



The dynamic allocation of attention to emotion: Simultaneous and independent evidence from the late positive potential and steady state visual evoked potentials

Greg Hajcak^{a,*}, Annmarie MacNamara^a, Dan Foti^a, Jamie Ferri^a, Andreas Keil^b

^a Department of Psychology, Stony Brook University, Stony Brook, NY 11794-2500, USA

^b Center for the Study of Emotion & Attention, University of Florida, PO Box 112766, Gainesville, FL 32611, USA

ARTICLE INFO

Article history:

Received 13 July 2011

Accepted 27 November 2011

Available online 9 December 2011

Keywords:

Motivated attention

Emotion

Directed attention

LPP

ssVEP

ABSTRACT

Emotional stimuli capture and hold attention without explicit instruction. The late positive potential (LPP) component of the event related potential can be used to track motivated attention toward emotional stimuli, and is larger for emotional compared to neutral pictures. In the frequency domain, the steady state visual evoked potential (ssVEP) has also been used to track attention to stimuli flickering at a particular frequency. Like the LPP, the ssVEP is also larger for emotional compared to neutral pictures. Prior work suggests that both the LPP and ssVEP are sensitive to “top-down” manipulations of attention, however the LPP and ssVEP have not previously been examined using the same attentional manipulation in the same participants. In the present study, LPP and ssVEP amplitudes were simultaneously elicited by unpleasant and neutral pictures. Partway through picture presentation, participants' attention was directed toward an arousing or non-arousing region of unpleasant pictures. In line with prior work, the LPP was reduced when attention was directed toward non-arousing compared to arousing regions of unpleasant pictures; similar results were observed for the ssVEP. Thus, both electrocortical measures index affective salience and are sensitive to directed (here: spatial) attention. Variation in the LPP and ssVEP was unrelated, suggesting that these measures are not redundant with each other and may capture different neurophysiological aspects of affective stimulus processing and attention.

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1. Introduction

Attention acts like a focused spotlight that facilitates information processing across multiple cognitive domains; for instance, attention can modulate perception, memory, and action (Luck and Kappenman, 2011). As an example, information presented in attended spatial locations is identified more rapidly and associated with increased early event-related potentials (ERPs) that index facilitated perceptual processing (e.g., an increased N1; Luck and Kappenman, 2011). Like attended information, emotional content is better perceived (Öhman et al., 2001) and remembered (Kensinger and Corkin, 2003) and primes organisms for responsive action (Hajcak et al., 2007). However, individuals do not need to be instructed to attend to emotional content; rather, the facilitated processing of emotional stimuli *seems* to happen automatically. In other words, the motivational value of environmental stimuli can

direct and impact attention – a phenomenon that has been referred to as *motivated attention* (Lang et al., 1997). Indeed, emotional stimuli elicit larger early ERPs – including the N1 – suggesting increased early selective attention to emotional stimuli (Foti et al., 2009).

Emotional stimuli do not merely *capture* attention. Rather, evidence suggests visual attention to emotional stimuli is often *sustained* (Hajcak and Olvet, 2008; Weinberg and Hajcak, 2011b). As long as threat or opportunity is present in the environment, it can benefit from the spotlight of attention. Hajcak and colleagues have argued that the late positive potential (LPP), an electrocortical positivity elicited by emotional and neutral stimuli, can be used to index sustained attention toward motivationally salient stimuli (Hajcak and Olvet, 2008; Weinberg and Hajcak, 2011b). The LPP is maximal at centro-parietal sites as early as 200 ms following stimulus presentation and can last throughout stimulus presentation (Cuthbert et al., 2000; Foti et al., 2010; Hajcak and Olvet, 2008; Schupp et al., 2000). The LPP is larger in response to emotional (i.e., both pleasant and unpleasant) compared to neutral stimuli, including images (Foti et al., 2009; Pastor et al., 2008), words (Fischler and Bradley, 2006; Kissler et al., 2009), and hand gestures (Flaisch et al., 2011). The LPP is larger when stimuli are framed in more negative than neutral terms (Foti and Hajcak, 2008; MacNamara et al., 2009,

* Corresponding author at: Department of Psychology, Stony Brook University, Stony Brook, New York 11794-2500, United States. Tel.: +1 631 632 6272; fax: +1 631 632 7876.

E-mail address: greg.hajcak@stonybrook.edu (G. Hajcak).

2011b). Further, the LPP is largest for emotional stimuli that are most directly related to biological imperatives (Briggs and Martin, 2009; Schupp et al., 2004; Weinberg and Hajcak, 2010). For example, pictures that depict erotica and threat elicit the biggest LPPs; on the other hand, exciting sports images are rated as very pleasant and highly arousing, but these images do not elicit particularly large LPPs (Weinberg and Hajcak, 2010).

Although the LPP is sensitive to emotional content, task parameters that reduce attention toward the emotional content of stimuli can attenuate the magnitude of the LPP. For instance, presenting concurrent non-affective tasks that are sufficiently difficult may draw attention away from emotional and neutral pictures, resulting in a reduced LPP (MacNamara et al., 2011a; Sand and Wiens, 2011). In one study, MacNamara et al. (2011a) tested the effect of working memory load on the LPP by having participants memorize either two letters (low-load) or six letters (high-load) followed by the presentation of a neutral or aversive IAPS image during the retention interval. Following picture offset, participants were instructed to recall the letters in the exact order that they appeared. Although the LPP was greater in response to aversive compared to neutral images under low and high working memory load, the overall LPP during high-load was reduced compared to low-load.

Moreover, emotional modulation of the LPP appears to depend on spatial attention. Specifically, when stimuli are presented in spatially unattended areas, or when participants are asked to direct their attention away from arousing picture regions, emotional modulation of the LPP is attenuated (Dunning and Hajcak, 2009; Hajcak et al., 2009; MacNamara and Hajcak, 2009, 2010). For instance, MacNamara and Hajcak (2009) had participants make judgments about whether pairs of neutral or aversive target pictures were the same or different while non-target pictures were simultaneously presented in unattended locations. Affective modulation of the LPP was only apparent when aversive images were presented in attended locations; the aversive pictures in unattended locations did not elicit an increased LPP.

