Contextual Modulation of Emotional Distraction: Attentional Capture and Motivational Significance

Antonia Micucci[1], Vera Ferrari[2], Andrea De Cesarei[1], and Maurizio Codispoti[1]

Abstract

■ Emotional stimuli engage corticolimbic circuits and capture attention even when they are task-irrelevant distractors. Whether top–down or contextual factors can modulate the filtering of emotional distractors is a matter of debate. Recent studies have indicated that behavioral interference by emotional distractors habituates rapidly when the same stimuli are repeated across trials. However, little is known as to whether we can attenuate the impact of novel (never repeated) emotional distractors when they occur frequently. In two experiments, we investigated the effects of distractor frequency on the processing of task-irrelevant novel pictures, as reflected in both behavioral interference and neural activity, while participants were engaged in an orientation discrimination task. Experiment 1 showed that, compared with a rare distractor condition (20%), frequent distractors (80%) reduced the interference of emotional stimuli. Moreover, Experiment 2 provided evidence that emotional interference was reduced by distractor frequency even when rare, and unexpected, emotional distractors appeared among frequent neutral distractors. On the other hand, in both experiments, the late positive potential amplitude was enhanced for emotional, compared with neutral, pictures, and this emotional modulation was not reduced when distractors were frequently presented. Altogether, these findings suggest that the high occurrence of task-irrelevant stimuli does not proactively prevent the processing of emotional distractors. Even when attention allocation to novel emotional stimuli is reduced, evaluative processes and the engagement of motivational systems are needed to support the monitoring of the environment for significant events. ■

INTRODUCTION

The selection of goal-relevant stimuli and the monitoring of the environment for emotionally salient events are paramount in determining appropriate survival behaviors and in successfully completing everyday tasks. Enhanced analysis of currently relevant or otherwise salient information is often accompanied by suppressed processing of the less relevant input. In life, there are abundant instances in which task-irrelevant stimuli capture attention and interrupt ongoing goal-directed activity; for example, drivers may have their attentional focus briefly drawn away from the road ahead by a flashy billboard advertisement or by a bee flying inside the vehicle (Buetti & Lleras, 2016; Folk, 2015; Kelley & Yantis, 2009).

Emotional stimuli or events that are relevant to the survival motive are effective stimuli in prompting an involuntary capture of attention, and these interference effects have been reported using a variety of stimuli and tasks (Anderson, 2018; Failing & Theeuwes, 2018; Most, 2014; Bradley, 2009). Research has shown that when emotional pictures, both pleasant and unpleasant, are task-irrelevant stimuli, they are especially disruptive for the ongoing task, elongating RTs more than neutral distractors (emotional interference; Calvo, Gutiérrez-García, & Del Líbano, 2015; Weinberg & Hajcak, 2011; De Cesarei & Codispoti, 2008; Ihssen, Heim, & Keil, 2007; Bradley, Cuthbert, & Lang, 1996).

From an evolutionary perspective, the attentional capture phenomenon is adaptive in making us quickly aware of important, and unexpected, environmental events that might require a prompt reaction but also implicates a delay or even a failure to accomplish our current goal (i.e., distraction). Given the implications that distraction can entail, huge research efforts have been made to clarify under which conditions and to what extent attentional capture by emotional stimuli can be modulated.

According to several studies, the viewing of an emotional stimulus activates corticolimbic (appetitive and aversive) motivational systems that, in turn, enhance attention allocation to optimally process the stimulus itself (e.g., Lang & Bradley, 2010; Lang, Bradley, & Cuthbert, 1997). In addition to the traditional behavioral measures of distraction (RTs and accuracy), other indexes, such as ERPs for task-irrelevant stimuli, have begun to be incorporated into the study of emotional distraction. Consistent research identifies the late positive potential (LPP) as a reliable cortical marker of emotional processing (Hajcak, Weinberg, MacNamara, & Foti, 2012; Bradley, 2009; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). Emotionally arousing

[1]University of Bologna, [2]University of Parma

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(pleasant and unpleasant) pictures elicit a larger LPP than neutral images, even when participants are actively engaged in an unrelated task (Codispoti, De Cesarei, Biondi, & Ferrari, 2016; Weinberg & Hajcak, 2011). Moreover, the affective modulation of the LPP persists despite massive repetition of the same stimulus exemplars, suggesting that it indexes motivational significance defined as the activation of corticolimbic systems that support perception and action (Codispoti et al., 2016; Ferrari, Bradley, Codispoti, & Lang, 2011; Lang & Bradley, 2010; Codispoti, Ferrari, & Bradley, 2007).

Several studies have shown that repeated exposure with events that are clearly irrelevant leads to more efficient filtering of those events (Vecera, Cosman, Vatterott, & Roper, 2014; Kelley & Yantis, 2009). One type of repeated exposure is simply when the same stimulus is repeated several times. It is well known that, after several repetitions, attentional capture prompted by this distractor is strongly attenuated (habituation of the orienting response; Folk & Remington, 2015; Sokolov, 1963); similarly, repetition of emotional pictures is associated with a clear reduction in emotional interference (Codispoti et al., 2016; Ferrari et al., 2011). On the other hand, another way of becoming experienced with distractors is to vary the frequency of their occurrence; distractors capture attention more strongly when they are infrequent than when they are frequent (Folk & Remington, 2015; Müller, Geyer, Zehetleitner, & Krummenacher, 2009; Geyer, Müller, & Krummenacher, 2008). More specifically, distractors interfere with performance, producing a cost in RTs when they are relatively rare within a block of trials, although they fail to capture attention when the frequency of occurrence is high (e.g., 80% vs. 20% over trials; Folk & Remington, 2015; Müller et al., 2009; Geyer et al., 2008). It has been proposed that observers learn to reject task-irrelevant distractors after having had enough experience with them (e.g., Vecera et al., 2014; Kelley & Yantis, 2009; Müller et al., 2009). Consistently, it has been shown that, after having been acquired, the underlined inhibitory mechanisms can be engaged in a sustained manner and not only transiently in the context in which observers are severely exposed to distractors (Müller et al., 2009). In their experiment, Müller and collaborators (2009) divided the observers into two groups: For one group of participants (run-up), the frequency of distractor presentation was increased from 0% to 100% over five blocks of 100 trials each (run-up group: 0%, 20%, 50%, 80%, and 100%); for the other group (run-down), distractor presentation was decreased systematically from 100% to 0% (run-down group: 100%, 80%, 50%, 20%, and 0%). Whereas the run-up group showed consistently elevated RTs for distractor compared with no-distractor trials, the run-down group showed no effect of the distractor even when presented rarely, suggesting that the initial exposure to distractors in the high-frequency block may have engaged a filtering mechanism in the following run-down blocks.

Unlike the typical attentional-capture paradigms, where simple and highly familiar stimuli (e.g., geometric or colored shapes, sounds) serve as distractors, in real life, we are mostly surrounded by stimuli that are novel and highly heterogeneous in appearance as well as in emotional relevance. For example, when we read a newspaper while sitting outside a café, we usually get frequently distracted by various salient events, some of which are emotionally charged, such as a child who starts crying at the table next to us, a dog that suddenly growls and barks, the appearance of a loved person, and so on. Curiously, little is known as to whether we can ignore novel (never repeated) emotional distractors that frequently interfere with task performance.

Our aim in this study was to examine whether and how distractor frequency (high-frequency block: 80% of distractors; low-frequency block: 20% of distractors) affects the processing of novel emotional distractors. A smaller emotional interference in the high-frequency block, compared with the low-frequency block, may reflect the existence of a top–down control mechanism triggered by contextual factors, such as the overall distractor frequency, which is actively tuned to prevent distraction.

