top-down factors may prevent the interference of emotional distractors (Benoni et al., 2020; Brown et al., 2020), little evidence exists so far regarding the role of implicit learning mechanisms in the inhibition of emotional interference.

Micucci and colleagues (2020) reported that high occurrence of distractors prompts an attenuation of emotional interference, compared to a context with rare distractors. Interestingly, this decline in attention allocation towards emotional stimuli does not depend on the number of emotional pictures presented over time or on the time interval between emotional distractors, but is, rather, triggered by the overall frequency of distractors. In the literature on distractor suppression (Awh et al., 2003; Geng, 2014), within a stimulus presentation sequence the performance cost engendered by a distractor on trial n is mitigated if the distractor was present (versus absent) in the preceding $n-1$ trial, indicating that distractor suppression may occur as a

result of short-term practice with distractors. However, this suppression could be driven by mere exposure to distractors, a case of habituation, or by repeated acts of active suppression across previous trials – a case of selection history effect. In Micucci and colleagues (2020) distractors were all different exemplars of stimuli, making the habituation account unlikely as an explanation of the reduced attentional capture in the high frequency context, as the filtering mechanism could not rely on the formation of a memory trace of the incoming stimuli that would prevent further information gathering. Moreover, the initial orienting towards the distractor was fully preserved, as shown by the emotional modulation of the late positive potential, an electrocortical marker of significance detection that was equally modulated by emotional distractors in the high as well as in the low distractor frequency context. In fact, with novel distractors it is more likely that a temporary filtering mechanism was activated to prevent further attention allocation to emotional stimuli, whereas evaluative processes and the engagement of motivational systems might occur in a mandatory fashion.

Distractor frequency implies that the more the stimuli appear frequently, the less sense of novelty one has with them; however, a more direct way to manipulate novelty, which has more to do with the specific stimulus and not with expectations or context, is to repeat the same stimulus several times across trials. Previous studies showed that the free viewing of centrally-presented repeated emotional pictures only slightly affected the emotional modulation of the late positive potential (LPP), suggesting that, in the absence of a competing task, mere repetition is not sufficient to inhibit the impact of these stimuli (Codispoti et al., 2006, 2007; Ferrari et al., 2011; MASTRIA et al., 2017). The introduction of a task would allow us to evaluate the impact of stimulus repetition on emotional processing in a competitive context in which emotional pictures are treated as distractors. Thus, in the present study, emotional pictures were task-irrelevant stimuli presented in peripheral vision while a central discrimination task was being performed. This design allowed

us to track the impact of the processing of repeated emotional distractors at the behavioral levels (i.e., emotional interference) as well as at the cortical level, in order to investigate at which stage of processing emotional distractors are filtered out.

We may hypothesize that if the filter is sensitive to the specific features of the repeated stimulus, regardless of its motivational relevance, the habituation process could already be evident at an early stage, that is, before the stimulus (i.e., distractor) is evaluated and engages the motivational systems. Within this scenario, we expect an absent or strongly attenuated emotional modulation of the LPP, as well as a lack of modulatory effects on reaction times. 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 performance.

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 et al., 2019). Although previous habituation studies found little evidence of repetition effects on the alpha-ERD enhancement for emotional pictures (Ferrari, Mastria & Codispoti, 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.

Moreover, at the end of the habituation phase, the introduction of a novel phase, with 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. On the other hand, the sensitivity to stimulus change may be different for emotional and neutral pictures. In a previous repetition study (Ferrari et al., 2020) in which affective habituation was measured in a free viewing context, the introduction of novel stimuli after an extensive habituation phase (which lasted for two sessions) prompted a response recovery in the LPP only for emotional but not for neutral pictures. 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, Reizenzein et al., 2017) may play a crucial role.

2. Method

2.1 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.

2.2 Material

The visual stimuli were 132 pictures of 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, 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 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 center 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 gray background. Stimuli were presented on a 16-in 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).

2.3 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 1 shows the sequence of events of the experimental paradigm. In each trial, a Gabor patch appeared in the center of the screen for 150 msec. 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 msec) 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 x 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.

2.4 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 k Ω . 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 et al., 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 et

al., 1983). Then, raw data were low-pass filtered at 30 Hz. ERP averages were computed with a 200-msec baseline and a 1000-msec time window. Trials and sensors containing artifacts were detected through a statistical procedure (Junghöfer et al., 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 Figure 3).

For time-frequency analysis, no low-pass filtering was applied on the raw 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 et al., 1997). The range of analysis was from 4 to 80 Hz and analysis was performed in time windows from 1,000-msec before picture onset to 1,500 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 (Hermann et al., 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 Figure 4) over the same temporal window of the LPP (450-900 ms).

2.5 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) x Block (3) x 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,) x 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.

