Fear and Disgust: Brain Responses to Two Signals of Motivational Salience

by

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A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of Bachelor of Science

with Honors in Brain, Behavior, and Cognitive Science from the

University of Michigan

2011

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Abstract

The late positive potential (LPP) is an event-related potential (ERP) component occurring in the centro-parietal scalp region and has shown to be reactive to emotional stimuli. The current study sought to evaluate LPP response to disgust and threat images, in particular, and to compare this response to self-report measures of disgust sensitivity, state and trait anxiety, and stimulus ratings. Twenty-eight participants were shown ninety emotionally evocative images (30 disgust, 30 threat, 30 neutral) while EEG data was recorded. Disgust images elicited a greater LPP than threat and neutral images, respectively. Disgust sensitivity ratings were correlated with LPP magnitude in response to both disgust and threat images, while anxiety measures were not correlated with LPP magnitude in response to any image type. Results show that magnitude of LPP response may be most related to stimuli and emotions significant to the individual; however, more research is necessary to corroborate this claim.

Keywords: late positive potential, disgust, event-related potential, ERP

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Based on evolutionary theory, individuals must devote attention to stimuli conveying information relevant to survival and reproduction in order to thrive in a given environment. It has been posited that that the types of emotions evoked by various stimuli help individuals determine which stimuli are relevant and also motivate them to act (Darwin 1872/1965; James 1894; Phan et al., 2005). For instance, stimuli evoking feelings of fear or threat signal the potential for harm and thus motivate individuals to avoid that harm (Bradley, Codispoti, Cuthbert, & Lang, 2001; Hajcak, Weinberg, MacNamara, & Foti, in press; Lang, Bradley, & Cuthbert, 1997; Lang, Bradley, & Cuthbert, 1998). In the modern world, harm can come from physically threatening stimuli, such as guns or knives; additionally, harm can come from internally threatening stimuli that could cause disease, such as contaminated objects or rancid meat (Curtis, 2011). Thus, the emotion of fear perhaps most intuitively signals threat; however, the emotion of disgust may also signal threat (Davey, 2011). Given this, both physically threatening and disgusting stimuli may both be motivationally salient to individuals because they convey information potentially affecting survival and reproduction (Bradley et al., 2003; Curtis, 2011; Davey, 2011; Schupp et al., 2004).

Recently, it has been posited that the evolutionary purpose of disgust is to signal danger to the individual and to motivate avoidance of potential disease-causing agents (Curtis, 2011; Davey, 2011). This idea is bolstered by evidence suggesting that many objects that individuals find disgusting are related to diseases. Curtis (2011) lists contaminated foods and vomit as disgusting items related to diarrheal infections; skin lesions and nasal discharges related to staphylococcal skin infections; and sexual and body fluids related to AIDS (Curtis, 2011). Furthermore, as Davey (2011) describes, disgust is correlated with various mental disorders commonly related to fear and anxiety, such as obsessive-compulsive disorder (OCD), blood-injection-injury phobia (BII), and spider phobia. Given that anxiety disorders are typically related to threat response, it follows that disgust may convey a version of threat (Davey, 2011).

Various brain regions have been correlated with disgust. For example, a review by Phan, Wager, Taylor, and Liberzon (2002) cited that the majority of studies reviewed (60%) found activation of the basal ganglia in response to stimuli inducing disgust (Phan, Wager, Taylor, & Liberzon, 2002). Additionally, a study by Sprengelmeyer, Rausch, Eysel, and Przuntek (1998) found activation in the basal ganglia as well as the insula in response to faces depicting disgust (Phan et al., 2002; Sprengelmeyer, Rausch, Eysel & Przuntek, 1998). A study by Wicker and associates (2003) also found activation in the insula and the right anterior cingulate cortex (ACC) in response to disgust stimuli (Wicker et al., 2003).

The brain regions implicated in disgust have been shown to be distinct from those involved in fear (e.g., Shapira et al., 2003; Sprengelmeyer et al., 1998), such as the amygdala (see Phan et al., 2002; Phillips et al., 1998). However, localizing emotional responses in the brain may not provide the full picture in evaluating the similarities between disgust and threat given that networks of structures can be involved in producing emotional responses; for instance, there is evidence for a system of brain structures involved in processing aversive stimuli, including the amygdala, insula, anterior cingulate cortex (ACC), ventrolateral orbitofrontal cortex, hippocampus, parahippocampal gyrus, dorsal striatum, rostral temporal gyri, and thalamus (Hayes & Northoff, 2011).