Where attention is allocated *within* an unpleasant picture also impacts the amplitude of the LPP. Dunning and Hajcak (2009, study 2) used a paradigm in which attention was directed to either more or less arousing areas of emotional images, and examined the impact of this manipulation on the LPP. In this study, participants passively viewed IAPS images for 3000 ms. Following the passive viewing period, a circle appeared over the image directing participants to either an arousing or non-arousing portion of an unpleasant image. The LPP was larger for unpleasant compared to neutral pictures during the passive viewing period; however, in the directed attention period, unpleasant pictures only continued to elicit a larger LPP than neutral pictures when attention was directed to arousing regions. That is, directing attention to non-arousing regions of unpleasant images reduced the amplitude of the LPP (see also Hajcak et al., 2009). Thus, emotional modulation of the LPP critically depends on attention to the emotional content of visually presented stimuli. Moreover, the sustained nature of attention to emotional stimuli is a dynamic process governed both by the motivational properties of stimuli, as well the manner in which organisms intentionally allocate attention.

Whereas the LPP provides information in the time domain about how top-down and bottom-up manipulations of attention influence the processing of emotional stimuli, complementary information in the frequency domain can be obtained using the steady-state visual evoked potentials (ssVEP). The ssVEP is a continuous neural response to stimuli that are repeatedly presented at a rate of approximately 6 Hz or greater, characterized as an oscillatory waveform with the same fundamental frequency as the driving stimulus. Because the driving frequency is known, power in the EEG signal at that frequency can be uniquely attributed to the processing of the flickering stimulus. This measure has been particularly

useful in studies of selective attention, in which competing stimuli are presented at different frequencies and ssVEP amplitude at those frequencies is interpreted as reflecting the amount of processing resources devoted to the corresponding stimulus. For example, when spatial attention is manipulated while keeping gaze fixed at a central location, ssVEP amplitude in response to a stimulus in the attended location is increased, regardless of whether that stimulus is task-relevant (Muller et al., 1998) or not (Hillyard et al., 1997; Morgan et al., 1996). Across studies, ssVEP amplitude is generally maximal at posterior sites, and combined EEG and fMRI evidence indicates that it reflects activity in occipital and temporal visual areas (Hillyard et al., 1997). A recent retinotopic mapping study attributed ssVEP amplitude to activity in visual areas V1 and V5/MT, and to a lesser extent V3A, V4, and V8 (Di Russo et al., 2007). Overall, this line of research demonstrates that the ssVEP is an effective tool for examining the effects of attentional manipulations on stimulus processing, representing a reliable measure of activity in both primary and secondary visual cortices.

Complementing this work on selective attention, the ssVEP has also been examined in response to emotional stimuli. Like the LPP, ssVEP amplitude is increased for both pleasant and unpleasant compared to neutral images at parietal and occipital sites (Keil et al., 2003). This finding has also been observed using the steady-state visual evoked field, the magnetic counterpart of the ssVEP (Moratti et al., 2004). In light of this evidence that ssVEP amplitude is sensitive to manipulations of both directed and motivated attention, recent work has begun to examine the interplay between these processes by presenting competing stimuli that vary in emotional content. In one study, participants were required to count geometric patterns presented in one hemifield while ignoring patterns presented in the other hemifield. At the same time, the ssVEP was measured in response to task-irrelevant emotional and neutral images super-imposed over patterns in both hemifields (Keil et al., 2005). Additive effects of spatial attention and emotion were found on the ssVEP, such that the largest ssVEP amplitude was observed for unpleasant images presented in the attended hemifield. By applying Granger causality analysis, a recent study demonstrated that the sustained emotional modulation of ssVEP amplitude is driven in part by re-entrant modulation of activity in visual areas (Keil et al., 2009). Finally, a recent study examined whether individual differences in self-reported social anxiety moderate the ssVEP response to task-irrelevant emotional facial expressions (Wieser et al., 2011). Among individuals high in social anxiety, ssVEP amplitude was increased to angry compared to happy and neutral faces, whereas the ssVEP was not sensitive to the emotional nature of task-irrelevant stimuli for individuals low in social anxiety. As a neural measure that is sensitive to both manipulations of selective attention and the affective content of stimuli, the ssVEP is well-suited for studying interactions between cognition and emotion during visual processing.

The ssVEP and LPP have yet to be considered together in the same study and thus it is unclear whether these measures are related or not. In the current study, we first presented pictures in an uninstructed manner for 3000 ms so that we could assess electrocortical activity elicited by unpleasant and neutral picture content; then, we directed attention to either more or less arousing aspects of unpleasant images for an additional 3000 ms so that we could evaluate the impact of this attentional manipulation on neural activity (Dunning and Hajcak, 2009, study 2; Hajcak et al., 2009). By flickering visual stimuli at 15 Hz, we were able to simultaneously assess the LPP and the ssVEP in both the passive viewing and directed attention portions of each trial. Consistent with our previous work, we predicted that the LPP would be increased when participants passively viewed unpleasant compared to neutral pictures, and that the LPP elicited by unpleasant pictures would be reduced when attention was directed to less emotional aspects of

pictures. Insofar as the ssVEP appears similarly sensitive to top-down and bottom-up manipulations of attention, we predicted a similar pattern of results for the ssVEP. Finally, we sought to determine whether these two electrocortical measures of attention – derived from the same data – would be correlated or unique effects.

2. Method

2.1. Participants

Twenty-five undergraduate students (13 female) participated in the current study. The study was approved by the Stony Brook University Institutional Review Board (IRB) and all participants received course credit for their participation.