3. Results

3.1 Behavioral data

Figure 2 shows the interference effects of distractors on the response times (RTs) to the gabor discrimination task. 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.

Statistical analysis of RTs revealed a main effect of trial type ($F_{3,72} = 34.6, p < .001, \eta^2_p = .59$), with slower RTs for distractor-present trials, compared to distractor-absent trials ($F_{s_{1,24}} = 44, 30.89, 43.79, ps < .001, \eta^2_p > .56$, 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 ($F_{s_{1,24}} > 20.89, ps < .001, \eta^2_p > .47$). RTs for pleasant and unpleasant distractors were similarly modulated.

The Block (3) x trial types (4) interaction ($F_{6,144} = 6.896, p < .001, \eta^2_p = .223$) 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, $F_{2,48} = 13.116, p < .001, \eta^2_p = .353$ and unpleasant, $F_{2,48} = 5.435, p = .016, \eta^2_p = .185$), and not for neutral distractors ($F_{2,48} < 1, p = .594, \eta^2_p = .020$). 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) x 2 blocks for pleasant, $F_{1,24} = 22.17, p < .001, \eta^2_p = .480$;

unpleasant, $F_{1,24} = 4.984$, $p = .035$, $\eta^2_p = .172$), such that the affective modulatory pattern found in block 1 (pleasant and unpleasant vs. neutral, $F_{s_{1,24}} > 18.259$, $ps < .001$, $\eta^2_p > .432$) was no longer evident at the end of the habituation phase (block 2: pleasant and unpleasant vs. neutral, $F_{s_{1,24}} > 1.85$, $ps > .082$, $\eta^2_p > .072$).

The introduction of novel pictures prompted a full recovery of emotional interference (pleasant and unpleasant vs. neutral in the novel block, $F_{s_{1,24}} > 15.371$, $ps < .001$, $\eta^2_p > .39$), that was similar to that observed in the first block of the habituation phase (block_{1,3} x 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.

3.2 Late positive potential (LPP)

Figure 3 illustrates that 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.

Statistical analysis of the LPP revealed a main effect of trial Type, ($F_{3,72} = 31.167$, $p < .001$, $\eta^2_p = .565$), showing the largest positivity for pleasant distractors, compared to all other trial types, including unpleasant distractors ($F_{1,24} = 10.165$, $p = .004$, $\eta^2_p = .298$), which in turn were more positive than neutral distractors ($F_{1,24} = 31.726$, $p < .001$, $\eta^2_p = .569$). Interestingly, the LPP amplitude did not differ between neutral distractor and distractor-absent trials ($F_{1,24} = .64$, $p = .43$, $\eta^2_p = .026$). A main effect of Block ($F_{2,48} = 6.528$, $p = .003$, $\eta^2_p = .214$) indicated that the LPP changed as a function of distractor repetitions, with a smaller amplitude in block 2 compared to block 1, ($F_{1,24} = 12.478$, $p = .002$, $\eta^2_p = .342$) as well as compared to block 3 (novel), $F_{1,24} = 6.466$, $p = .018$, $\eta^2_p = .212$. The Block x trial Types

interaction ($F_{6,144} = 4.133, p = .001, \eta^2_p = .147$) revealed that the effect of repetition impacted only emotional distractors (Pleasant over blocks, $F_{2,48} = 7.672, p = .001, \eta^2_p = .242$, Unpleasant over blocks, $F_{2,48} = 6.53, p = .003, \eta^2_p = .214$) but not neutral distractors ($F_{2,48} = 1.199, p = .307, \eta^2_p = .048$). 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, $F = .376, p = .546$).

The affective modulation was highly significant in block 1 ($F_{2,48} = 14.962, p < .001, \eta^2_p = .384$) with both pleasant and unpleasant being more positive than neutral pictures ($F_{1,24} = 32.998, p < .001, \eta^2_p = .50$; $F_{1,24} = 17.276, p < .001, \eta^2_p = .419$, respectively), but similar to each other. Unlike reaction times, in block 2 the affective modulation of the LPP was still significant, ($F_{2,48} = 6.293, p = .004, \eta^2_p = .208$), 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 (Block_{1,2} x trial Type_{pl, neu}, $F_{1,24} = 2.184, p = .152, \eta^2_p = .083$). Unpleasant distractors, on the other hand, were significantly affected by repetitions (Block_{1,2} x trial Type_{unpl, neu}, $F_{1,24} = 4.885, p = .037, \eta^2_p = .169$), such that in block 2 there was no LPP difference between unpleasant and neutral distractors ($F_{1,24} = 1.119, p = .301, \eta^2_p = .045$). In the novel phase the LPP was again larger for both pleasant and unpleasant distractors compared to neutral ones ($F_{1,24} > 15.522, p < .001, \eta^2_p > .393$, although novel unpleasant distractors continued to prompt a smaller LPP compared to pleasant stimuli $F_{1,24} = 8.882, p = .007, \eta^2_p = .270$).