In addition to studies using functional magnetic resonance imaging (fMRI) to identify brain regions involved in emotional processing, electroencephalography (EEG) has been used to measure event-related potentials (ERPs), which occur as a result of electrical signaling between neurons in the brain, in response to emotional stimuli. There is evidence that a particular component (characteristic peak in electrical activity happening at certain time points in response to various types of stimuli) called the late positive potential (LPP) tracks with motivational salience (see Briggs & Martin, 2009; Hajcak et al, in press; Schupp et al., 2004; Weinberg & Hajcak, 2010). Based on this evidence, the LPP has been shown to be a valid measure of motivational salience (Hajcak et al., in press).

Following this, recent research has shown the greatest LPP responses to images conveying threat and mutilation, as compared with other unpleasant images, such as disgust (e.g., Schupp et al., 2004; Weinberg & Hajcak, 2010). This larger LPP response to images conveying threat and mutilation is to be expected because these types of images convey information most directly related to survival (Weinberg & Hajcak, 2010). However, it is less clear why disgust would not also elicit a comparable LPP given that disgust may also relate potential harm to survival (i.e., through disease) (Curtis, 2011; Davey, 2011). Although, these studies did not measure the level of disgust elicited by the pictures on a disgust rating scale; therefore, the level of disgust experienced by the participants remains unknown. Perhaps, more truly disgusting images would, in fact, elicit a larger LPP response- one comparable to that elicited by threat images.

If the LPP tracks with motivational salience, then individual differences in what constitutes motivationally salient information should be reflected in the magnitude of the LPP (Hajcak et al., in press). Accordingly, research has shown that anxious individuals show greater LPP responses to threat images than non-anxious individuals (see Hajcak et al., in press; Holmes, Nielsen, Tipper, & Green, 2009; MacNamara & Hajcak, 2009; MacNamara & Hajcak, 2010). Also, the LPPs of phobic individuals have been shown to be higher than those of controls when viewing images relevant to the phobia (see Flykt & Caldara, 2006; Hajcak et al., in press; Michalowski et al., 2009; Schienle, Schafer, & Naumann, 2008). Schienle, Schafer, and Naumann (2008) also found that phobic individuals differed from controls in LPP response to phobia-relevant stimuli but not to non-specific fear-inducing, disgust, or neutral stimuli (Hajcak et al., in press; Schienle et al., 2008). Michalowski and colleagues (2009) similarly found that phobic individuals and controls differed in LPP response to phobia-relevant stimuli but not to unpleasant, neutral, or pleasant stimuli (Hajcak et al., in press; Michalowski et al., 2009). Given that LPP seems to track with individual differences in motivational salience, it may be the case that individual differences in disgust sensitivity elicit larger LPPs to disgust stimuli while showing similar LPP responses to threat stimuli (see Hajcak et al., in press; Michalowski et al., 2009; Schienle et al., 2008). It must first be established, however, that the LPP does, in fact, track with motivational salience.

The LPP is a large, slow waveform that has been shown to be reactive to emotional stimuli (e.g., pictures depicting unpleasant or pleasant scenes) (Hajcak, Dunning, & Foti, 2007; Schupp et al., 2000; Weinberg & Hajcak, 2010) and is typically observed in the centro-parietal region of the scalp (Foti & Hajcak, 2008; Hajcak et al., 2007; Schupp et al., 2000; Weinberg & Hajcak, 2010). This waveform has been detected beginning in the earliest ranges at approximately 200-300 ms post-stimulus presentation (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000) and at the latest ranges at approximately 1,000-1,500 ms post-stimulus presentation (Weinberg & Hajcak, 2010).