2.2. Stimulus materials

Forty unpleasant pictures (e.g., war scenes, sad faces) and 20 neutral pictures (e.g., buildings, neutral faces) were selected from the International Affective Picture System (IAPS; Lang et al., 2005).¹ Normative ratings indicated that the unpleasant pictures were less pleasant (valence $M=2.09$, $SD=0.41$) and more emotionally arousing ($M=6.13$, $SD=0.61$) than the neutral pictures ($M=5.11$, $SD=0.50$ and $M=2.94$, $SD=0.79$, respectively; higher numbers indicate more pleasant and higher arousal ratings). Two versions of each of the 40 unpleasant pictures were created: the outline of a blue circle measuring 7 cm in diameter, and occupying approximately 7° of visual angle was placed over either an arousing or non-arousing portion of each unpleasant picture. For example, in a picture of a man holding a gun to his head, the circle either focused on the man's ear where the tip of the gun touched his head or the man's other ear (where no gun was present, Dunning and Hajcak, 2009; Hajcak et al., 2009). For each of the 20 neutral pictures, the same blue circle was superimposed over a non-arousing region of the picture. These stimuli were identical to those used previously and care was taken to equate circle placement between conditions such that the objects contained within the circles were similar in terms of complexity (Dunning and Hajcak, 2009; Hajcak et al., 2009).

2.3. Procedure

On each trial, participants viewed either an unpleasant or neutral picture for 6000 ms, and stimuli were flickered at a frequency of 15 Hz throughout the entire trial. Participants were told that on each trial, a circle would appear after 3000 ms; they were further told to focus their attention and look only at the area within the circle while it remained on the screen – and that they could freely view the picture prior to the onset of the blue circle. Thus, the first half of the trial was a passive picture viewing portion, and, 3000 ms after picture onset, attention was directed to a specific portion of the picture by presenting the modified version of the same picture that contained a blue circle. The procedure was identical to that described in Dunning and Hajcak (study 2, 2009), except that IAPS pictures were flickered at a frequency of 15 Hz throughout the entire trial. Following each trial, a white fixation cross was presented on a black background for 2000 ms.

Each picture was displayed in color at the maximum size for the monitor screen (which measured 48.26 cm, diagonally). Participants were seated approximately 60 cm from the screen and the images (mostly in landscape format) occupied about 34° of visual angle horizontally and 28° of visual angle vertically. Some images were in portrait format, and these images occupied about 17° of visual angle horizontally and 28° of visual angle vertically. Each participant saw all pictures exactly one time; importantly, the allocation of unpleasant pictures to the arousing or non-arousing condition was determined randomly for each participant. There were 60 trials in total: 20 trials on which a neutral picture was presented, followed by a circle placed over a non-arousing picture region (neutral, non-arousing); 20 trials on which an unpleasant picture was presented, followed by a circle placed over an arousing picture region (unpleasant, arousing focus); and 20 trials on which an unpleasant picture was presented, followed by a circle placed over a non-arousing picture region (unpleasant, non-arousing focus). Trial types were intermixed and the order of these trials was completely random; a break was given after every 15 trials. Participants performed 2 practice trials at the beginning of the experiment to familiarize themselves with the procedure.

2.4. Electroencephalographic recording, data reduction and analyses

Continuous EEG was recorded using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Sixty-four electrode sites were used, based on the 10/20 system, as well as one electrode on each of the left and right mastoids. The electrooculogram (EOG) generated from eyeblinks and eye movements was recorded from four facial electrodes: vertical eye movements and blinks were measured with two electrodes placed approximately 1 cm above and below the right eye; horizontal eye movements were measured using two electrodes that were placed approximately 1 cm beyond the outer edge of each eye. The EEG signal was pre-amplified at the electrode to improve the signal-to-noise ratio. The data were digitized at 24-bit resolution with a Least Significant Bit (LSB) value of 31.25 nV and a sampling rate of 512 Hz, using a low-pass fifth order sinc filter with –3 dB cutoff point at 104 Hz. The voltage from each active electrode was referenced online with respect to a common mode sense (CMS) active electrode producing a monopolar (non-differential) channel. Off-line analyses were performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). Data were re-referenced offline to the average of the two mastoids and band-pass filtered with low and high cutoffs of .1 and 40 Hz, respectively. The EEG was segmented for each trial beginning 1000 ms prior to picture onset and continuing for 7500 ms (i.e., 500 ms beyond picture duration). Baseline-correction was performed for each trial using the 500 ms immediately prior to picture onset.

Eye blink and ocular corrections were made using the method developed by Gratton et al. (1983). Noisy data due to technical problems necessitated the removal of data from isolated electrodes in 5 subjects; data was interpolated from the 4 nearest channels in each case. Artifact analysis identified a voltage step of more than 50.0 μ V between sample points, a voltage difference of 300.0 μ V within a trial, and a maximum voltage difference of less than .50 μ V within 100 ms intervals. Trials were also inspected visually for any remaining artifacts, and individual channels containing artifacts were rejected on a trial-to-trial basis.

To eliminate effects associated with ERPs elicited by stimulus train onset, a period from 1000 to 2000 ms following both picture onset ('passive viewing') and 1000–2000 ms following circle onset ('directed attention') were used for subsequent analyses (see Fig. 1). The LPP was scored by averaging amplitudes in each of these windows, at five posterior sites where the LPP was maximal:

¹ The numbers of the IAPS pictures used were as follows: unpleasant (1525, 2053, 2095, 2141, 2352.2, 2703, 2717, 2811, 3005.1, 3010, 3015, 3016, 3017, 3030, 3053, 3063, 3181, 3225, 3261, 3266, 3530, 6312, 6313, 6315, 6415, 6550, 6570.1, 6571, 6831, 9252, 9253, 9300, 9405, 9410, 9420, 9430, 9433, 9570, 9635.1, 9810) and neutral (2102, 2190, 2206, 2235, 2320, 2383, 2580, 2745.1, 2980, 5390, 5740, 7000, 7002, 7004, 7010, 7140, 7175, 7491, 7560, 7595).

