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Motivated attention to fear-related stimuli: Evidence for the enhanced processing of fear in the late positive potential

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Abstract

Differences in the processing of emotions like fear and sadness have important implications for our understanding of many psychological phenomena (e.g., attentional biases, psychopathology). The late positive potential (LPP) is an established event-related potential that reflects motivated attention to emotional stimuli at the neural level with excellent temporal resolution, but has been infrequently used to study differences across emotions. Drawing on functional theories of emotion suggesting that the quick processing of fear-inducing stimuli increases chances of survival, we hypothesized that fear-inducing pictures would produce larger LPP amplitudes compared to other emotions (happy and sad) in the early time windows of the LPP (e.g., 400–700, 700–1000 ms). The results supported our hypothesis, offering new, albeit preliminary, evidence of the differential processing of threat-related stimuli on the LPP.

Keywords Motivated attention · Fear · Late positive potential · ERP

Introduction

Neural systems have evolved to support the rapid processing of emotional information (Friedman and Förster 2010; Lang et al. 1997; Öhman et al. 2000; Schupp et al. 2012) by motivating attention to information that functionally increases the chances of survival (Bradley et al. 2003; Eimer et al. 2003; Lang et al. 1997). Specific kinds of emotional information should theoretically differ in the speed with which they are processed based on their motivational significance. For example, fear should be preferentially processed because it offers relevant information about the environment for survival (Eimer et al. 2003). The experience of fear prompts hypervigilance to the environment and active defensive reactions aimed at mobilizing resources to increase the chances of survival (de Jongh et al. 2003; Muris 2010; Plutchik 2003). Faster processing of fear or threat-relevant stimuli has been shown in behavioral studies with adults (Öhman et al. 2001) and children (LoBue and DeLoache 2008), supporting the idea that processing of fear may be evolutionarily prioritized.

Prior work on the preferential processing of threat-related stimuli has largely focused on people with specific phobias, as phobic individuals are thought to have a dysregulated attentional hypervigilance to threat (e.g., Michalowski et al. 2015). Preferential processing of threat-relevant stimuli in phobic individuals is often found at both the behavioral and neural levels, with increased attention allocation and evaluative processing reflected in more pronounced neural reactions to these stimuli (e.g., larger P1, EPN, and LPP event-related components; Mitlner et al. 2005; Michalowski et al. 2009, 2015). Even in these studies, however, non-phobic control participants still preferentially process fear-relevant stimuli. These results suggest that hypervigilance to threat is not exclusive to phobias, but rather reflects a dysregulated pattern of processing that over taxes resources by allocating too much effort to the processing of threat. A deeper understanding of how fear is preferentially attended to, and thus processed and appraised, could help elucidate when adaptive patterns of emotional responding become dysregulated and maladaptive.

The late positive potential (LPP) is an event-related potential (ERP) commonly used in emotion research

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because it reflects motivated attention to emotional stimuli. The LPP develops 300–400 ms after an affective stimulus is presented and is maintained throughout stimulus exposure (Moran et al. 2013). Despite its high temporal resolution, the LPP has been used infrequently to study the processing of specific emotions such as fear. LPP studies have focused on broad affective comparisons, such as neutral versus emotionally-charged or pleasant versus unpleasant (Hajcak and MacNamara 2010; Hajcak et al. 2012). These studies have reliably shown differences between neutral and emotional stimuli from as early as 250 ms after stimulus onset and maintained for the entire presentation time (Hajcak and MacNamara 2010; Hajcak et al. 2012; Thiruchselvam et al. 2011). However, LPP studies have largely ignored the distinct consequences that discrete emotions carry for adaptive responding (e.g., behavior, physiology, cognition; Kreibig 2010; Lerner and Keltner 2001; Roseman 1996). Combining discrete emotion stimuli within these categories (e.g., "unpleasant" includes sadness *and* fear) obscures the differences among discrete emotions that would be predicted by functionalist perspectives. Furthermore, breaking the LPP down into smaller windows (e.g., 300 ms segments) allows for more precise assessment of these theoretically-grounded differences (Langeslag and Van Strien 2010; Thiruchselvam et al. 2011).

One study of differences across multiple positively and negatively valenced emotions examined processing of sad, happy, disgusting, and neutral stimuli across several ERP segments, including the LPP (Hot and Sequeira 2013). They found differences in early ERPs (< 200 ms post-stimulus), but not in later time windows (e.g., the LPP). One reason why prior studies have not investigated processing of specific emotions with the LPP may be a reliance on stimuli sets that inadvertently constrain the type of questions that can be answered. For example, the lack of differences in the LPP time window from the Hot and Sequeira (2013) study may be attributable to the specific emotions examined—fear was omitted because the IAPS (Lang et al. 2008) does not include enough pictures that reliably induce this emotion.