Moreover, this filtering may occur at various stages of processing. Therefore, besides behavioral responses, we were also interested in examining ERPs, with a specific focus on the LPP, to better clarify at which stage the filter can operate. The experience with frequent distractors that are learned to be clearly inconsequential may affect the activation of motivational systems, preventing the cascade of perceptual and motor responses that are typically prompted by the detection of emotional stimuli. Alternatively, appetitive and defensive motivational systems might continue to be activated by frequent emotional distractors to support some fundamental sensory processing, without necessarily interfering with the concurrent behavioral response. Although a reduction in emotional interference, indexed by RTs, could be predicted by both these scenarios, the LPP affective modulation may reveal the extent to which frequent distractors are actually ignored.

EXPERIMENT 1

In Experiment 1, we aimed to determine the extent to which behavioral interference of novel emotional distractors and the LPP affective modulation were affected by distractor frequency, while performing a central orientation discrimination task with distractor pictures flanked on either the left or right of the task stimulus. We used a distraction context manipulation paradigm in which the frequency of presentation of distractors was varied across blocks. In the low-frequency block, task-irrelevant pictures were presented in 20% of the trials (10% neutral, 10% emotional), whereas in the high-frequency block, distractors were presented in 80% of the trials (40% neutral, 40% emotional). Moreover, the order of presentation of the two blocks was counterbalanced across participants: One group of participants (run-up) started with the low-frequency block, whereas the other group (run-down) started with the high-frequency block. If previous experience with distractors is a critical factor in shaping the filtering (a learning process), then an attenuated impact of emotional (compared with neutral) distractors in the low-frequency block should be expected for participants who performed it after the high-frequency block, compared with those who performed this block first. In other words, participants in the run-down condition should have the opportunity to learn a durable filtering strategy.

Methods

Participants

Twenty-four healthy students (10 women; mean age = 20 years, *SD* = 0.8 years) from the University of Bologna (Italy) participated in the experiment as volunteers and signed an informed consent form before the experiment. The participant set size of the present and the following experiment was selected on the basis of similar previous studies (e.g., Codispoti et al., 2016; Calvo et al., 2015; Schupp et al., 2006). The experimental protocol conforms to the Declaration of Helsinki and was approved by the Bioethical Committee of the University of Bologna. All participants had normal or corrected-to-normal visual acuity. Participants were randomly assigned to the run-down (n = 12) or run-up (n = 12) condition order. Because of technical problems, EEG data from one male participant were not included in the analyses.

Material

Stimuli were presented on a 16-in. monitor at 1024 × 768 resolution and at a refresh rate of 120 Hz, controlled by an IBM computer. Stimulus presentation and data collection were performed using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). Pictures of natural scenes served as distractor stimuli and were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and from public domain pictures available on the Internet. Pictures were 75 pleasant (heterosexual erotic couples), 75 unpleasant (mutilated bodies), and 150 neutral (people in a variety of daily activities) scenes. Emotional pictures were selected as the most arousing based on subjective ratings (ranging from 1 to 9), cortical arousal (LPP amplitude change), and autonomic arousal (skin conductance response), from a previous pilot study. In the pilot study, emotional pictures were rated as more arousing (M = 6.12, SD = 0.67) compared with neutral pictures (M = 2.52, SD = 0.80). Consistent with arousal ratings, there was also a stimulus type effect on LPP amplitude and skin conductance changes, with a significantly larger positivity (M = 2.50, SD = 0.85) and larger skin conductance changes (M = 0.06, SD = 0.05) for emotional stimuli (M = 0.14, SD = 0.88) compared with neutral stimuli (M = 0.02, SD = 0.04).

Stimuli were displayed on a gray background at a constant viewing distance of 60 cm. Each scene subtended 14.3° (horizontal) × 10.8° (vertical) visual angle and was positioned to either the left or right of a central Gabor patch. The distance between the inner edge of the distractor image and the center of the Gabor patch was 4°. The Gabor patch (sinusoidal gratings with a Gaussian envelope) subtended a 5.3° × 5.3° visual angle, and it could be horizontally or vertically oriented. Gabor patches were generated using custom MATLAB software (The MathWorks) by overlapping two distinct Gabor patches with the same orientation but different frequencies (0.94 and 9.4 cycles per degree of visual angle, respectively). All stimuli were equated in brightness and contrast to avoid potential confounds resulting from low-level visual properties of the images.

Procedure

Figure 1 shows the sequence of events of the experimental paradigm. In each trial, after a 500-msec gray background, 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 by pressing the corresponding key with the index finger of the dominant hand. The intertrial interval was variable (1000, 1325, 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 emotional 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 experimental session consisted of two blocks, namely, a high-frequency block and a low-frequency block, with 300 trials each. The order of the two blocks was counterbalanced across participants. In the low-frequency block, distractors appeared in 20% of the trials and 60 pictures (30 neutral and 30 emotional) were presented. In the high-frequency block, distractors were displayed in 80% of the trials, for a total of 240 pictures (120 neutral, 120 emotional). No picture exemplar was ever repeated across trials or blocks. Participants were not explicitly informed of the difference in distractor frequency across blocks.

Before the beginning of the experiment, each participant performed a practice block of 100 trials in which distractors were never presented. Brief breaks were introduced between blocks.

EEG Recording and Processing

EEG was recorded at a sampling rate of 512 Hz using the ActiveTwoBioSemi system, with a 62-channel dense

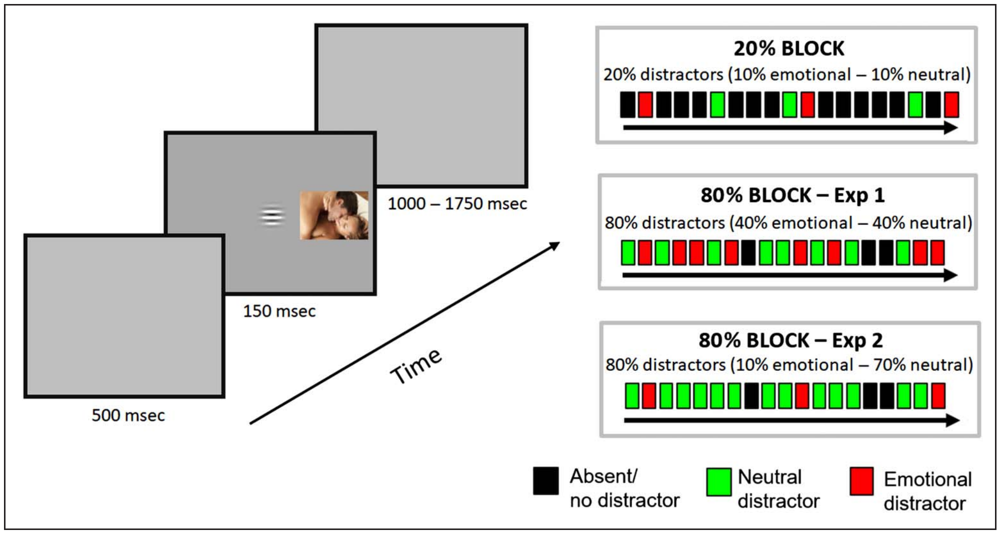

Figure 1. Schematic representation of the trial sequence in the discrimination orientation task. An initial dark-gray blank screen appeared for 500 msec, followed by a Gabor patch presented for 150 msec. In some trials, a picture (neutral or emotional) appeared simultaneously with the Gabor patch, flanking 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. Stimuli are not to scale; see text for actual size. Exp = Experiment.