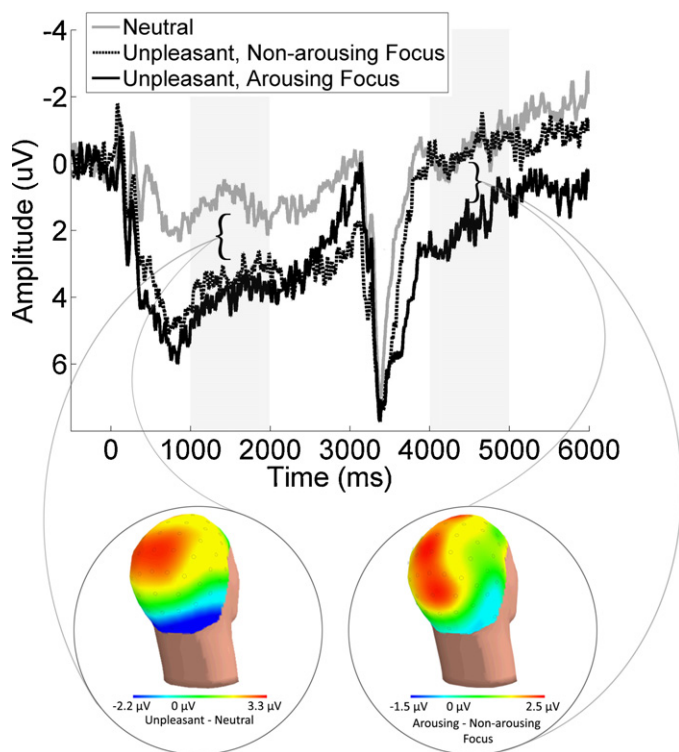


Fig. 1. Grand-averaged ERP waveforms at a pooling of POz, Pz, P1, P2 and CPz (top) in each of the three Trial Types, from picture onset (0 ms) until picture offset (6000 ms). Each trial began with passive picture viewing for 3000 ms; following this, a circle appeared over an arousing or a non-arousing picture region. The temporal windows used for the LPP and ssVEP analyses are shaded in grey. Scalp distributions of voltage differences (using mastoid-referenced data) for unpleasant minus neutral pictures (i.e., in passive viewing; left) and for arousing minus non-arousing foci (i.e., in directed attention; right) are depicted below the ERPs (note the different voltage scales used).

POz, Pz, P1, P2 and CPz (Dunning and Hajcak, 2009). The ssVEP amplitude was extracted from the same two time segments of the trial-averaged ERP (see Fig. 1) using Discrete Fourier Transform (DFT) on a channel-by-channel basis. To this end, the time periods from 1000 to 2000 ms following picture onset (the middle segment of the passive-viewing period) and from 1000 to 2000 ms following circle onset (the middle segment of the directed attention period) were multiplied with a cosine square window of 50 ms rise/fall time and 900 ms of unity. DFT was then calculated and ssVEP amplitude was obtained as the vector length of the complex DFT spectrum at 15 Hz, normalized by the number of time points entering DFT. For statistical analyses, the ssVEP amplitude was averaged across six posterior electrodes, corresponding to Oz, O1, O2, POz, PO3 and PO4.

The LPP and ssVEP voltage data were evaluated with a 3 (Trial Type: neutral non-arousing, unpleasant non-arousing, and unpleasant arousing) \times 2 (Window: passive viewing, directed attention) repeated-measures analysis of variance (ANOVA) with Greenhouse-Geisser correction. Significant interaction effects were followed by paired-sample *t*-tests. To determine whether the LPP and the ssVEP index similar neural activity across individuals, Pearson's correlations were performed between the LPP and ssVEP voltages: first, the LPP and ssVEP differences between unpleasant and neutral trials in the passive viewing window were correlated; second, the LPP and ssVEP differences between arousing and non-arousing trials in the directed attention window were correlated. Statistical analyses were performed using PASW (Version 18.0) General Linear Model software.

3. Results

Fig. 1 depicts the grand average waveforms for the LPP: picture onset occurred at 0 ms; circle onset occurred at 3000 ms and picture offset occurred at 6000 ms. The passive viewing and directed attention windows analyzed are denoted in grey; the distribution of voltage differences on the scalp for unpleasant minus neutral pictures (collapsed across attentional focus) and arousing minus non-arousing focus (collapsed across picture type) are depicted for the passive viewing and directed attention windows, respectively. Fig. 2 graphs LPP and ssVEP amplitudes in each of the three conditions, for the windows 1000–2000 ms after picture and circle onset (i.e., the passive and directed attention windows, respectively).

3.1. LPP

There was a main effect of Trial Type ($F(2,48)=7.32$, $p < .01$, $\eta_p^2 = .23$), confirming the impression from Figs. 1 and 2 that the LPP varied as a function of picture content and attentional focus overall. There was also a main effect of Window indicating that the LPP was larger in the passive viewing compared to the directed attention window ($F(1,24)=26.80$, $p < .0001$, $\eta_p^2 = .53$). Of primary relevance to the study hypotheses, and as suggested by Figs. 1 and 2, there was a significant interaction between Trial Type and Window ($F(2,48)=3.26$, $p < .05$, $\eta_p^2 = .12$).

In the passive viewing window, unpleasant pictures with an arousing focus and unpleasant pictures with a non-arousing focus elicited larger LPPs than neutral pictures, ($t(24)=3.91$, $p < .01$ and $t(24)=2.62$, $p < .05$, respectively); the LPP elicited by unpleasant pictures with an arousing focus did not differ from the LPP elicited by unpleasant pictures with a non-arousing focus in the passive viewing portion of the trial ($t(24)=1.24$, $p > .22$). However, in the directed attention window, unpleasant pictures with an arousing focus elicited larger LPPs compared to both unpleasant pictures with a non-arousing focus and compared to neutral pictures ($t(24)=2.46$, $p < .05$ and $t(24)=2.35$, $p < .05$, respectively); the LPP elicited by unpleasant pictures with a non-arousing focus and the LPP elicited by neutral pictures did not differ in the directed attention window ($t(24)=.01$, $p > .99$). Overall, these data exactly replicated previous results indicating that directing attention to non-arousing aspects of unpleasant pictures can reduce the LPP (Dunning and Hajcak, 2009).

3.2. ssVEP

The frequency spectrum of the ERP was extracted to confirm that the ssVEP was indeed driven at 15 Hz – and these data are presented in Fig. 3, using voltages extracted during the passive-viewing window at representative midline frontal (Fz), central (Cz) and occipital (Oz) sites. These data confirm increased spectral power at 15 Hz, maximal over occipital recording sites.