3.3 Alpha Event Related Desynchronization (alpha-ERD)

Figure 4 illustrates that the overall alpha-ERD was enhanced for emotional (both pleasant and unpleasant) compared to neutral distractors, and this affective modulation was preserved over

blocks. 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 (2) x Block (3) x distractor Valence (3): Alpha-ERD was significantly modulated by distractor valence ($F_{2,48} = 26.859, p < .001, \eta^2_p = .528$) with stronger desynchronization for both pleasant, $F_{1,24} = 43.991, p < .001, \eta^2_p = .647$, and unpleasant ($F_{1,24} = 21.216, p < .001, \eta^2_p = .469$) compared to neutral pictures, and for pleasant, compared to unpleasant pictures ($F_{1,24} = 11.015, p = .003, \eta^2_p = .315$). The amount of affective modulation of alpha was not affected by distractor spatial position (distractor Position x Valence, $F_{2,48} = 2.091, p = .138, \eta^2_p = .080$), and did not show a consistent repetition effect (Block x Valence, $F_{4,96} = 2.526, p = .058, \eta^2_p = .095$), as was, however, the case for the RTs and the LPPs.

Distractor Position (3) x Block (3): The scalp topography and modulation of alpha desynchronization was clearly affected by the occurrence of a peripheral distractor (distractor Position, $F_{2,48} = 32.142, p < .001, \eta^2_p = .573$), prompting a larger occipital alpha decrease in both the contralateral and ipsilateral hemispheres ($F_{S_{1,24}} > 18.154, p < .001, \eta^2_p > .431$), 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 ($F_{1,24} = 47.5, p < .001, \eta^2_p = .664$).

Alpha oscillations changed across blocks ($F_{2,48} = 6.18, p = .005, \eta^2_p = .202$) and the distractor Position x Block interaction ($F_{4,96} = 8.657, p < .001, \eta^2_p = .265$) revealed that for distractor-absent trials alpha-

ERD decreased linearly over the three blocks ($F_{1,24} = 8.261, p = .008, \eta^2_p = .256$) whereas for distractor-present trials alpha-ERD decreased across repetitions (block 1 vs. block 2, $F_{1,24} = 9.822, p = .005, \eta^2_p = .290$), and then strongly recovered in the novel phase, with a similar pattern in both the contralateral and ipsilateral hemispheres ($F_{s_{1,24}} > 9.2, ps < .001 \eta^2_p > .277$).

4. Discussion

The present study investigated whether attentional capture by high arousing emotional distractors can be attenuated through a non-strategic learning mechanism mediated by mere stimulus repetition. Several studies have shown that repeated exposure to a distracting stimulus is able to improve our capacity to ignore this distracting information, leading to a reduced RT cost. This filtering mechanism has been shown to work efficiently with perceptually salient stimuli (Kelly & Yantis, 2009; Turatto & Pascucci, 2016), but emotional distractors, especially those depicting sexual or blood/wound cues, belong to a special category of significant stimuli that may be more resistant to habituation (Folk, 2015). 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, indicating 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. Unlike emotional stimuli, novel neutral distractors, however, were not effective at prompting attentional capture.

In terms of cortical reactivity, the enhancement of the LPP for pleasant and 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, no trace emerged, neither at the behavioral nor at the neural level, of the 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.

These findings provide a new and unexpected glimpse into the attentional filter mechanisms that operate to inhibit irrelevant information. Among different cognitive mechanisms for distractor filtering, the most suitable and parsimonious interpretation of these findings relies on the “Comparator theories” of habituation (Öhman, 1992; Ramaswami, 2014; Siddle, 1991), that developed from the original “neural model” concept of the orienting reflex (OR) by Sokolov (1960, 1963). Among the most defining features of the OR were the fact that orienting responses were elicited in the context of stimulus change, and that orienting habituated with stimulus repetition. Some authors challenged this apparently simple model; for example, Bernstein (1979) argued that if stimulus novelty alone is sufficient to elicit an OR, orienting may be maladaptive in that the organism’s ongoing behavior will be frequently disrupted by encounters with novel but non-important stimuli. But of course it depends on how “novelty” is defined and measured (Bradley, 2009; Reichardt et al., 2020). A long debate then followed (Bernstein, 1979; Maltzman, 1979; O’Gorman, 1979) on the definition of the OR as a measure of novelty or significance, with the fundamental idea that mere recognition of a stimulus change is not in itself a sufficient condition for the appearance of an OR, unless the change has some consequences for the organism. A revision of the traditional OR theory was needed, with the formulation (Bernstein, 1979) of a two-stage process in which novelty is first assessed in terms of the degree of match with a neuronal model, followed by the evaluation of stimulus significance. Maltzman (1979) proposed a somewhat