sensor array. The EEG was referenced to an additional active electrode (common mode sense; with ground in an additional electrode: driven right leg) during recording. Additional sensors were positioned below the left eye, and lateral to the outer eye canthi, to measure eye movements. These sensors were discarded from the analysis after correction for eye movements. For each trial, EEG signals were corrected for blinks and eye movements using a regression technique based on the electrodes above and below the left eye as well as to the left and right sides of the eyes (Schlögl et al., 2007). Off-line analysis was performed using EMEGS (Peyk, De Cesarei, & Junghöfer, 2011). First, all data were filtered (40-Hz low-pass and 0.1-Hz high-pass) and rereferenced to the average of all scalp electrodes. Then, trials and sensors containing artifacts were detected through a statistical procedure specifically developed for dense-array EEG (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). Trials containing a high number of neighboring bad sensors were discarded; for the rest of the trials, sensors containing artifactual data were replaced by interpolating the nearest good sensors. The percentage of good trials was 90.6%, and this percentage did not vary across blocks or distractor emotionality (ranging between 89.9% and 93.3%). Finally, a baseline correction based on the 200 msec before stimulus onset was performed, and averaged ERP waveforms were calculated for each Block (high vs. low distractor frequency) and Trial type (distractor absent, neutral and emotional distractors). ROI and time interval of interest were identified by both visual inspection and previous studies (Luck, 2014; Hajcak et al., 2012; Schupp et al., 2006). The LPP was scored as the average of the ERP waveform in the 450 and 900 msec after stimulus onset at the parieto-occipital sensor group (see inset in Figure 3 for sensor cluster, blue dots).

Data Collection and Analysis

RT and ERP analyses were performed only on accurate trials. For each participant, block, and trial type, RTs above or below 3 *SD*s from the mean were discarded as outliers. These criteria removed 3.7% of the data. A repeated-measures ANOVA was performed with the two within-participant factors of Block (high vs. low distractor frequency) and Trial type (absent, neutral, emotional). Because our main interest was to examine the effects of distractor frequency on emotional processing, a more specific analysis was performed on distractor-present trials only, with the factors Block and Emotionality (emotional or neutral). The order of block presentation was then introduced as a between-participant factor, Order: one group of participants that started with the 20% block (run-up group) and the other group that started with the 80% block (run-down group). To deal with violations of sphericity, a Huynh–Feldt correction was applied to the degrees of freedom. For each ANOVA test, we reported the partial eta-squared statistic (η_p^2) indicating the proportion of variance that is explained by experimental conditions over the total variance. Nonsignificant effects of condition (Block × Emotionality) were further evaluated with a one-sided equivalence test to provide statistical support for the absence of the frequency effect (Lakens, 2017). In this test, one concludes that a meaningful effect is absent if the observed effect size is reliably larger than the smallest effect size of interest (SESOI). SESOIs were computed with a post hoc sensitivity test for two-tailed t tests between dependent means (conducted on G*Power with an error probability of .05 and 80% power; Faul, Erdfelder, Lang, & Buchner, 2007) and yielded an expected SESOI of $d_z = -0.611$. Following Lakens (2017), we compared the actual effect size d_z against the expected negative SESOI, based on the hypothesis that 80% distractor frequency would determine a reduction in affective modulation.

Results

RTs

As shown in Figure 2, compared with distractor-absent trials, the appearance of a distractor image prompted slower RTs in the orientation discrimination task, and performance was especially disrupted when such images had an emotional, compared with a neutral, content. Critically, this emotional interference effect was attenuated in the 80% block in comparison with the 20% block. Statistical analysis of RTs yielded a significant effect of Trial type, $F(2, 46) = 25.651$, $p < .001$, $\eta^2_p = .527$, indicating slower RTs in distractor-present trials (both neutral and emotional) compared with distractor-absent trials, Fs$(1, 23) > 39.171$, ps $< .001$, $\eta^2_{ps} > .630$, and in emotional distractor trials compared with neutral distractor trials, $F(1, 23) = 12.259$, $p = .002$, $\eta^2_p = .348$. A main effect of Block was not found, $F(1, 23) = 1.663$, $p = .210$, $\eta^2_p = .067$. A significant Block × Trial Type interaction was observed, $F(2, 46) = 23.318$, $p < .001$, $\eta^2_p = .503$. More relevantly to our experimental question, a subsequent ANOVA confirmed a significant Block × Emotionality (neutral, emotional) interaction, $F(1, 23) = 6.694$, $p = .015$, $\eta^2_p = .232$. This interaction appeared to reflect the fact that emotional interference, although significant in both frequency blocks (80% block: $F(1, 23) = 4.906$, $p = .037$, $\eta^2_p = .176$; 20% block: $F(1, 23) = 11.369$, $p = .003$, $\eta^2_p = .331$), was smaller in the 80% block ($M = 9.21$), compared with the 20% block ($M = 32.78$). Further pairwise comparisons were performed to test the effect of Block on each trial type: Slower RTs were observed when emotional distractors were presented in the 20%, compared with the 80%, block, $F(1, 23) = 10.834$, $p = .003$, $\eta^2_p = .320$, but no significant difference was found for neutral distractors, Block: $F(1, 23) = 1.421$, $p = .245$, $\eta^2_p = .058$. A significant difference in distractor-absent trials was also found, $F(1, 23) = 5.707$, $p = .025$, $\eta^2_p = .199$, indicating that participants were slower at responding to the task in the 80% block compared with the 20% block.

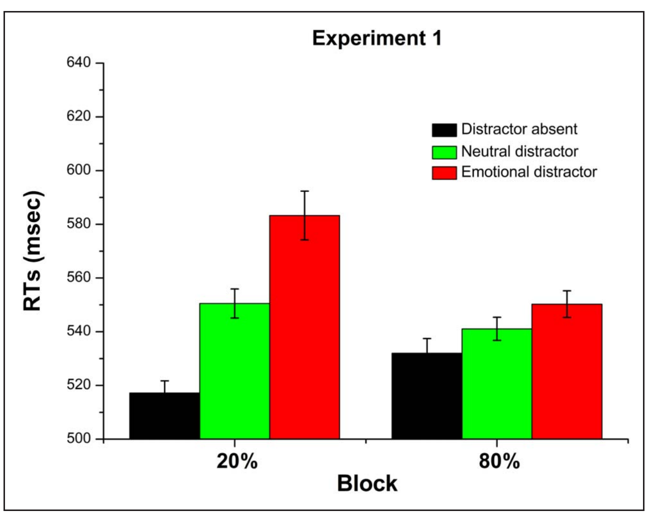

Figure 2. RTs in the discrimination orientation task for distractor-absent, neutral distractor, and emotional distractor trials as a function of the distractor frequency block. Error bars show ±1 *SEM* calculated within participants using the method of O'Brien and Cousineau (2014).

The order of presentation of the two blocks did not affect the modulation of distractor interference, as revealed by both Order × Block × Trial Type, $F(2, 44) = 0.859$, $p = .404$, $\eta^2_p = .038$, and Order × Block × Emotionality, $F(1, 22) = 0.724$, $p = .404$, $\eta^2_p = .032$. The comparison between the two groups of participants revealed the emotional interference in the 20% block to not be attenuated for the run-down group compared with the run-up group, 28.51 versus 37.05 msec.