Fig. 4 presents the spatial distribution of grand average 15 Hz ssVEP amplitudes on the scalp for each of the three conditions, in the passive viewing (left) and directed attention (right) portions of each trial. There was a main effect of Trial Type for ssVEP amplitude ($F(2,48)=4.45$, $p < .05$, $\eta_p^2 = .16$). Amplitudes did not vary by Window overall ($p > .82$). As is suggested by Fig. 4 and central to the study hypotheses, the impact of Trial Type varied between the passive viewing and directed attention windows to determine ssVEP amplitude ($F(2,48)=4.07$, $p < .05$, $\eta_p^2 = .15$).

Follow-up tests revealed that the ssVEP results were identical to the LPP results. In the passive viewing window, unpleasant pictures with an arousing focus and unpleasant pictures with a non-arousing focus elicited larger ssVEP amplitudes than neutral pictures ($t(24)=2.47$, $p < .05$ and $t(24)=2.47$, $p < .05$, respectively); on the other hand, ssVEP amplitudes elicited by unpleasant pictures

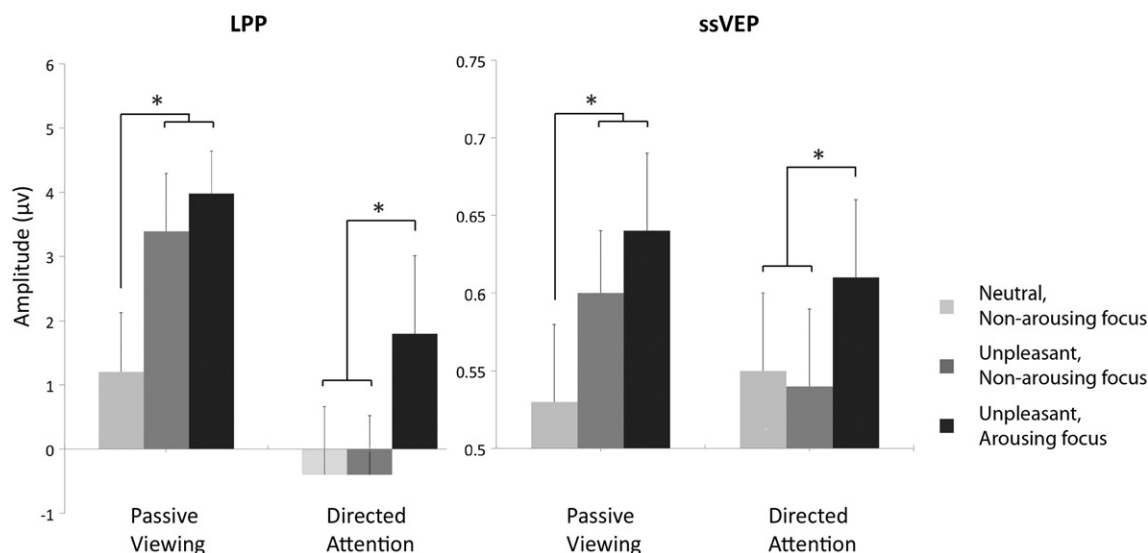


Fig. 2. Mean LPP and ssVEP amplitudes (including standard error of the mean) elicited by pictures in the passive viewing window (1000–2000 ms after picture onset) and directed attention window (1000–2000 ms after circle onset), in each of the three Trial Types. Asterisks denote significant differences (all p s < .05).

with an arousing focus did not differ from those elicited by unpleasant pictures with a non-arousing focus in this window ($t(24) = .23$, $p > .82$). In the directed attention window, unpleasant pictures with an arousing focus elicited larger ssVEP amplitudes compared to both neutral pictures ($t(24) = 2.61$, $p < .05$) and unpleasant pictures with a non-arousing focus ($t(24) = 3.09$, $p < .01$); ssVEP amplitudes elicited by unpleasant pictures with a non-arousing focus did not differ from amplitudes elicited by neutral pictures in this window ($t(24) = .06$, $p > .95$).

3.3. Correlations

To determine whether the ssVEP and the LPP index similar neural measures of attention, Pearson's correlations were performed using the differences scores for: unpleasant minus neutral pictures in the passive viewing window; and arousing minus non-arousing focus in the directed attention window. Correlations between amplitudes of the ssVEP and the LPP did not reach significance in either window (unpleasant minus neutral in the passive viewing window, $r(25) = -.01$, $p = .98$; arousing minus non-arousing focus in the directed attention window, $r(25) = -.14$, $p = .51$). Thus, those individuals with a larger LPP in response to unpleasant compared to neutral pictures in the passive viewing portion of each trial were not the same individuals who had a larger ssVEP. Along the same lines, a greater reduction in the LPP by directed attention did not predict the degree of ssVEP reduction by directed attention across individuals.

4. Discussion

Compared to neutral pictures, unpleasant pictures elicited an increased LPP and increased amplitude of the ssVEP during the passive viewing portion of each trial. These data are consistent with previous work on both the LPP (Cuthbert et al., 2000; Foti et al., 2009; Pastor et al., 2008; Schupp et al., 2000) and ssVEP (Keil et al., 2003, 2005) – both neural measures have been used to index the relatively automatic increase in attention to emotional compared to neutral stimuli. Further, in the current study, both the LPP and ssVEP were sensitive to where visual attention was directed within unpleasant pictures: the LPP and ssVEP were reduced and did not differ from neutral pictures when attention was directed toward relatively neutral portions of unpleasant pictures. This finding replicates previous work on the LPP (Dunning

and Hajcak, 2009; Hajcak et al., 2009), and further suggests that the ssVEP is similarly modulated by manipulations of attention within unpleasant pictures. In particular, the modulation of ssVEP amplitude by attentional focus here builds upon the results of a prior study in which additive effects of spatial attention and affective content were observed, with the largest ssVEP response elicited by attended unpleasant images (Keil et al., 2005). Extending that result, the current study demonstrates that, like the LPP, the ssVEP is modulated by the dynamic allocation of attention during affective stimulus processing, and that shifts in ssVEP amplitude can be observed as attention is manipulated within emotional stimuli.