The present study examined differences in affectively-motivated attention as measured by the LPP for fear stimuli compared to sad and happy stimuli. Based on functionalist views of emotion that posit the motivational significance of fear, we predicted that fear would produce larger LPP amplitudes compared to happy and sad in the early time windows of the LPP (i.e., the first 1000 ms after picture onset), but that there would be no differences after 1000 ms since fear is initially preferentially processed, but all emotions should eventually motivate attention. To ensure an adequate number of stimuli to elicit these emotions (fear, sadness, happiness), we combined IAPS pictures with pictures drawn from a newer set (NAPS; Marchewka et al. 2014).

Method

Participants

A total of 46 undergraduate students were recruited from the psychology subject pool. Data collection proceeded until there were at least 20 participants in each of two experimental conditions that were part of a larger study (not described in this report). Study procedures were identical for all participants, and the experimental manipulation for the larger study occurred after the procedures that are described in this report. Data were excluded due to technical errors (N = 1), discontinued participation (reported being too tired to do the passive-viewing task, N = 1), and excessive artifacts from eye movements or noisy electrodes (N = 4). The final sample consisted of 40 participants (age: $M = 19.20$, $SD = 1.22$, range: 18–24 years, 26 women and 14 men), an appropriate sample size to detect even small within-subject effects (around $\eta^2 = 0.04$; and larger than samples used in previous studies; e.g., Hajcak et al. 2007; Hajcak and Olvet 2008; Thiruchselvam et al. 2011). From this final sample, two reported being left handed, and all reported normal or corrected-to-normal vision. Participants received course credit for participation.

Stimuli

Seventy-two images were selected from the International Affective Picture System (31 from IAPS; Lang et al. 2008) and the Nencki Affective Picture System (41 from NAPS; Marchewka et al. 2014; see supplemental material 1) to create four discrete emotion categories of stimuli (fear, sadness, happiness, and neutral) with 18 images in each category. Pictures included animals, household objects, people, and natural scenes. All three emotion categories (sadness, fear, happiness) included some combination of animals, people, and natural scenes, which allowed for blocks of emotional images to be generally matched in terms of picture complexity. The neutral photos mainly included household objects. The NAPS picture set is a newer standardized affective stimulus dataset, similar to the well-known IAPS picture set. NAPS represents an improvement over IAPS because of the higher picture quality of the stimuli. Despite this enhancement, the number of pictures that reliably elicit any discrete emotion (such as fear) is limited. By selecting pictures from both IAPS and NAPS stimulus sets, we increased the number of discrete emotion trials that could be included in each block without having to repeat pictures. Initially, 120 images were selected and rated by undergraduate research assistants using a 1–9 scale (1 = not at all; 9 = extremely) for six different common emotions (sadness, fear, anger, happiness, disgust and surprise). The pictures that were rated as belonging to one emotion only were then selected for the study. The final set of 72 pictures was rated by a separate group of 10 undergraduate students (see supplemental material 2 for the descriptives for the picture set). All 72 images (including neutral images) were rated using a 1–9 scale for the four different emotions used for the ratings for the study (sadness, fear, anger, and happiness). Using a 1–9 scale, the participants for this study reported feeling sad after the sad pictures ($M = 3.93$; $SD = 1.56$; range = 1–7), feeling scared after the scary pictures ($M = 2.25$; $SD = 1.37$; range = 1–6), and happy after the happy pictures ($M = 4.50$; $SD = 1.65$; range = 1–9).

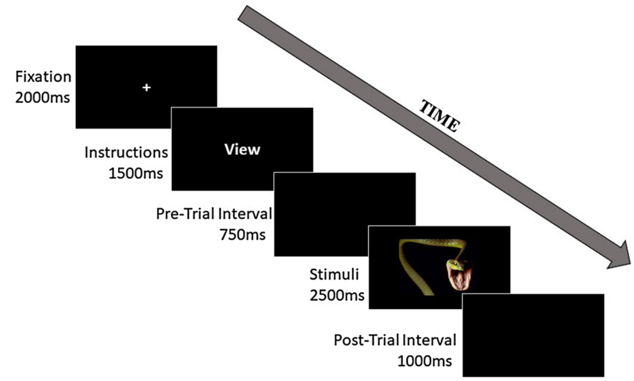

Fig. 1 Trial structure for the task (all pictures within a block belonged to the same emotion)

Design and procedure

All participants completed a single 2-h session. After providing consent to participate and completing a computerized cognitive task not considered here (everyone did the same task), they were capped using the Brain Products ActiCHamp active electrode system (see EEG recording section) in preparation for the passive picture viewing task. Participants were instructed to pay close attention to the screen and to do what they would normally do when looking at pictures, while trying to focus on the center of the screen.