A further analysis was conducted to evaluate the possibility that the attenuation of the emotional interference effect reflected the number of times the participants were exposed to distractors, rather than frequency per se. In fact, in the 80% block, distractors appeared in 240 of 300 trials, whereas in the 20% block, they appeared in only 60 trials, making the alternative explanation possible: The cognitive system might require a minimum number of exposures to distractors to learn how to ignore them. To test this hypothesis, in the 80% block, we analyzed only the first 60 trials in which distractors were presented. If the number of distractors was the crucial factor, then the emotional interference effect should not differ between the two blocks. Otherwise, we expected to still find an attenuated emotional interference effect in the 80% compared with the 20% block. Results confirmed the latter hypothesis, favoring the role of distractor frequency, as a significant Block × Emotionality interaction was found, $F(1, 23) = 8.129$, $p = .009$, $\eta^2_p = .261$, with an interference effect of emotional stimuli in the 20% block, $F(1, 23) = 11.369$, $p = .003$, $\eta^2_p = .331$, but not in the 80% block, $F(1, 23) = 0.100$, $p = .755$, $\eta^2_p = .004$.

Accuracy

Error rates are shown in Table 1. The overall accuracy was high ($M = 97.4\%$), indicating that the discrimination task was perceptually easy (low-load perceptual task). The ANOVA revealed a significant effect of Trial type, $F(2, 46) = 11.445$, $p = .001$, $\eta^2_p = .332$, indicating lower accuracy during viewing of emotional stimuli, compared with neutral trials, $F(1, 23) = 12.110$, $p = .002$, $\eta^2_p = .332$, and distractor-absent trials, $F(1, 23) = 15.491$, $p = .001$,

Table 1. Mean Percentage of Accurate Response (*SEM* in Parentheses) for Each Trial Type, Block, and Experiment

	20% Block	*80% Block*
Experiment 1		
Absent	97.7 (0.3)	97.8 (0.4)
Neutral	98.3 (0.7)	96.6 (0.5)
Emotional	94.3 (1.1)	96.6 (0.5)
Experiment 2		
Absent	97.3 (0.3)	97.8 (0.5)
Neutral	96.5 (0.7)	97.3 (0.4)
Emotional	95.3 (0.9)	96.8 (0.6)

η_p^2 = .402, whereas no significant difference was found between neutral distractor trials and distractor-absent trials, $F(1, 23) = 0.520$, $p = .478$, $\eta_p^2 = .022$. No significant effect of Block was found, $F(1, 23) = 1.582$, $p = .221$, $\eta_p^2 = .064$. Crucially, neither the Block × Trial Type interaction, $F(2, 46) = 2.878$, $p = .080$, $\eta_p^2 = .111$, nor the Block × Emotionality interaction, $F(1, 23) = 3.707$, $p = .067$, $\eta_p^2 = .139$, was significant. Overall, the pattern of error rates does not explain RT performance as a speed–accuracy trade-off.

LPP

As illustrated in Figure 3, emotional compared with neutral stimuli elicited a larger positivity over parieto-occipital sensor sites[1] in the 450- to 900-msec time interval, and this affective modulation of the LPP was evident in the 80% block as well as in the 20% block. The interaction Block × Trial Type, $F(2, 44) = 8.217$, $p = .001$, $\eta_p^2 = .272$, indicated that distractors, both emotional and neutral, elicited a larger LPP when presented in the 20% block compared with the 80% block ($F(1, 22) = 10.189$, $p = .004$, $\eta_p^2 = .317$, and $F(1, 22) = 7.038$, $p = .015$, $\eta_p^2 = .242$, for emotional and neutral distractors, respectively), whereas no difference was found for distractor-absent trials between the two blocks ($p > .05$). Emotional pictures elicited a larger LPP, compared with neutral pictures, in both blocks (Emotionality: 20% block, $F(1, 22) = 12.449$, $p = .002$, $\eta_p^2 = .361$; and 80% block, $F(1, 22) = 34.267$, $p < .001$, $\eta_p^2 = .609$), and the critical interaction Block × Emotionality (neutral, emotional) was not significant, $F(1, 22) = 1.462$, $p = .239$, $\eta_p^2 = .062$, suggesting that the LPP emotional modulation was unaffected by distractor frequency. Corroborating this null effect, the observed effect size for the difference between the 20% and 80% conditions ($d_z = -0.244$) did not reach the SESOI ($d_z = -0.611$), $t(1, 22) = 1.721$, $p = .049$, indicating that the magnitude of the affective modulation of the LPP in the high-frequency block was equivalent to that in the low-frequency block. Furthermore, when considering the differences between participants who performed the two blocks in ascending order (20%–80%) or in descending order (80%–20%), we observed neither an interaction of Order × Block × Trial Type, $F(2, 42) = 0.562$, $p = .574$, $\eta_p^2 = .026$, nor an interaction of Order × Block × Emotionality, $F(1, 21) = 1.660$, $p = .212$, $\eta_p^2 = .073$.

To summarize, when participants were rarely exposed to distractors (20% block), emotional pictures captured more attentional resources compared with neutral ones, causing a behavioral interference (RT slowdown) with the ongoing task. However, this RT affective modulation decreased when the frequency of distractors increased in the 80% block. Although behavioral interference findings suggest that frequent emotional stimuli can be suppressed to some extent, the affective modulation of the LPP was not affected by distractor frequency, suggesting that emotional engagement was strongly preserved even with frequent distractors.

EXPERIMENT 2

In a context of frequent distractors, do participants need to be exposed specifically to emotional stimuli to reject them? In the high-frequency block, both the overall distractor frequency (80%) and the specific frequency of emotional distractors (40%) were higher compared with those in the low-frequency block (20% overall distractor frequency and 10% emotional distractors), and thus an important question is whether the difference in emotional interference between the two blocks was because of the specific exposure to emotional distractors, rather than to distractors in general, regardless of their content. In fact, although we have excluded the possibility that emotional interference was modulated by the number of distractors that participants had encountered, by analyzing the first 60 trials with distractors in both blocks, the time interval between the occurrence of one emotional stimulus and the next was shorter in the 80% block (M = 5.03 sec) compared with the 20% block (M = 20.60 sec). The short time interval between emotional distractors, and the higher predictability of the occurrence of emotional distractors, may have played a crucial role in reducing the impact of emotional distractors, thus making them less effective in capturing attention. If this is the case, then we should fail to observe a reduction in emotional interference when rare emotional distractors are intermixed with frequent neutral distractors. Otherwise, if the critical factor is the mere high occurrence of distractors independently of their content (overall distractor frequency), we should observe a reduction in emotional interference when several distractors are presented. To disentangle this issue, in Experiment 2, we reproduced the paradigm used in Experiment 1, but emotional pictures were equally rare (10%) and with the same temporal gap (approximately