Both the ssVEP and LPP appear to reflect an increase in attentional allocation and perceptual processing of emotional stimuli – what has been referred to in terms of motivated attention and perception (Lang et al., 1997). However, both of these electrocortical measures also appear to depend heavily on where attention is allocated within emotional stimuli. As we have suggested before, the implicit effects of *motivated attention* can be modulated by explicitly *directed attention* (Dunning and Hajcak, 2009; Hajcak et al., 2009). Taken together, these data suggest that both the LPP and ssVEP reflect the dynamic interplay between bottom-up and top-down processes that influence sustained attention.

Future work might further investigate the functional similarity of the LPP and ssVEP. For instance, increased LPPs elicited by task-irrelevant visual stimuli have been shown to predict longer reaction times and reduced P300s to targets (Weinberg and Hajcak, 2011b). It might be interesting to examine whether the increased ssVEP elicited by task-irrelevant emotional stimuli can similarly predict reduced attention to task-relevant stimuli. Moreover, the amplitude of the LPP can be modulated by a number of manipulations that have not been examined using the ssVEP. For example, the LPP is reduced by descriptions that frame pictures in more neutral terms (Foti and Hajcak, 2008; MacNamara et al., 2009, 2011b); the LPP is also reduced when participants make non-affective compared to affective appraisals about emotional pictures (Hajcak et al., 2006), and when participants intentionally modulate the intensity of their response to emotional pictures (Moser et al., 2006). Increased working memory load has also been shown to reduce the amplitude of the LPP (MacNamara et al., 2011a). By examining whether the ssVEP is also sensitive to these manipulations, it may be possible to discern conditions that impact the LPP but not the ssVEP.

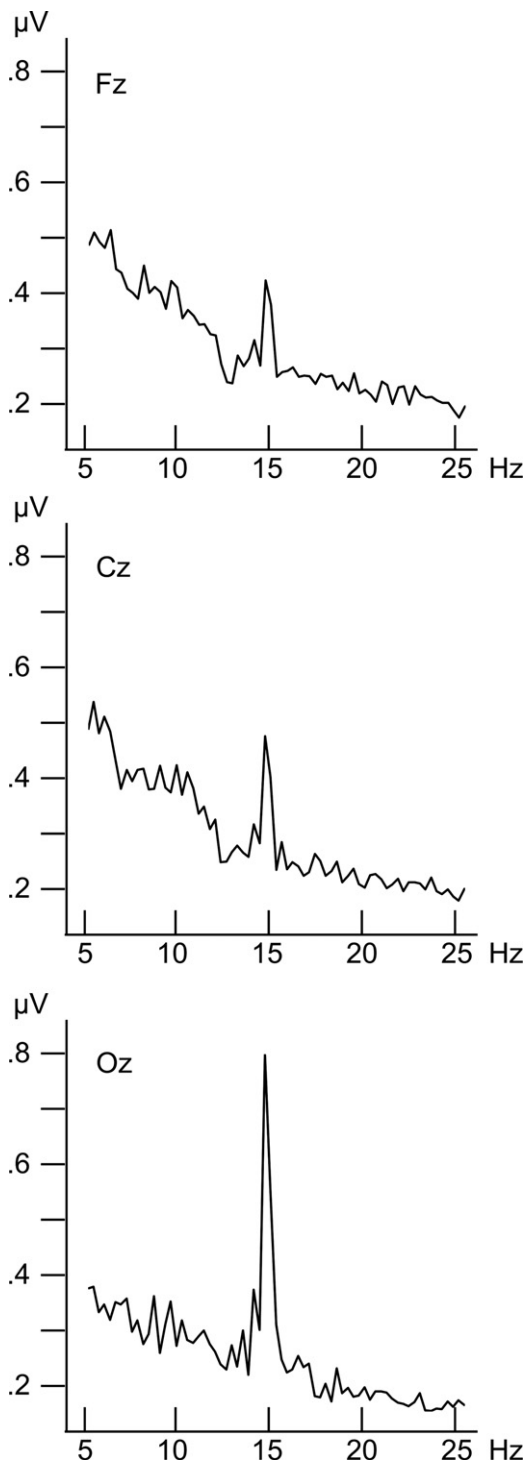


Fig. 3. Frequency spectra extraction of voltage elicited during the passive-viewing window (from 1000 to 2000 ms after picture onset), at representative midline frontal (Fz, top), central (Cz, middle) and occipital (Oz, bottom) sites.

Although the LPP and ssVEP were both increased in response to emotional pictures and decreased with the directed attention manipulation, it is noteworthy that the LPP and ssVEP – derived from the same data – were not correlated with one another in the current study. This suggests that although they are functionally similar, these two electrocortical measures may provide unique information about emotional attention, a point to which we return to below (see Question 3). Caution is warranted because the reliability of emotion-related amplitude modulation of both the LPP

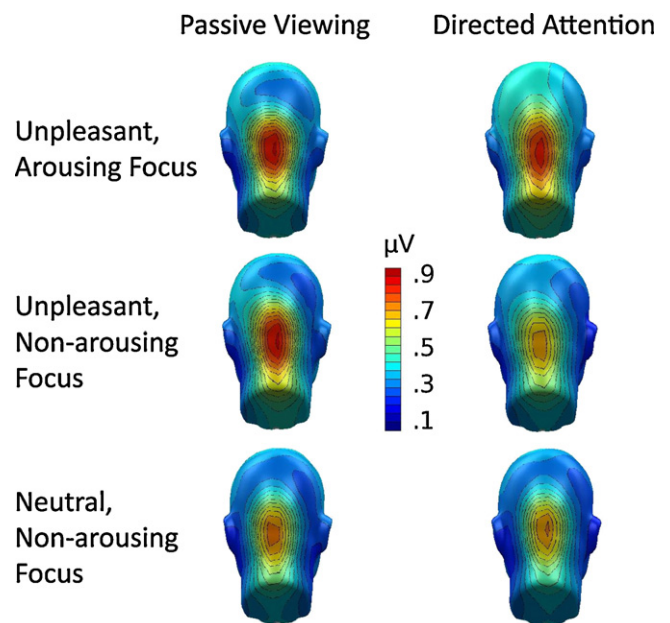


Fig. 4. Spatial distributions of grand average 15 Hz ssVEP voltage amplitudes, for each of the three Trial Types in the passive viewing (1000–2000 ms after picture onset; left) and the directed attention (1000–2000 ms after circle onset; right) portions of each trial.