Passive picture-viewing task

The passive picture-viewing task was modeled after similar tasks designed to assess the LPP (Hajcak et al. 2007; Hajcak and Olvet 2008; Thiruchselvam et al. 2011) and was presented using E-Prime 2 (Psychology Software Tools 2012) using 75% of the screen (to reduce eye movements likely to happen from full-screen presentation and to ensure all pictures occupied the same amount of screen space; Fig. 1). Each of the 72 trials started with a white fixation point in the center of a black screen for 2000 ms, followed by an instruction cue to "view" the picture that appeared for 1500 ms. Following the instruction cue, a black screen was presented for 750 ms during the pre-trial interval. Each image appeared on the screen after pre-trial interval offset and remained on screen for 2500 ms. After each picture, there was another black screen presented during a 1000 ms post-trial interval. Participants were monitored through a camera located beneath the monitor to ensure they were paying attention to the screen during the entire experimental session, as well as to contingently remind the participants to minimize blinks, eye movements, and body movements. Blocks for each discrete emotion picture type were created (neutral, happiness, fear, and sadness) for a total of 18 trials for each block (one trial per image). The neutral block was always presented first to avoid any affective carryover from the emotional blocks, and to enable an assessment of participants' engagement with the task before emotional pictures were presented. The presentation order of the three subsequent emotional blocks was randomized across participants to minimize order effects. The picture order within each block was also randomized.

Emotion self-report

After the end of each block, participants indicated the intensity with which they felt each discrete emotion (sadness, fear, anger, and happiness) using a 1–9 scale described below. At the beginning of the study, participants were trained to self-report their emotions in terms of both general emotional valence and (separately) discrete emotion intensity. For self-reported valence, participants were told, "Before we start, we want to know how you are feeling right now. We will ask you a series of questions to assess how you are feeling at the moment. Please respond as accurately as possible to each of the questions." Participants indicated their current valence of emotional state using a 3-point scale (1 = negative; 2 = neutral; 3 = positive). For the self-reports of discrete emotion intensity, participants were told, "For the next series of questions, we will ask you about specific emotions. Using a 1–9 scale, please indicate how strongly you feel that emotion. For example, a one would indicate not feeling the emotion at all, a five would indicate feeling the emotion, and a 9 would indicate extremely feeling the emotion." Participants self-reported their emotions (valence and discrete emotional intensity ratings) four times during the picture viewing task (at the end of each block). Self-reports are often used in LPP research to ensure the stimuli evoke an emotional response (Shafir et al. 2015; Thiruchselvam et al. 2011).

EEG recording, data reduction, and analysis

EEG data were acquired continuously during the study using a 10–20 system with 32 scalp electrodes (Brain Products, Gilching, Germany). The EEG was sampled at 500 Hz. Offline processing of the data was carried out using Brain Vision Analyzer 2. The left earlobe was used as the reference during recording. For analyses, all data were re-referenced to the average of both earlobes and band-pass filtered using 0.1 Hz (high pass) and 30 Hz (low pass) cutoffs with a 60 Hz notch filter. Eye movements and blinks were corrected using the Gratton et al. (1983) method, commonly used in LPP research (Hajcak et al. 2013; Thiruchselvam et al. 2011). Event-locked EEG epochs were extracted starting at 500 ms pre-stimulus onset (standard 20% of the trial duration) and continuing for the entire duration of the trial (2500 ms). Segments were baseline corrected using the first 500 ms pre-stimulus. Artifact rejection was performed semi-automatically using the following criteria: a voltage step of more than 50 µV between sample points, a voltage difference within a trial greater than 300 µV, a maximal voltage difference smaller than 0.50 µV within a 100 ms interval, and an amplitude ± 100 µV within a 100 ms interval (Hajcak et al. 2013; Weinberg and Hajcak 2011). Trials with excessive physiological artifacts (e.g., eye blinks, movement) were rejected before averaging the segments. All participants whose data were retained for analyses had more than 50% of trials available. Participants were required to have a minimum of nine trials for each block to be included in analyses. ERPs were averaged from the resulting trials for each emotion type. The LPP was defined a priori as the average activity of the CP1, CP2, Pz, and Cz electrodes. These are commonly averaged electrodes in LPP research, and an a priori selection of electrodes reduced the chances of obtaining spurious results from making multiple comparisons during the 400–2500 ms time window following picture onset (Brown et al. 2012; Hajcak et al. 2013; MacNamara et al. 2011; Thiruchselvam et al. 2011). We subdivided the first 400–1300 ms window after picture onset into 300 ms segments to capture three different windows of early emotional processing: 400–700, 700–1000, and 1000–1300 ms, following similar approaches (Langeslag and Van Strien 2010; Thiruchselvam et al. 2011). We chose the first 1300 ms of stimulus exposure because several studies have noted this time frame reflects the early stages of the LPP (Thiruchselvam et al. 2011). But, because we wanted to clearly quantify the early LPP, we divided the early stage of the LPP into smaller (300 ms) windows.