different conception of a neural model as a detector of stimulus change: the occurrence of an OR as a consequence of novel stimuli presupposes a particular state of the organism, that is a consequence of ontogeny, phylogeny, past learning experiences, and sets established by the immediate stimulus context, as well as previous stimulation. Given a particular state of the organism, a stimulus change may evoke an OR. More recently, in line with the current predictive coding framework (Friston, 2005), the role of unexpectedness has been emphasized as a crucial property mediating the automatic orienting of attention (Reichardt et al., 2020). The basic idea is that a certain threshold needs to be overcome by any given event to elicit these responses (Reisenzein et al., 2017) and other determinants such as motivation, the complexity of the environment, or uncertainty may all influence the threshold (i.e., the degree of unexpectedness needed to evoke the orienting response). According to this view, the present findings 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. More likely, our results 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 an OR 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 (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 (Bacon & Egeth, 1994; Leber & 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.

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 (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), 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 (Codispoti, De Cesarei, Biondi, & Ferrari, 2016), but pictures were presented in the center, and the LPP enhancement for both pleasant and unpleasant pictures was totally 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 (Boucart et al., 2016; Rousselet et al., 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 et al., 2017) and several brain responses, such as the early posterior negativity (EPN, e.g. De Cesarei & Codispoti, 2006; Farkas et al., 2020; Schupp & Kirmse, 2021), the late positive potential (LPP, e.g., Ferrari et al., 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.

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, both pleasant and unpleasant, compared to neutral pictures during a passive viewing condition (Ferrari

et al., 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 et al., 2016).

Taken together, these findings show that implicit learning mechanisms, such as those triggered by stimulus repetition, play an important role in modulating the impact of emotional distractors. Micucci et al. (2020) previously showed that a high occurrence of distractors prompts an attenuation of emotional interference, compared to a context with rare distractors, but the present study reveals that only the formation of a clear memory trace of the stimulus exemplar throughout

repetitions activates an efficient filtering mechanism that not only suppresses behavioral interference but also prevents early motivational engagement, reflected in the LPP modulation, at least for unpleasant contents. Moreover, the exclusive OR recovery of novel emotional distractors further supports the hypothesis that novelty and emotion share the same motivational circuits that evolved to support adaptive perceptual and motor processes in survival contexts (Bradley, 2009). The activation of several cortical and subcortical structures sensitive to emotional processing (e.g., the locus coeruleus and the amygdala) is also enhanced in response to novel neutral stimuli, compared to repeated ones, suggesting that novelty is integral of their function (Bradley et al., 2015; Schomaker & Meeter, 2015; Schwartz et al., 2003; Wright et al., 2003; Zald, 2003). In the absence of any stored information (i.e., past experience) regarding the stimulus, novel stimuli reflexively engage the motivational circuits, primarily because they may be dangerous. On the other hand, it is also evident that repeated experience refines the orienting response mechanism in order to detect only those stimulus changes that may have implications for survival.

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Figure captions

Figure 1: Schematic diagram showing the sequence of events in the present study. Two blocks of repeated distractors (habituation phase) were followed by one block consisting wholly of novel distractors (novel phase). The trial sequence was the same in each block, with an initial dark-gray blank screen appearing for 500 msec, followed by a Gabor patch presented for 150 msec. In some trials, a picture (neutral, pleasant, or unpleasant) appeared simultaneously with the Gabor patch, flanking it on the left or right, and stayed on the screen until the Gabor patch disappeared. Participants were instructed to focus their attention on the Gabor patch and to determine its orientation (vertical or horizontal) by pressing one of two buttons while ignoring the distracting scenes. Then a blank screen that ranged from 1000 to 1750 msec was presented.

Figure 2: (a) RTs in the discrimination orientation task for each trial type. Behavioral interference is plotted as a function of block, showing that pleasant and unpleasant distractors initially produced enhanced interference compared to neutral scenes, but that this slowing declined with repetition. Novel distractors prompted a full recovery of emotional interference. 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.

Figure 3: The effects of distractor repetition on the LPP amplitude. (a) Grand-averaged ERP waveforms (average across the sensor cluster, 3b) for pleasant, neutral, and unpleasant distractors across the two blocks of the habituation phase and the final novel block. Insets show the back view of scalp topography (450–900 msec) of the LPP enhancement for pleasant and unpleasant distractors, compared to neutral 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. (d) Single subject plot of the LPP affective modulation (emotional minus neutral), separately for pleasant (blue dots) and unpleasant distractors (red dots). Line represents the mean.

Figure 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. (c) Single subject plot of alpha-ERD affective modulation (emotional minus neutral), separately for pleasant (blue dots) and unpleasant distractors (red dots). Line represents the mean. (d) The sensor cluster used for statistical analyses is reported on the sensor map (gray dots). (e) 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. (f) 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).