and ssVEP may be low, allowing significant effects for mean comparisons within each measure, but not across the two measures. Although such an explanation for the absence of inter-measure correlations cannot be excluded, it has been established previously that single trials of ssVEPs have reliabilities (Cronbach's Alpha) of .8 and higher (Keil et al., 2008) and equally high internal consistency can be expected for late ERP positivities (Polich and Kok, 1995). This suggests that LPP and ssVEP measure different neurophysiological processes. Rather than being redundant, the LPP and ssVEP appear to be complementary neural indices of emotional attention, and considering both of these measures simultaneously may provide a more comprehensive understanding of how top-down and bottom-up manipulations interact in the processing of emotional information. In the three sections below, we elaborate on some ways in which the ssVEP and LPP may be used separately and in conjunction with one another to inform knowledge about the neural mechanisms involved in emotional attention, to inform the treatment of information-processing abnormalities in psychopathology, and how these measures might be integrated with other complementary methodologies.

Question 1 (Specificity of Emotional Attention brain mechanisms): How can emotional attention brain mechanisms be dissociated from brain systems involved in the control of non-emotional attention (either exogenous or endogenous)?

Some studies have suggested that emotional processing is a unique process that can occur in the absence of awareness (Maratos et al., 2001; Morris et al., 1998; Whalen et al., 1998). For instance, masked emotional stimuli have been shown to increase activity in the amygdala (Whalen et al., 1998) as well as increase the magnitude of early sensory ERP components such as the P1 (Bernat et al., 2001). These studies seem to suggest that emotional stimuli may receive increased processing even when they are not consciously perceived, and therefore, that emotional attention is distinct from non-emotional attention.

However, investigations of sustained attention to emotion, as indexed by neural measures such as the LPP, suggest a more critical role of attention during the elaborative processing of emotional

stimuli. For instance, in a study using masked emotional stimuli, emotional modulation of the LPP was only evident when the timing of the mask was such that participants were able to identify the valence and arousal of the stimuli (Codispoti et al., 2009). In terms of the more elaborative processing of emotional stimuli indexed by the LPP, there is substantial evidence that the relationship between emotional and non-emotional attention can be bidirectional, indicating competition as well as cooperation depending on task requirements.

For example, Weinberg and Hajcak (2011b) demonstrated that when task demands are relatively low, irrelevant emotional content can impact responses to task-relevant stimuli. In that study, subjects were asked to identify a target as either a circle or a square. Participants also viewed task-irrelevant emotional and neutral images, presented before and after the targets. Participants were slower to categorize targets when they were preceded by an emotional compared to a neutral image (see Ihssen et al., 2007, for a converging finding). In addition, the LPP to task-irrelevant images that preceded targets predicted both response speed and the size of the P300 to the targets, with a larger LPP predicting a slower response and a reduced P300. In this way, attention to emotional stimuli can impede the processing of task-relevant stimuli.

On the other hand, there are contexts in which task directives and the emotional nature of stimuli may work together; in these instances, attention and emotion can operate to further increase stimulus-processing (Ferrari et al., 2008; Weinberg et al., under review). In one study, Ferrari et al. (2008) presented neutral, pleasant or unpleasant images of humans, and images of animals and objects for 30 ms each. In separate sessions, participants were asked to categorize these pictures according to whether there was an animal or a human in the image. In this way, Ferrari et al. (2008) examined the impact of emotion, target status (i.e., the presence of an animal or human in an image) and their interaction on the picture-elicited LPP. The LPP was larger both in response to target (compared to non-target) stimuli and in response to task-irrelevant emotional (compared to non-emotional) content; moreover, the LPP was largest when emotional pictures were also targets. Such additive effects are often taken to suggest two processes that are independent. The additive enhancement of the LPP with emotion and attention may thus suggest that non-emotional attention and emotional attention may operate independently of each other, and thus will both work to increase neural processing when stimuli are emotionally engaging and task-relevant. These additive effects are not unique to the LPP; current and previous findings have also demonstrated that they occur when using the ssVEP (Keil et al., 2005) and neuroimaging investigations that employ fMRI have also observed these effects (Vuilleumier et al., 2001). In sum, paradigms that manipulate both non-emotional and emotional attention simultaneously seem best positioned to investigate the ways in which emotional and non-emotional attention can be regarded as independent processes, and the ways in which they interact dynamically to influence information processing in the brain.

Question 2 (Emotional Attention in psychopathology): How can what we have learned about emotional attention in specific clinical, sub-clinical or healthy samples inform improved intervention strategies for relevant pathologies?

Research using the LPP and ssVEP suggests that anxiety and depression may be associated with the abnormal processing of emotional stimuli (e.g., Dennis and Hajcak, 2009; MacNamara and Hajcak, 2010; McTeague et al., 2011; Weinberg and Hajcak, 2011a; Wieser et al., 2011). For instance, anxiety may be associated with the increased processing of task-irrelevant threatening stimuli dimensions (MacNamara and Hajcak, 2009, 2010; Wieser et al., 2011), and in children, symptoms of anxiety and

depression may be associated with less effective emotion regulation, as indexed by the LPP (Dennis and Hajcak, 2009). Indeed, ineffective emotion regulation may underlie emotion processing abnormalities in anxiety and mood disorders.

A variety of studies have implicated the pre-frontal cortex in the regulation of attention toward emotional stimuli (e.g., Banks et al., 2007; Hariri et al., 2003; Lévesque et al., 2003; Ochsner and Gross, 2005) and depression and anxiety have been associated with the reduced recruitment of frontal regions during the regulation of attention toward emotional distracters (Bishop et al., 2004; Mayberg et al., 1999). Therefore, interventions that target the activation of frontal regions might be useful in combating anxiety and depression.