Results

Analyses were conducted in SPSS (Version 24), with Greenhouse-Geisser corrections applied to *p*-values associated with multiple comparisons. Planned comparisons probed hypothesized effects, and *p*-values for these follow-up tests were Bonferroni-corrected.

The late positive potential (LPP)

We conducted a single repeated measures ANOVA, which we probed in several ways to test hypotheses. Values for the first three segments of the LPP (400–700, 700–1000, and 1000–1300 ms) across the four blocks (neutral, happy, sad, fear) were included in this model. The main effect of picture type (sadness, fear, happiness, neutral) was significant, $F(3,117) = 24.14$, $p < .001$, $\eta^2 = 0.38$ as was the main effect of segment, $F(2,78) = 9.71$, $p = .002$, $\eta^2 = 0.20$. These main effects were qualified by the significant interaction of picture type by segment, $F(6,180) = 4.282$, $p = .001$, $\eta^2 = 0.10$.

LPP to emotional versus neutral stimuli

We expected the LPP to be larger in all three discrete emotion blocks compared to the neutral block, which was the pattern suggested by the main effect of picture type (see Fig. 2). We conducted pairwise comparisons of LPP amplitude with Bonferroni correction (corrected $\alpha = 0.050/9 = 0.006$; Table 1) between emotional and neutral blocks within each time window. LPP amplitudes were smaller in the 400–700 ms window for neutral compared to sad, $t(39) = -5.58$, $p < .001$, $d = -0.90$, neutral compared to fear, $t(39) = -7.40$, $p < .001$, $d = -1.17$, and neutral compared to happy, $t(39) = -5.03$, $p < .001$, $d = -0.80$. The same was true in the 700–1000 ms window, with smaller LPP amplitudes for neutral compared to sad, $t(39) = -5.71$, $p < .001$, $d = -0.91$, neutral compared to fear $t(39) = -6.55$, $p < .001$, $d = -1.04$, and neutral compared to happy, $t(39) = -5.24$, $p < .001$, $d = -0.83$. We found the same pattern in the 1000–1300 ms window for sad pictures, $t(39) = -4.92$, $p < .001$, $d = -0.80$, fear pictures, $t(39) = -5.37$, $p < .001$, $d = -0.86$, and happy pictures, $t(39) = -4.83$, $p < .001$, $d = -0.76$. Thus, our new picture stimuli set effectively elicited a stronger LPP to emotional versus neutral images, replicating past research with the LPP.

LPP to discrete emotions in the early 400–700 ms window

Our subsequent analyses examined LPP amplitude differences between the three discrete emotions in each time window to test hypotheses about emotion-motivated attentional differences among fear, sadness, and happy pictures (Figs. 2b, 3). Planned comparisons (Bonferroni corrected $\alpha = 0.050/2 = 0.025$) showed that, as expected, in the earliest segment of emotional processing, LPP amplitudes for fear pictures were larger than LPP amplitudes for sad pictures, $t(39) = 2.99$, $p = .005$, $d = 0.48$, or happy pictures $t(39) = 5.43$, $p < .001$, $d = 0.86$. Thus, in the early phase of