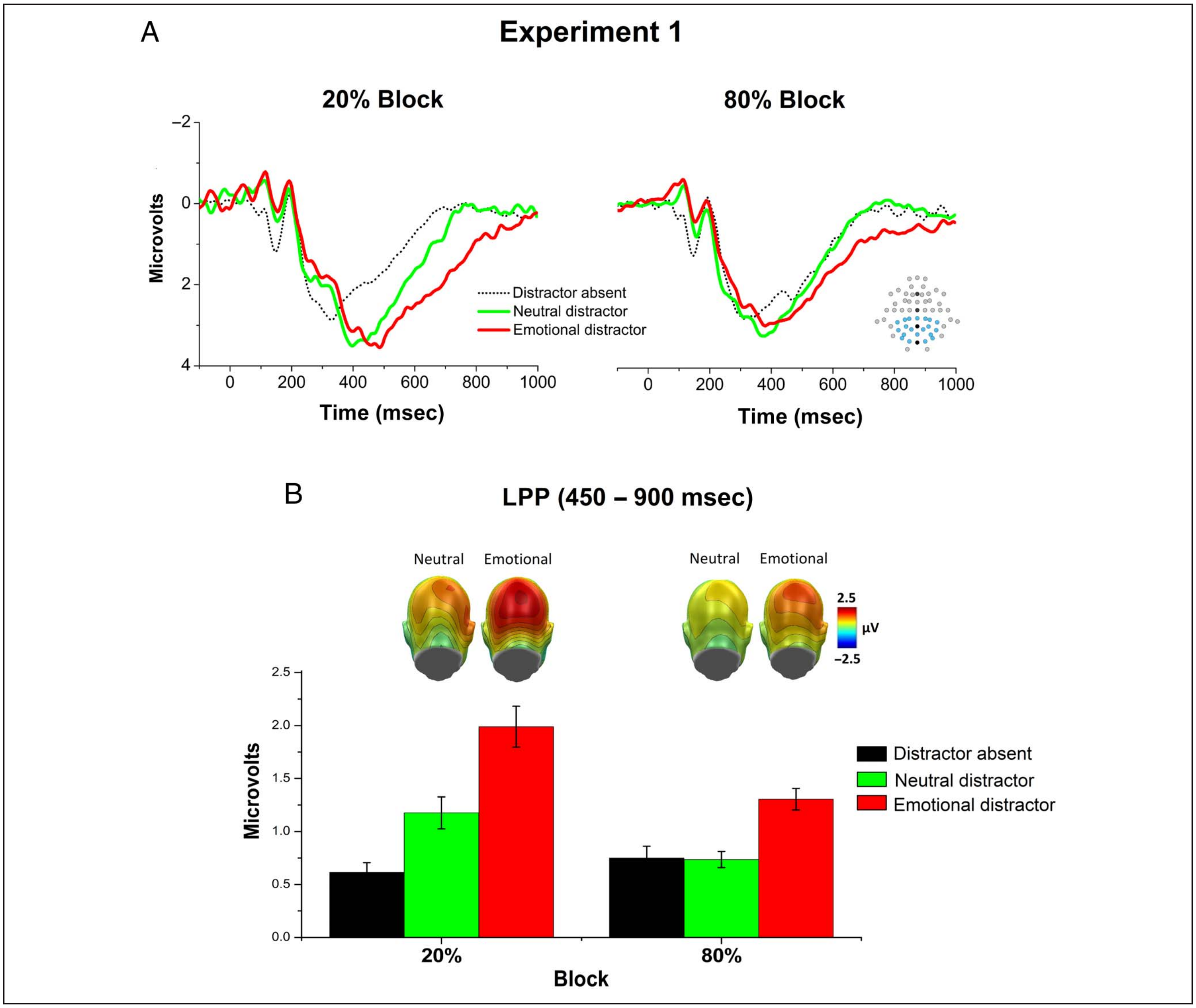

Figure 3. The effects of Block on the LPP amplitude. (A) Grand-averaged ERP waveforms for neutral and emotional pictures, separately in the 20% block and in the 80% block, are represented. The sensor cluster used for statistical analyses is reported in blue on the sensor map, and the black dots represent four representative midline sensors, namely, Fz, Cz, Pz, and Oz. (B) The bar graph shows the LPP amplitude and the within-participant *SEM* for distractor-absent, neutral distractor, and emotional distractor trials as a function of block. Insets are the back view of scalp topography (450–900 msec) of the electrocortical activity during neutral (left) and emotional picture (right) processing in the 20% and 80% blocks, respectively.

20 sec) in both blocks (20% and 80%), and only the frequency of occurrence of neutral distractors differed between the two blocks. If what matters is the time interval between emotional distractors, regardless of the overall distractor frequency, then we should not find a frequency effect on emotional interference; that is, the larger RT slowdown for emotional compared with neutral distractors should be similar across the two blocks. By contrast, if the critical factor is the overall distractor frequency, regardless of distractor emotionality, then we should expect an attenuated emotional interference for rare emotional distractors in the 80% block compared with the 20% block, similarly to what was found in Experiment 1.

Methods

Participants

Twenty healthy students (11 women) of the University of Bologna (Italy) agreed to participate in the experiment and signed an informed consent form. Mean age was 21.6 years (*SD* = 2.3 years). The experimental protocol conforms to the Declaration of Helsinki and was approved by the Bioethical Committee of the University of Bologna. All participants had normal or corrected-to-normal visual acuity and were all naive as to the aim of the experiment. Participants were randomly assigned to the run-down (*n* = 10) or run-up (*n* = 10) condition order.

Material and Procedure

Stimuli, equipment, and procedure were the same as in Experiment 1 except that 180 new neutral images (depicting objects, interior, and urban street) were selected to be presented in the 80% block.

Data Collection and Analysis

Collection and analysis of RT and ERP data were similar to Experiment 1. Concerning ERPs, the percentage of trials that were not discarded by the artifact detection procedure (see Method section of Experiment 1) was 91.2% and was similar across blocks and distractor emotionality (range = 89%–91.5%). The LPP was scored using the same ROI and temporal window of interest used in Experiment 1. Regarding RTs, for each participant, block, and trial type, RTs above or below 3 *SD*s from the mean were discarded as outliers. These criteria removed 3.9% of data. Following Lakens (2017), the SESOI for the calculation of one-sided equivalence test was −0.660.

Results

RTs

As illustrated in Figure 4, the emotional interference effect was reduced in the 80% block, compared with the 20% block. Analysis of RTs[2] yielded a significant interaction of Block × Trial Type, $F(2, 38) = 12.317$, $p < .001$, $\eta_p^2 = .393$. Importantly, the emotional interference differed between the two blocks, as confirmed by a significant Block × Emotionality interaction, $F(1, 19) = 5.880$, $p = .025$, $\eta_p^2 = .236$. Following up on this interaction, a separate analysis on the Emotionality effect in each block showed that, although emotional interference was present in both blocks (80% block: $F(1, 19) = 22.881$, $p < .001$, $\eta_p^2 = .546$; 20% block: $F(1, 19) = 20.398$, $p < .001$, $\eta_p^2 = .518$), it was attenuated in the 80% block ($M = 30.88$ msec), compared with the 20% block ($M = 55.54$ msec). Pairwise comparisons were performed to test the Block effect for each Trial type: Slower RTs were found for emotional distractors presented in the 20% block compared with the 80% block, $F(1, 19) = 7.509$, $p = .013$, $\eta_p^2 = .283$, but no difference was found for neutral distractors between the two blocks, $F(1, 19) = 0.490$, $p = .493$, $\eta_p^2 = .025$. RTs in distractor-absent trials were significantly slower in the 80% block compared with the 20% block, $F(1, 19) = 5.256$, $p = .033$, $\eta_p^2 = .217$. In addition, the order of presentation of the two blocks did not affect the reduction of distractor interference, as both interactions involving the factor Order (Order × Block × Trial Type and Order × Block × Emotionality) were not significant. A main effect of Trial type was also found, $F(2, 38) = 40.699$, $p < .001$, $\eta_p^2 = .682$, with slower RTs in distractor-present trials (both emotional and neutral) compared with distractor-absent trials, $Fs(1, 19) > 58.503$, $ps < .001$, $\eta_{ps}^2 > .755$, and in emotional distractor trials compared with neutral distractor trials, $F(1, 19) = 26.442$, $p < .001$, $\eta_p^2 = .582$. No significant effect of Block was observed, $F(1, 19) = 0.938$, $p = .345$, $\eta_p^2 = .047$.