The LPP seems to be reactive to both pleasant and unpleasant stimuli. For example, in a study by Schupp et al. (2000), 60 pictures of varying emotional quality (20 unpleasant, 20 pleasant, and 20 neutral) were presented to participants. Images were selected from the

International Affective Picture System (IAPS), a large bank of pictures for which normative ratings of pleasure, dominance, and arousal have been collected. Results showed that unpleasant and pleasant images elicited larger LPPs than neutral images using a random picture presentation (Schupp et al., 2000). In another study by Hajcak and colleagues (2007), participants were first shown a series of 120 emotional images (also including unpleasant, pleasant, and neutral pictures) selected from the IAPS; for the second portion of the study, participants were asked to perform concurrent mathematics tasks of varying difficulty as the images were presented. Researchers found larger LPP responses to pleasant and unpleasant visual stimuli in the first task; in addition, they found that having participants perform the mental arithmetic tasks did not significantly modulate the LPP, offering more evidence for the involuntary and robust nature of this signal (Hajcak et al., 2007). A later study also provides support for the presence of the LPP; this study involved a passive viewing task of 135 images including a wide array of emotional images and also found greater LPP responses elicited by unpleasant and pleasant images versus neutral (Weinberg & Hajcak, 2010). Thus, there is substantial evidence of the presence of an LPP response to emotional stimuli.

Based on these and other studies (e.g., Cuthbert et al., 2000; Dillon, Cooper, Grent-'t-Jong, Woldorff, & LaBar, 2006; Hajcak, Dunning, & Foti, 2009; Schupp et al., 2004), the LPP seems to be reactive to emotional content, in general, whether in response to stimuli with positive or negative valence. Some research has shown evidence specifically for a negativity bias, however. For example, a study by Ito, Larsen, Smith, and Cacioppo (1998) showed a greater LPP in response to emotionally negative images (i.e., mutilated face, handgun aimed at camera) as compared to positive images (i.e., red Ferrari, people on a roller coaster) even though the negative and positive images were matched in terms of normative valence and arousal ratings (i.e., the negative images were equally unpleasant and arousing as the positive images were pleasant and arousing), providing support for a negativity bias in the LPP (Ito, Larsen, Smith, & Cacioppo, 1998). Furthermore, a later study included more pleasant and unpleasant images (40 pleasant, 40 unpleasant, 40 neutral) than the previous study and still showed a larger LPP in response to negative images as compared with positive and neutral images, respectively, thus adding evidence for the presence of a negativity bias in the LPP (Foti, Hajcak, & Dien, 2009). Other studies have reinforced these results, as well (e.g., Hajcak & Olvet, 2008; Huang & Luo, 2006).

Given this evidence in support of a negativity bias, the LPP seems to be reactive to emotional content, generally, and also seems to track with valence, increasing from neutral to pleasant to unpleasant. However, recent research investigating what the LPP may be specifically reactive to suggests that the LPP may not be most closely tied to emotional valence.

A recent study by Weinberg and Hajack (2010) presented participants with a set of images varying in broad emotional content (i.e., 45 pleasant, 45 neutral, 45 unpleasant). These broad images categories were also split into specific subcategories (pleasant: 15 erotic, 15 affiliative, 15 exciting; neutral: 15 objects, 15 scenes with people, 15 scenes without people; unpleasant: 15 mutilation, 15 threat, and 15 disgusting). Results showed that when analyzed using broad category distinctions, there was evidence for a negativity bias; however, when the broad categories were broken down, there were discrepancies found within the specific subcategories. Within the unpleasant domain, images depicting mutilation produced the largest LPP response; within the pleasant category, images depicting erotic scenes produced the largest LPP response, and these respective LPPs were of similar magnitude. Smaller than those produced by mutilation and erotic images, threat images within the unpleasant category and affiliative images within the pleasant category produced similar LPPs, as well. However, disgusting pictures and exciting pictures generated markedly smaller LPP amplitudes within their respective categories. Scenes with people generated larger LPPs than images without people and objects within the neutral domain. Additionally, while disgusting pictures generated LPPs similar to those of neutral images with people, exciting pictures generated even smaller LPP amplitudes. Due to these discrepancies, researchers redefined the broad categories to include only mutilation and threat images in the unpleasant category, only erotic and affiliative images in the pleasant category, and only images without people and objects in the neutral category. Results did not show evidence for a negativity bias with the discrepant categories left out (Weinberg & Hajcak, 2010).