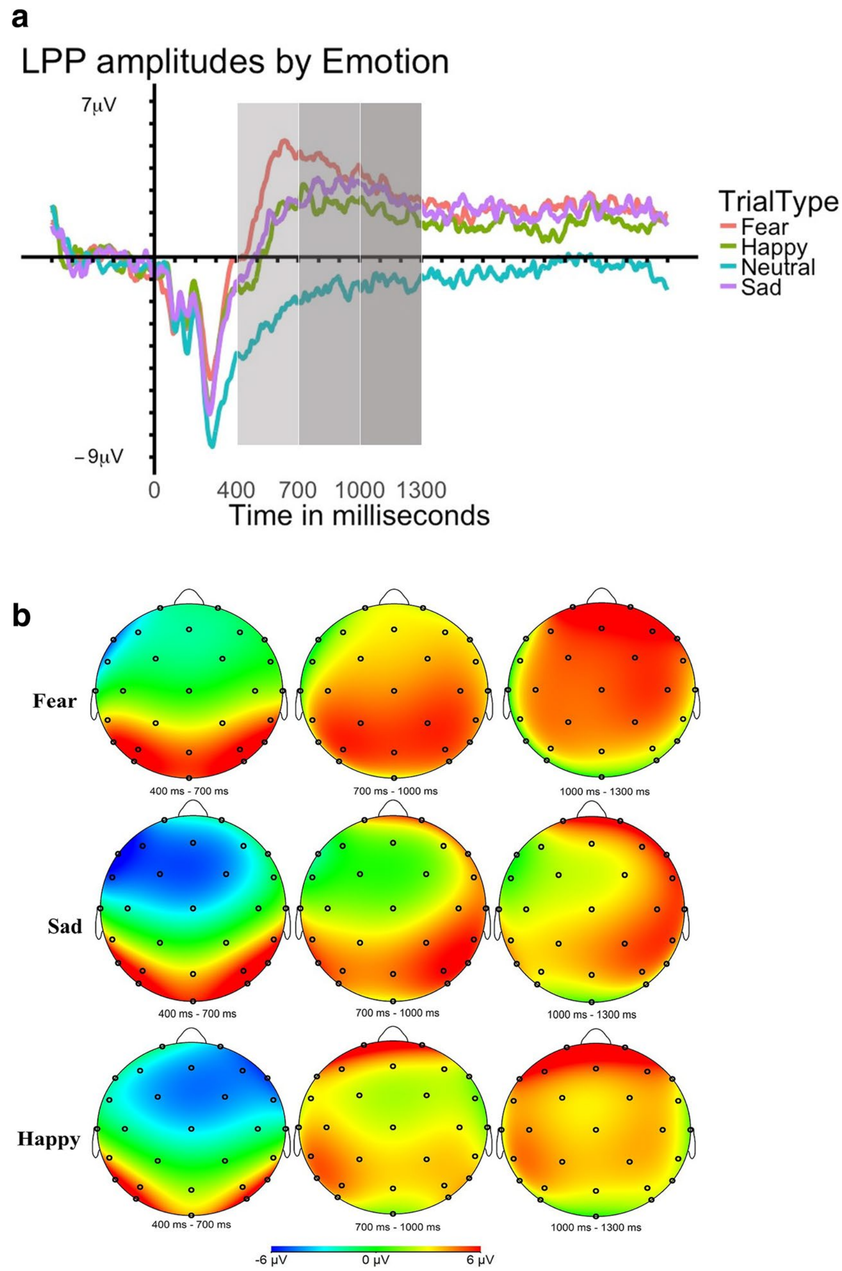

Fig. 2 **a** LPP amplitudes for the discrete emotions across the entire presentation time (Average of electrodes Cz, CP1, CP2, and Pz). Gray areas represent segments included in discrete emotion differences (400–1300 ms). **b** Scalp distribution for the LPP amplitudes to fear, sad, and happy stimuli for each segment

the LPP, a predicted processing advantage was found for fear-eliciting stimuli, relative to other discrete emotions (sadness, happiness).

LPP to discrete emotions in the middle 700–1000 ms window

LPP amplitudes for the fear pictures during this segment were larger than amplitudes for happy pictures, $t(39) = 2.64$, $p = .012$, $d = 0.42$, but not different than LPP amplitudes for sad pictures, $t(39) = 1.45$, $p = .154$, $d = 0.23$.

LPP to discrete emotions in the late 1000–1300 ms window

Finally, LPP amplitudes for fear pictures in the latest segment we examined were not different from LPP amplitudes for sad pictures, $t(39) = 0.378$, $p = .707$, $d = 0.06$, or happy pictures, $t(39) = 1.65$, $p = .107$, $d = 0.26$. Results suggest that fear pictures did evoke a larger LPP in the earliest window than other discrete emotions, but that this difference in LPP amplitude waned by the latest segment of early emotional processing that we examined (the 1000–1300 ms segment post-stimulus presentation), when all emotional stimuli showed similar LPP amplitudes.

Table 1 Overview of paired t-tests examining the effects of discrete emotion on LPP amplitude

Comparisons	Difference between blocks	*t*	*p*	95% CI	Cohen's *d*
With neutral					
400–700 ms					
Neutral—fear	−6.179	−7.404	<.001	[−7.868, −4.491]	−1.172
Neutral—sad	−4.129	−5.582	<.001	[−5.625, −2.633]	−0.903
Neutral—happy	−3.704	−5.029	<.001	[−5.193, −2.214]	−0.796
700–1000 ms					
Neutral—fear	−5.650	−6.552	<.001	[−7.395, −3.906]	−1.039
Neutral—sad	−4.582	−5.552	<.001	[−6.204, −2.960]	−0.910
Neutral—happy	−3.977	−5.242	<.001	[−5.512, −2.443]	−0.829
1000–1300 ms					
Neutral—fear	−4.173	−5.370	<.001	[−5.745, −2.601]	−0.855
Neutral—sad	−3.892	−4.923	<.001	[−5.491, −2.293]	−0.788
Neutral—happy	−3.125	−4.826	<.001	[−4.435, −1.815]	−0.763
Across emotions					
400–700 ms					
Fear—sad	2.051	2.994	.005	[0.665, 3.436]	0.482
Fear—happy	2.476	5.428	<.001	[1.553, 3.398]	0.857
700–1000 ms					
Fear—sad	1.068	1.452	.154	[−0.420, 2.556]	0.230
Fear—happy	1.673	2.635	.012	[0.389, 2.957]	0.419
1000–1300 ms					
Fear—sad	0.281	0.378	.707	[−1.225, 1.787]	0.059
Fear—happy	1.048	1.651	.107	[−0.235, 2.332]	0.264