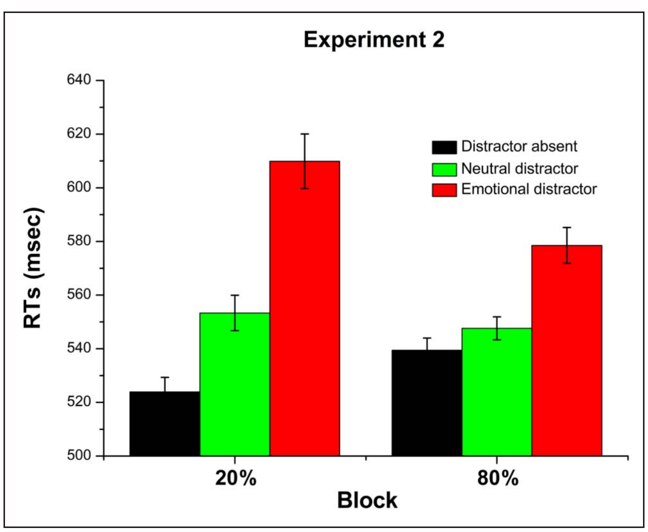

Figure 4. Mean of RTs and within-participant *SEM* in the discrimination orientation task for distractor-absent, neutral distractor, and emotional distractor trials as a function of block.

Accuracy

An analysis of accuracy (see Table 1) did not show any statistically significant main effect of Block, $F(1, 19) = 3.190$, $p = .090$, $\eta_p^2 = .144$, or Trial type, $F(2, 38) = 2.734$, $p = .101$, $\eta_p^2 = .126$, or a Block × Trial Type interaction, $F(2, 38) = 0.449$, $p = .641$, $\eta_p^2 = .023$.

LPP

As illustrated in Figure 5, emotional stimuli elicited a larger positivity compared with neutral distractors over parieto-occipital sensor sites[1] in the 450- to 900-msec time interval, and this cortical emotional modulation was evident in both frequency blocks. The ANOVA revealed that the LPP was significantly modulated by Trial type, $F(2, 38) = 43.438$, $p < .001$, $\eta_p^2 = .696$, with a more positive LPP elicited by distractor-present trials compared with distractor-absent trials, $F_s(1, 19) > 4.451$, $p_s = .048$, $\eta_{ps}^2 > .190$, and by emotional compared with neutral distractors, $F(1, 19) = 60.910$, $p < .001$, $\eta_p^2 = .762$. No effect of Block, $F(1, 19) = 0.013$, $p = .911$, $\eta_p^2 = .001$, or Block × Trial Type interaction, $F(2, 38) = 2.207$, $p = .124$, $\eta_p^2 = .104$, was observed. More importantly, the Block × Emotionality analysis did not reach the significance level, $F(1, 19) = 3.413$, $p = .080$, $\eta_p^2 = .152$, and this null effect was supported by a significant one-sided equivalence test, $t(1, 19) = 4.799$, $p < .001$, observed $d_z = -0.413$, SESOI $= -0.660$), indicating that the magnitude of the affective modulation of the LPP was not reduced in the high-frequency block compared with

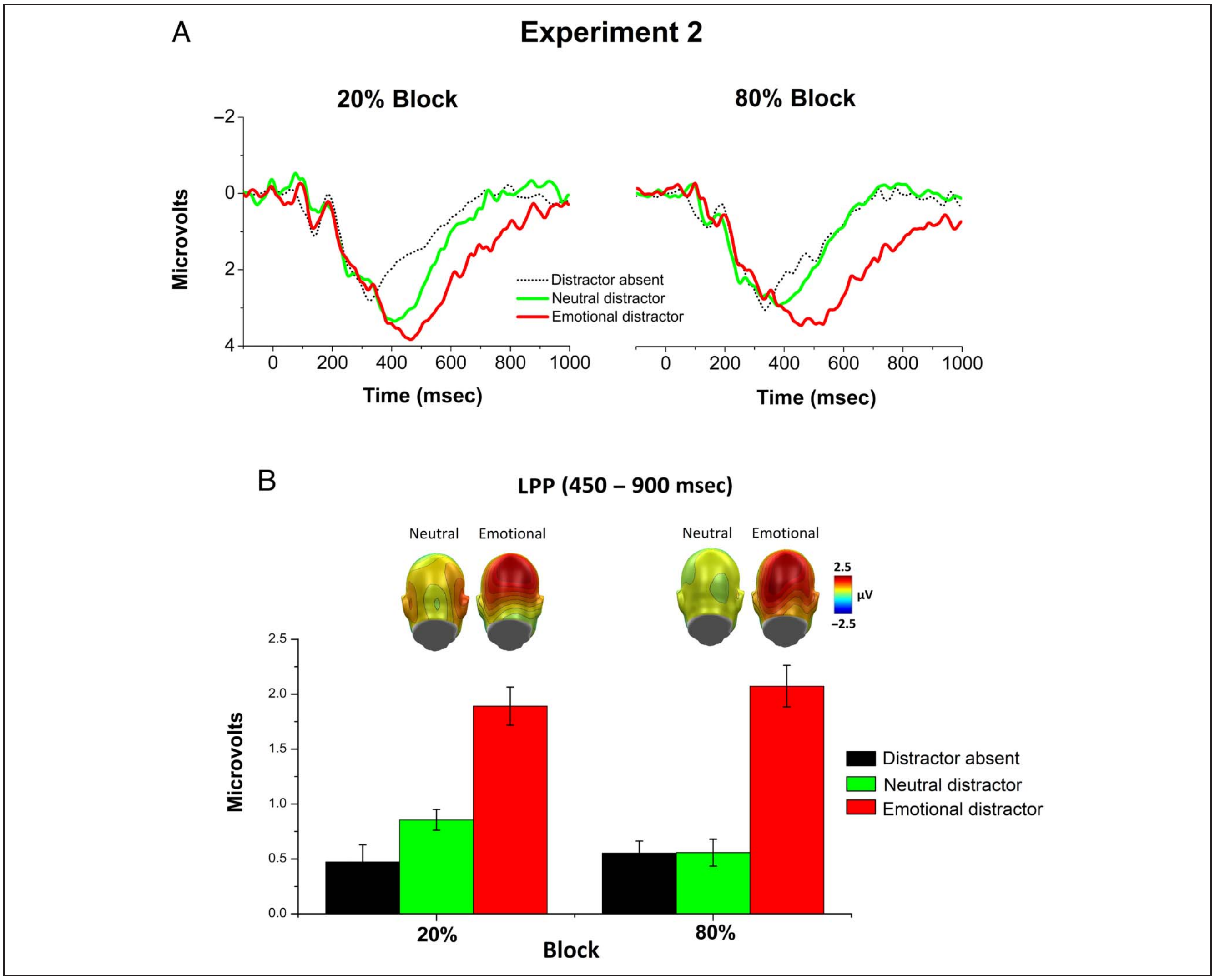

Figure 5. The effects of Block on the LPP amplitude. (A) Grand-averaged ERP waveforms for neutral and emotional pictures, separately in the 20% block and in the 80% block, are represented. (B) The bar graph shows the LPP amplitude and the within-participant *SEM* for distractor-absent, neutral distractor, and emotional distractor trials as a function of block. Analyses of the LPP are reported from the same sensor group that is shown in Figure 3. Insets are the back view of scalp topography (450–900 msec) of the electrocortical activity during neutral (left) and emotional picture (right) processing in the 20% and 80% blocks, respectively.

the low-frequency block. As for behavioral results, the interaction of Order × Block × Emotionality was not significant, $F(1, 18) = 1.596$, $p = .223$, $\eta_p^2 = .081$, indicating that the order of presentation of the two blocks did not affect emotional modulation.