Since the mid-1990s, there have been several investigations of brain stimulation treatments for mood disorders, including transcranial magnetic stimulation, deep brain stimulation and more recently, neurosurgery (see Nahas et al., 2004 for a review). For example, Nahas and colleagues implanted epidural stimulator paddles above the dorsolateral prefrontal cortex (DLPFC; Brodmann's area 46) and the frontopolar cortex (Brodmann's area 10) in a group of mood-disordered, treatment-resistant patients. After 7 months of treatment, three of the five patients in this study showed complete remission of depressive symptoms (Nahas et al., 2010). To determine whether stimulation at these locations moderated emotional attention, the stimulators were turned on while participants viewed aversive and neutral pictures while EEG was recorded (participants could not distinguish stimulator activation from a sham condition). Stimulation of the DLPFC – yet *not* stimulation of the frontopolar cortex – reduced the LPP elicited by aversive pictures, suggesting regionally specific regulation of attention toward emotional pictures (Hajcak et al., 2010). Thus, physiological stimulation of the DLPFC may be useful in treating chronic mood disorders and appears to reduce sustained attention toward emotional stimuli, as indexed by the LPP.

Attentional training treatments that utilize behavioral paradigms to activate pre-frontal regions may also be effective in treating anxiety and mood disorders (Papageorgiou and Wells, 2000; Siegle et al., 2007; Wells, 2000; Wells et al., 1997). These treatments may, for example, involve selective attention tasks in which patients listen to sounds presented in different corners of a room or working memory tasks in which patients add serially presented digits to a sum held in working memory. One study found that just two weeks of this kind of treatment was more effective at reducing depressive symptomatology than six weeks of a well-validated outpatient program (Siegle et al., 2007). Moreover, pre- and post-measures helped validate the proposed mechanisms of change, which included changes in DLPFC activation (Siegle et al., 2007). As discussed earlier, working memory load (known to activate the DLPFC) appears to reduce the picture-elicited LPP (MacNamara et al., 2011a). Therefore, the LPP might be used to measure the effects of attentional training treatments or to measure or predict treatment-related changes that target DLPFC function.

Visual selective attention also modifies emotional attention (as in the current results), and recent work has investigated whether visual attention – and therefore emotional attention – might be trained through practice (see Wadlinger and Isaacowitz, 2011, for a review). In some of these studies, participants have been asked to locate a single happy face presented among an array of disapproving faces (Dandeneau and Baldwin, 2004; Dandeneau et al., 2007) or to respond to a target (e.g., a dot) that consistently appears in place of a non-threatening cue (e.g., Eldar and Bar-Haim, 2009). Over repeated trials, participants tended to develop biases toward pleasant stimuli or away from unpleasant stimuli, and these biases generalized to other tasks

(e.g., a Rejection Stroop; Dandeneau and Baldwin, 2004). Moreover, this type of training has been associated with lower physiological and self-reported levels of stress, and increased work productivity (Dandeneau et al., 2007). Therefore, basic research on emotional attention has inspired new treatments, and the LPP and ssVEP may provide ideal measures of process and change for these treatments – the effects of which may be primarily evident in later-onset electrocortical activity (i.e., beyond 200 ms; Eldar and Bar-Haim, 2009).

An emotional attention approach can also be used to inform our understanding of the mechanisms by which pre-existing interventions operate. For example, antidepressants appear to increase biases toward pleasant stimuli (Browning et al., 2007) and decrease biases toward unpleasant stimuli (Murphy et al., 2009); successful treatment of anxiety via CBT seems to decrease threat-related attentional biases (e.g., Legerstee et al., 2010). From this perspective, electrocortical activity measured using ERPs and ssVEPs might shed light on the stages at which these interventions affect emotional attention. For example, antidepressants appear to reduce attention toward unpleasant stimuli within the first 250 ms of their presentation (Kerestes et al., 2009), in line with the notion that pharmacotherapy may primarily alter the bottom-up processing of emotional stimuli, whereas psychotherapy may affect top-down attentional systems (Browning et al., 2010). As sensitive indices of attention toward emotional stimuli, the LPP and the ssVEP might be used to validate the proposed mechanisms behind pre-existing treatments, so that this knowledge could be used to develop new and improved treatments.

Question 3 (Methodology of Emotional Attention): How can the results from different research methodologies (different types of brain imaging, clinical vs. healthy samples, animal models) be combined to develop and test models of emotional attention?

In the current study, increases in the LPP and ssVEP for unpleasant compared to neutral pictures during passive viewing were uncorrelated with one another. Similarly, changes in the LPP as a function of directed attention did not predict corresponding changes in the ssVEP. Despite being functionally similar in terms of their sensitivity to both passive viewing and directed attention, these measures appear to be relatively independent. One possible explanation is that the LPP and ssVEP index distinct correlates and mechanisms of motivated and directed attention. Whereas the LPP may track activation in parietal attentional networks (Sabatinelli et al., 2007), emotional modulation of ssVEP amplitude may reflect re-entrant modulation of lower-tier visual cortex from multiple sources (Keil et al., 2009). In this way, the LPP and ssVEP may provide complementary information about distinct patterns of neural activity relevant to emotional attention.

By combining these EEG measures with other functional neuroimaging methods (e.g., fMRI), a more comprehensive understanding of distinct and overlapping neural networks involved in emotion-attention interactions might be achieved. As an example of this approach, one recent study combined fMRI and EEG to investigate the temporal and spatial dynamics of neural activity elicited during a spatial attention task (Di Russo et al., 2007): the hemodynamic response was used to identify specific regions of activation within primary and secondary visual areas, source localization techniques yielded a correspondence between these sources and the scalp-recorded ssVEP, and phase information from the ssVEP was used to infer the timing of activation across cortical regions. Extending this approach to the study of emotional attention – and incorporating both the ssVEP and LPP – may be fruitful for identifying specific neural networks that are sensitive to manipulations of directed and motivated attention, and understanding how activity in those networks unfolds over time.

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