Neutral = LPP amplitudes during the neutral block

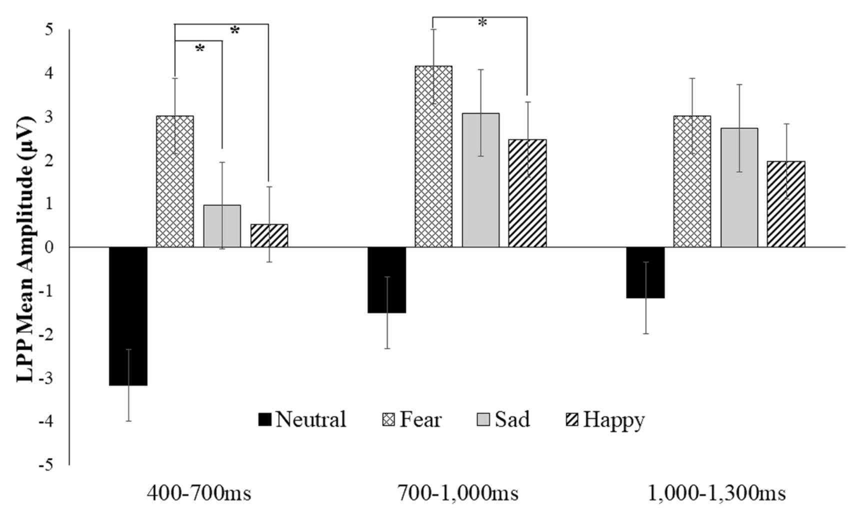

Fig. 3 Two-way interaction of discrete emotion by LPP window for LPP amplitudes during the passive viewing task. *Note*. Error bars are standard errors. Only significant discrete emotion differences are highlighted. $^{*}p < .05$

Emotion self-reports

We conducted a manipulation check with behavioral data to confirm that the picture blocks elicited the intended discrete emotions. A repeated measures ANOVA was used to compare intensity ratings of the emotions felt (sadness, fear, or happiness) after the neutral block, with the target emotion after each emotion block (e.g., sadness after sad block). The main effect of self-reported discrete emotional intensity after picture presentation (e.g., sadness after the neutral block versus sadness after the sad block) was significant, $F(1,42) = 29.43$, $p < .001$, $\eta^2 = 0.41$, suggesting that our stimuli elicited the expected emotional response. The effect of picture type (sadness, fear, and happiness) was also significant, $F(2, 84) = 47.28$, $p < 0.001$, $\eta^2 = 0.53$, suggesting that there were differences in self-reported emotional intensity across the discrete emotion blocks. Lastly, the interaction of self-reported emotional intensity and picture type was significant, $F(2, 84) = 8.96$, $p < 0.001$, $\eta^2 = 0.18$, suggesting that changes in emotional intensity varied depending on the discrete emotion.

Follow-up planned analyses confirmed that each block of emotional stimuli elicited the target discrete emotion more strongly than did the neutral block (Table 2). We again applied a Bonferroni alpha correction when making these comparisons (corrected $\alpha = 0.050/3 = 0.016$). The fear pictures elicited more self-reported fear than did the neutral pictures, $t(43) = -2.19$, $p = .006$, $d = -0.45$; the sad pictures elicited more sadness than the neutral pictures, $t(43) = -6.20$, $p < .001$, $d = -0.95$; and the happy pictures elicited more happiness than the neutral pictures, $t(43) = -2.56$, $p = .014$, $d = -0.40$.

To further unpack the differences across emotions in self-reported emotional intensity, a second set of comparisons was carried out with the discrete emotion blocks. The comparisons (corrected $\alpha = 0.016$) indicated that the sad pictures elicited more intense feelings of self-reported sadness than the fear pictures elicited fear $t(43) = -7.11$, $p < .001$, $d = -1.08$, and that the happy pictures elicited more intense self-reported happiness than the sadness elicited by the sad pictures, $t(43) = -2.54$, $p = .015$, $d = -0.38$, or the fear elicited by the fear pictures, $t(43) = 7.68$, $p < .001$, $d = -1.16$. The results from these comparisons suggest that our happy and sad pictures elicited stronger emotional responses than our fear pictures.

Correlations between emotional intensity self-reports and LPP amplitudes

To assess if our behavioral measures of experienced emotions were associated with LPP amplitudes during viewing of the emotional pictures, we conducted bivariate correlations between our behavioral measure of intensity of each emotion and the LPP amplitudes for each emotional block.