Explicit Comparison of the Modulation of Emotional Interference between Experiment 1 and Experiment 2

To assess whether the impact of distractor frequency (low and high frequency) on emotional interference differed between the two experiments, we performed a direct comparison between them. An ANOVA with Block and Emotionality as within-participant factors and Experiment as a between-participant factor did not find a significant interaction for RTs, $F(1, 42) = 0.006$, $p = .936$, suggesting that the extent to which the high-frequency block affected emotional interference was similar between the two experiments (modulation of emotional interference [20% block minus 80% block]: Experiment 1, $M = 23.57$ msec; Experiment 2, $M = 24.65$ msec).

In summary, behavioral interference prompted by emotional stimuli in the discrimination task declined in the high-frequency block, although emotional stimuli were equally rare in the two blocks. Moreover, this effect was similar in the two experiments, suggesting that the frequency effect did not depend on the degree of exposure to emotional distractors per se but rather to the mere high occurrence of distractors, independently of their content (overall frequency of distractor occurrence). Unlike behavioral interference, emotional modulation of the LPP was not attenuated by a frequent distractor context, and this was evident in both experiments.

GENERAL DISCUSSION

The goal of our study was to assess whether and how distractor frequency affects the processing of novel emotional distractors. Experiment 1 showed that interference of emotional distractors declined when these stimuli were frequently presented. Interestingly, we found a similar reduction in emotional interference when rare, and unexpected, emotional stimuli appeared among frequent neutral distractors (Experiment 2), indicating that the high occurrence of task-irrelevant stimuli can bias the attentional allocation system by reducing the impact of emotional distractors. Did distractor frequency prevent any processing of distractors, or did it simply reduce further attention allocation? In other words, at which stage of stimulus processing were emotional distractors filtered out? We analyzed the LPP to examine more thoroughly the extent to which such suppression occurred. Although distractor frequency similarly reduced attentional capture by emotional distractors in both studies, the frequency effect on the affective modulation of the LPP, a cortical marker of emotional processing, was not reduced in either study, suggesting that emotional stimuli continued to engage the motivational system even when the emotional interference on the primary task was suppressed.[3] In addition, these LPP findings help to rule out the hypothesis that the reduction of emotional interference in the high-frequency block could be mediated by a spatially specific inhibition of any sensory stimulus appearing in the distractor locations. Because the affective modulation of the LPP amplitude was observed for emotional, compared with neutral, distractors in both the high-frequency block and the low-frequency block, it is clear that these spatial positions were not filtered out. Altogether, these data suggest that the engagement of corticolimbic motivational systems is mandatory even when further allocation of attention to emotional stimuli is attenuated by distractor frequency.

Recently, two studies have examined the effect of distractor frequency on emotional interference, albeit with mixed results. In a study by Grimshaw, Kranz, Carmel, Moody, and Devue (2018), participants were engaged in a primary task while distracting images appeared simultaneously in task-irrelevant spatial positions. The valence of distractors was blocked so that participants were exposed to either emotional or neutral distractors in each given context; distractor frequency was varied in a between-participant design, with half of the participants exposed to distractors in infrequent trials (25%) and half exposed to distractors in frequent trials (75%). Findings indicated that the interference effect of emotional stimuli was present when distractors were rarely presented but disappeared when those distractors were frequent. Different results were observed using a variant of the attentional blink paradigm in which emotional images interrupt processing of a subsequent target image—an effect called "emotion-induced blindness" (Most, 2014). Zhao and Most (2019) found that, in a block where the target was preceded by an emotional distractor in most trials, and only rarely by neutral distractors, participants were as inaccurate as in a block in which emotional distractors were rare and neutral distractors appeared frequently. Thus, these results showed no effect of relative emotional distractor frequency in modulating emotional interference, when absolute distractor frequency was kept constant. One hypothesis put forward by the authors, also based on different results (Kennedy, Newman, & Most, 2018), takes into consideration the predictability of the valence of the occurring distractors when distractor content is manipulated within blocks, compared with across blocks. In Zhao and Most's (2019) study, emotional and neutral distractors were intermixed within the same block, making it impossible for the observers to predict the emotionality of the forthcoming distractor and therefore to shield themselves against emotional interference. According to this interpretation, when distractor content is manipulated across blocks, it should, however, be possible to reduce emotional interference, as the content of a distractor is constant and predictable within each block. Consistently, Grimshaw and collaborators (2018) found a reduction in the emotional interference in the high-frequency condition, within a paradigm in which each block contained only a certain type of distractor (pleasant, unpleasant, or neutral), and participants were also informed as to the frequency with which distractors would appear at the beginning of the experimental blocks.

Our findings, however, indicate that distractor frequency affects emotional interference even when the emotionality of the occurring distractor is unpredictable. Therefore, one possibility is that emotion-induced blindness, which relies more on temporal attention than on spatial attention as in the present paradigm, is less modulated by contextual factors, such as distractor frequency. We should also consider, however, that in Zhao and Most's (2019) study, the overall distractor frequency was kept constant across conditions and what varied was the relative frequency of emotional compared with neutral distractors. In this regard, the findings of Experiment 2, in which a clear frequency effect was observed despite the specific frequency of emotional distractors was kept constant across the low- and high-frequency blocks, suggest that a critical factor that may prompt efficient filtering is the overall frequency of distractors, rather than the specific frequency of emotional stimuli.

It has been proposed that frequent exposure to emotional stimuli can desensitize people to them, leading to reduced distraction (e.g., Staude-Müller, Bliesener, & Luthman, 2008), and Experiment 1 demonstrated a reduction in emotional interference when emotional distractors were frequently presented, compared with a rare distractor condition (see also Grimshaw et al., 2018). Therefore, a possible critical factor in determining this reduction could be the fact that the higher frequency of emotional distractors might prompt faster learning (generalization of habituation) of these stimuli (novel but with similar content) within a block compared with the low-frequency condition. To clarify these issues, in Experiment 2, we kept constant the number and time interval of emotional distractors between the blocks, and we manipulated the overall distractor frequency by adding neutral distractors. We found a similar reduction in the emotional interference even when rare, and unexpected, emotional stimuli appeared among frequent neutral distractors, indicating that this effect does not depend on the number of emotional pictures presented over time or on the time interval between emotional distractors.

Frequent exposure to emotional stimuli might trigger a proactive control mechanism, which facilitates the maintenance of goal-relevant information to reduce distractor interference (e.g., Grimshaw et al., 2018; Braver, 2012). In addition, it has been suggested that frequent exposure to distractors incentivizes observers to acquire a top–down suppression strategy, and such a strategy could remain available over time (Müller et al., 2009). In a previous study, Müller et al. (2009) found a carry-over effect of distractor frequency, as participants were less affected by rare distractors when a frequent distractor block was presented beforehand (run-down condition), compared with when participants were exposed first to a low-frequency block (run-up condition). In our study, one group of participants was exposed to the low-frequency block after several trials without distractors (100 trials), whereas another group was exposed to the same low-frequency block after a consistent experience with distractors during the same task (300 trials). Unexpectedly, results indicate that both groups show the same emotional interference in the low-frequency block, regardless of the experience gained beforehand. These findings suggest that the putative suppression mechanism was rapidly disengaged as soon as distractors became rare, with it being immediately engaged in the highly distracting context. Consistent with this interpretation, we also examined the emotional interference effect across trials in the high-frequency block; the reduction of the emotional interference did not emerge gradually but was already present in the first few trials ($n = 25$),[4] indicating that the reduction was not a result of learning that occurs over many trials but, more likely, that a change in the context (low to high frequency) immediately prompted a change in emotional interference. Therefore, the reduction in emotional interference by distractor frequency seems less consistent with a learned strategic process; conversely, one possibility is that, when several distractors occur in a short temporal window (also neutral distractors; see Experiment 2), this activates a filtering mechanism that prevents the attentional system from allocating resources to upcoming emotional distractors for several seconds. On the other hand, this filtering mechanism did not completely prevent the detection of distractor pictures, which were semantically processed, as reflected in the emotional modulation of the LPP, but only reduced the amount of attention allocated to them.

It seems reasonable to predict that proactive control can lead to reduced distraction by emotional stimuli, and to explore this possibility, previous studies directly manipulated strategic control by forewarning participants with explicit information as to the specific emotional content of the upcoming distractors. Did they observe similar findings as in this study? Augst, Kleinsorge, and Kunde (2014), who also used a spatial attention task, showed that announcing the emotional content of an upcoming distractor did not decrease emotional interference of such a distractor (Experiment 3). Similar findings were observed in a recent study by Dieterich, Endrass, Kathmann, and Weinberg (2019) that examined behavioral interference and the LPP for aversive and neutral distractors when participants were informed of their specific content (predictable condition) or were not informed (unpredictable). RTs to the target that immediately followed the distractor were generally longer in the unpredictable trials, but emotional interference (aversive minus neutral distractors) was not affected by distractor predictability. A similar pattern was found for the LPP, which was enhanced for unpredictable trials, and for emotional distractors, but again, the affective modulation of the LPP was not affected. Taken together, the findings from previous studies indicate that providing participants with explicit information about the specific emotional content of the distractors does not reduce emotional interference, whereas the high frequency of distractors in the present studies prompted a consistent attenuation. A possible explanation may rely on the fact that these previous studies compared two conditions in which distractors were always expected (Dieterich et al., 2019; Augst et al., 2014), and only the content could be uncertain, whereas in these studies, we compared a condition where distractors were rare and unexpected with a condition where they were frequently presented. Therefore, distractor frequency and explicit cueing (announcing the emotional content of an upcoming distractor) seem to engage different top–down mechanisms.

A dissociation between the affective modulation of the LPP and emotional interference has been recently described in a habituation study, in which distractors were repeated (Codispoti et al., 2016): Emotional interference waned after only a few presentations of the same distractor, whereas the LPP amplitude was still enhanced for emotional, compared with neutral, distractors despite picture repetition. Stimulus repetition determines habituation of the orienting response because, after several repetitions, no further information (i.e., increased stimulus intake) is necessary, and therefore allocation of attention to emotional stimuli is reduced when stimuli are not novel anymore. On the other hand, the engagement of the motivational systems was still evident in the LPP affective modulation for stimuli that were highly familiar (Codispoti et al., 2016). However, in this study, different picture exemplars were presented, making it unlikely that the reduction of emotional interference reflects some sort of habituation related to there being no further need for "information gathering" (Näätänen, 1992).

Differently, a reduction of attentional capture by emotional stimuli in a high-frequency distractor context could be because of a different mechanism that is possibly related to a transient inhibition of orienting to emotional events when distractors have recently been presented and, thus, when their novelty is lessened. Future research is needed to further examine the influence of novelty and distractor frequency on the processing of emotional stimuli.

Previous studies examined the filtering of simple and highly familiar (repeated) distractors (e.g., geometric shapes); however, in real life, we are mostly surrounded by visual and acoustic stimuli that are highly heterogeneous in appearance as well as in emotional relevance. Therefore, we examined here the filtering of novel emotional scenes. Future studies should examine interference effects prompted by dynamic emotional stimuli, such as short video clips (Huff, Papenmeier, & Zachs, 2012), or sound distractors (Max, Widmann, Kotz, Schröger, & Wetzel, 2015) compared with static natural scenes. Moreover, because emotional distraction has been implicated in several disorders, including anxiety (Moran, 2016; Eysenck, Derakhshan, Santos, & Calvo, 2007), future studies should seek to elucidate the contribution of top–down control mechanisms and contextual factors in clinical populations.

A long-standing debate in the field of emotion and cognition is whether emotional cues engage corticolimbic systems and capture attention in a mandatory fashion or whether contextual factors can modulate the impact and processing of these stimuli (Pessoa, 2017; Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, Armony, & Dolan, 2004; Öhman & Wiens, 2003). In two experiments, we showed that the impact of emotional stimuli can be modulated by contextual factors; therefore, emotional interference can be reduced not only through stimulus repetition but also by increasing the frequency of occurrence of all novel distractors, which are never repeated throughout the experiment and are not necessarily emotionally relevant. Although the exposure to task-irrelevant stimuli plays a critical role in modulating further attention allocation to novel emotional distractors, evaluative processes and the engagement of motivational systems might occur in a mandatory fashion. After all, from an evolutionary perspective, it is not advantageous to fully inhibit the processing of task-irrelevant stimuli (i.e., distractors), because this could prevent the detection of a potential threat or reward. Instead, a system that evaluates emotional salience of the distractors provides an adaptive advantage, as we are always performing "a task of paramount importance, namely, monitoring the environment for significant events" (Donchin, Ritter, & McCallum, 1978, p. 384).

Reprint requests should be sent to Maurizio Codispoti, Department of Psychology, Alma Mater Studiorum – University of Bologna, Viale Berti Pichat 5, 40127 Bologna, Italy, or via e-mail: maurizio.codispoti@unibo.it

Notes

1. A prior analysis investigating the effect of Block (20%, 80%) on Emotionality (neutral, emotional) as a function of the distractor location (left, right) and hemisphere (left sensors, right sensors) failed to show a significant interaction in either Experiment 1, $F(1, 22) = 1.929$, $p = .179$, $\eta_p^2 = .081$, or Experiment 2, $F(1, 19) = 2.566$, $p = .126$, $\eta_p^2 = .119$. Therefore, for all following analyses, left and right sensors were averaged together in a single sensor group.
2. Differently from Experiment 1, neutral categories in the 80% block of Experiment 2 included not only images with people but also images depicting inanimate scenes and objects. To examine whether images with people could be more engaging than objects, we performed an explicit comparison between the two neutral categories, and we found no statistical difference between them either in terms of LPP ($M = 0.54$ vs. 0.58 μV), $F(1, 19) = 0.242$, $p = .628$, $\eta_p^2 = .013$, or in terms of RTs ($M = 544.05$ vs. 548.83 msec), $F(1, 19) = 1.736$, $p = .203$, $\eta_p^2 = .084$. Therefore, we collapse them into a single "neutral" category for statistical analyses.
3. A post hoc sensitivity analysis conducted on G*Power (Faul et al., 2007) indicated that our sample sizes were sufficient to detect a medium effect size of distractor frequency on the affective modulation of the LPP (Cohen $d_z = 0.611$ in Experiment 1; Cohen $d_z = 0.660$ in Experiment 2), with an error probability of .05 and 80% power, but not a small effect size (Cohen $d_z = 0.2$). Therefore, future studies with a large sample size are necessary to rule out this possibility.
4. In Experiment 1, we examined whether emotional interference in the 80% block was gradually reduced over 12 mini-blocks of 25 trials each (10 neutral distractors and 10 emotional distractors). However, the interaction Mini-Block × Distractor Emotionality was not significant, $F(11, 253) = 1.570$, $p = .108$, $\eta_p^2 = .064$.

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