Sadness

Self-report of intensity of sadness to the sad block was not correlated with LPP amplitudes during the 400–700 ms window ($r = .174$, $p = .283$), during the 700–1000 ms window ($r = .191$, $p = .237$), or the 1000–1300 ms window ($r = .150$, $p = .356$).

Happiness

Self-report of intensity of happiness to the happy block was not correlated with LPP amplitudes during the 400–700 ms window ($r = .201$, $p = .214$), during the 700–1000 ms window ($r = .030$, $p = .856$), or the 1000–1300 ms window ($r = .003$, $p = .983$).

Fear

Self-report of fear to the fear block was not correlated with LPP amplitudes during the 400–700 ms window ($r = .268$, $p = .094$), but *was* correlated with LPP amplitudes during the 700–1000 ms window ($r = .423$, $p = .006$) and the 1000–1300 ms window ($r = .382$, $p = .014$).

Discussion

This study offers new, albeit preliminary, evidence of the preferential processing of fear stimuli as measured by the LPP. We took a novel approach to assessing these differences by selecting stimuli from two picture sets, and examined potential differences in emotional processing (as measured by the LPP) among fear, sadness, and happiness (three commonly experienced emotions that have not been studied together). Results supported our hypothesis that fear would

Table 2 Overview of paired *t* tests exploring the effects of discrete emotion on self-report

Comparisons	Difference between trials	*t*	*p*	95% CI	Cohen's *d*
With neutral					
Neutral—fear	− 0.682	− 2.914	0.006	[− 1.154, − 0.210]	− 0.450
Neutral—sad	− 1.814	− 6.202	< 0.001	[− 2.404, − 1.224]	− 0.945
Neutral—happy	− 0.659	− 2.555	0.014	[− 1.179, − 0.139]	− 0.393
Across emotions					
Fear—sad	− 1.591	− 7.113	< 0.001	[− 2.042, − 1.140]	− 1.081
Fear—happy	− 2.295	− 7.677	< 0.001	[− 2.898, − 1.692]	− 1.164
Sad—happy	− 0.705	− 2.544	0.015	[− 1.263, − 0.146]	− 0.382

Neutral = the self report of the target emotion during the neutral block elicit greater LPP amplitudes in the early stages of the LPP, because of its motivational significance. We found a larger LPP to fear versus sad and happy pictures during the earliest 400–700 ms time window, and a difference between fear and happiness in the 700–1000 ms window. All three emotions evoked a similar LPP in the latest stage examined (1000–1300 ms). The pattern suggests that fear had a stronger effect compared to sadness and happiness on motivated attention early in emotional processing. The preferential processing of fear began to decrease after 700 ms and disappeared after 1000 ms, suggesting that although fear initially showed a differential effect, broadly speaking, the discrete emotions used in this study have a similar effect in affectively-motivated attention (measured by the LPP).

Fear has been theorized to elicit faster processing than other emotions, due to its significance in promoting survival (Lang et al. 1997). Most research on later components such as the LPP has not examined discrete emotion differences, although such differences have been shown in earlier ERPs that index other attention processes (Eimer et al. 2003). Thus, our finding that fear elicited a stronger LPP in the earliest measured time window suggests that fear might elicit faster motivated sustained attention and evaluative processing, in addition to the other attentional processes measured by the earlier ERPs usually used for this kind of studies. This aligns with research on people with phobias, in which threat-relevant stimuli are often found to elicit attention and further processing compared to other types of negative stimuli (Michalowski et al. 2009, 2015). Our results extend this knowledge to typical (rather than dysregulated) emotional functioning and complement behavioral evidence of the impact of fear on adaptive responding (Lerner and Keltner 2001; Öhman et al. 2001) by providing new insight into the neural underpinnings of these patterns.

Of course, there is substantial evidence that the LPP is sensitive to affective salience, raising the possibility that differences in arousal would account for our findings. For instance, participants may have found fear pictures to be more arousing than sad or happy pictures. We did not ask participants to self-report arousal for each block of pictures they viewed, but they did report the intensity with which they felt different discrete emotions (a reasonable proxy for arousal ratings). In these self-reports of discrete emotional intensity, happy *and* sad blocks evoked more intense emotions on average than the fear block, so the fearful images were not simply more arousing or affectively salient than those in the other emotion blocks. The range of the intensity reports for happiness and sadness were also larger than for fear (happiness: 1–9; sadness: 1–7; fear: 1–6). And, when we examined the correlations between LPP amplitudes and self-reports of discrete emotion intensity, self-reported intensity of fear was associated with LPP amplitudes only in the 700–1000 ms and the 1000–1300 ms windows. If intensity/arousal of the experienced emotion could fully account for our results, the significant correlation would be present in the earliest time window (400–700 ms) and not the later time windows.

Related, the standardized IAPS and NAPS arousal ratings for each picture included in the blocks of fear and sad pictures were comparable, suggesting that we would have obtained a different pattern of LPP amplitudes (i.e., no difference in amplitude for sadness versus fear) if results were attributable solely to arousal levels. Thus, it is unlikely that our findings are accounted for by differences in arousal across blocks. Because of the novelty of our findings, however, our results should be considered preliminary and should be replicated in future studies, ideally including psychophysiological assessment of arousal.

Our finding that fear differs from sadness and happiness in the early LPP supports Hot and Sequeira's (2013) conceptual argument that different emotions would elicit different temporal patterns of brain activation and that classical approaches that average across emotions obscure these potential differences. Our results contrast with their empirical findings of no differences across emotions (sad, happy, disgusting, and neutral) which suggests that the detection of differences across emotions is likely to depend on the specific emotions that are studied. There is robust empirical support for the idea that some emotions are more motivationally salient than others. Fear is more motivationally salient because it increases our chances of survival. The Hot and Sequeira (2013) study did not include fear pictures, which might explain why they did not find differences across emotions. Other work by Wheaton et al. (2013) did include threat-relevant pictures. In that study, they compared threat and disgust pictures and failed to find significant differences between those two emotional categories (Wheaton et al. 2013). The lack of discrete emotion differences may be partially explained by the high biological relevance of both threat- and disgust-inducing pictures, which would explain why both emotions elicited comparable LPPs in the large time window they used (400–1000 ms). It is also possible that, as in this study, differences between these two emotions would be found at earlier windows of the LPP, if they had broken their window into smaller segments.

The idea that some stimuli will result in faster elaborate processing is not new (Lang et al. 1997), but most of this research has ignored semantic labels such as fear, sadness, happiness, as important emotional categories that might differ in their capacity to motivate attention (regardless of other characteristics of the pictures; e.g., humans versus animals). For example, Wheaton et al. (2013) finding no differences in LPP amplitudes between threat and disgust pictures could be attributed to the fact that they did not ask participants about fear (they asked only about feeling threatened and feeling disgusted). The disgusting pictures chosen for the study may have elicited fear, as the threat pictures arguably did, and the common underlying emotion could have accounted for the lack of differences between these two groups of pictures. Thus, more research is needed to clarify whether fear (threat) and disgust are differentiable at any point, and the potential preferential processing associated with discrete emotions with pronounced biological relevance beyond just fear.

Our study adds to a growing body of research on motivated attention and how specific characteristics of the environment preferentially capture attention. A greater understanding of how different emotions capture and sustain attentional processes and the implications this has for appraisals and other cognitive processes would not only be informative for healthy populations, but also for understanding how these processes go awry in psychopathologies like phobias and generalized anxiety. Our study incorporated discrete emotion-evoking pictures to begin to address these issues on the differential processing of discrete emotional categories, but future work will need to expand and extend these efforts, to further elucidate commonalities and differences across discrete emotions.

Limitations and future directions

Combining pictures from two picture sets allowed us to explore discrete emotions like fear, sadness, and happiness. But, the stimuli set we created is new and precludes direct comparisons of our results with those obtained in previous LPP studies. Additionally, because the IAPS and NAPS picture sets report different standardized stimuli parameters (e.g., brightness), it was not possible to fully match all pictures across sets on these features. We also note that some other LPP studies have used smaller time windows to test their hypothesis (i.e., 200 ms; Thiruchselvam et al. 2011). Given the novelty of our hypotheses, we sought to reduce the number of estimations that could result in spurious findings and opted for a wider time window. Related, though our a priori choice of electrodes was also aimed at reducing the likelihood of spurious findings, future studies should explore differences across sets of electrodes to map overall brain activity across emotions. Another potential limitation is that we recruited a generally healthy undergraduate sample, and did not exclude participants based on psychiatric screenings or diagnoses. But, this inclusive approach facilitates the generalization of findings, as some symptomatology would be expected to occur in typical community samples. Lastly, it should be mentioned that although this study focused on discrete emotional categories on the LPP, we acknowledge that to fully understand any potential differences in the temporal patterns of brain activation across emotional categories it will be necessary to look at multiple components throughout a larger time window than the one considered in this study. While more research is still needed to fully understand the neural processing of discrete emotional categories, our findings can be taken as initial evidence of the usefulness of using later ERP components, such as the LPP, for understanding threat processing in normal populations as well as in populations with psychopathological disorders characterized by enhanced processing of threat such as generalized anxiety and phobias.

Conclusion

Our study highlights the benefits of moving from broad conceptualizations of emotion using valence and arousal to examine specific discrete emotional categories, clarifying the neural mechanisms underlying emotional processing.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All the procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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