Weinberg and Hajcak (2010) posited that the negativity bias found in past research may have been produced by the markedly smaller LPP generated by exciting images pulling down the average for pleasant-category images (Weinberg & Hajcak, 2010). Researchers proposed this in consideration of the fact that many past studies have included exciting IAPS images in the pleasant category, including the studies mentioned above (see Foti et al., 2009; Hajcak & Olvet, 2008; Huang & Luo, 2006; Ito et al., 1998; Weinberg & Hajcak, 2010). Given these results and others (e.g., Hajcak & Nieuwenhuis, 2006), the LPP may track more closely with a different aspect of emotionality than valence.

In light of the strong evidence that the LPP is, indeed, sensitive to emotional stimuli but may not track exclusively with emotional valence, a pertinent follow-up question exists regarding whether the LPP tracks with arousal or intensity of emotional stimuli. A study by Cuthbert and associates (2000) set out to address this question. Participants were shown a series of images belonging to unpleasant, pleasant, or neutral categories. They were also asked to rate the images on scales of valence and arousal. Results showed a positive correlation between arousal ratings and magnitude of the LPP (i.e., the more arousing the stimulus, the greater the LPP response). Thus, arousal may modulate the LPP in a stronger way than valence (Cuthbert et al., 2000).

Also helping to answer this question, recent research has shown that cognitive reappraisal of stimuli modulates the LPP. In a study by Hajcak and Nieuwenhuis (2006), participants first passively viewed images of varying emotional quality (i.e., neutral, pleasant, unpleasant); then, in a second viewing task, they were asked to cognitively reappraise the unpleasant images in order to make them seem less unpleasant (i.e., to affect emotional arousal to the images). Results showed a greater LPP response to unpleasant and pleasant stimuli versus neutral in the passive viewing context; furthermore, as compared to the passive viewing condition, the LPP was reliably smaller when unpleasant images were reappraised. This smaller LPP was positively correlated with self-report measures of emotional intensity; thus, the LPP was again shown to be sensitive to the emotional quality of stimuli (i.e., pleasant/unpleasant versus neutral), in general, as well as to emotional awareness of stimuli (i.e., experienced intensity) (Hajcak & Nieuwenhuis, 2006).

Another recent study by Foti and Hajcak (2008) built upon these results. In this study, participants were presented with a series of neutral and unpleasant images. Neutral images were preceded by neutral descriptions; unpleasant images were either preceded by a more negative description or a more neutral description (Foti & Hajcak, 2008). This design addresses the potential issue of cognitive load as a confounding variable in the Hajcak and Nieuwenhuis (2006) study (Hajcak & Nieuwenhuis, 2006); that is, participants in this study did not have to come up with their own reappraisals, they were simply presented with a preceding description, helping to eliminate any effects from participants allocating resources to thinking about new descriptors. Results showed that unpleasant images preceded by more negative descriptions elicited a larger LPP than unpleasant images preceded by more neutral descriptions. However, while arousal ratings generally tracked with magnitude of LPP, changes in arousal ratings at the individual level did not translate to LPP modulation (Foti & Hajcak, 2008).

Although the LPP seems to more closely track with arousal than valence, arousal does not provide the full picture. For example, in the Weinberg and Hajcak (2010) study, it was shown that although participants rated exciting images higher on the arousal scale than neutral images including people, the LPP generated by exciting images was smaller than that generated by neutral scenes with people. Furthermore, although disgust and threat images were not rated significantly differently in terms of arousal, disgust images generated a significantly smaller LPP than threat images (Weinberg & Hajcak, 2010). Taken together, the LPP does not seem to directly track with arousal.

Perhaps, motivational salience is the primary factor modulating LPP response (Hajcak et al, in press). Motivational salience refers to the relevance of stimuli and evoked emotion to the individual. This can mean evolutionary relevance, such as images of threat relating information important to survival, or it can mean emotional relevance, for instance social scenes evoking heightened anxiety in an individual with social phobia. This idea is reinforced by the Weinberg and Hajcak (2010) study, which showed the greatest LPP response to mutilation images and threat images, respectively. In evolutionary terms, information relating to mutilation/death and threat would seemingly be most important in providing survival advantages; thus, it follows that brain components may be most reactive to these types of images (Weinberg & Hajcak, 2010).

The idea of motivational relevance was explored in a recent study by Briggs and Martin (2009). Results showed greater P3 (a component of the LPP) activation in response to highly arousing sexual images versus highly arousing sport/adventure images. Thus, given that these image categories are rated as similarly arousing, perhaps motivational salience is the key issue affecting the amplitude of the P3. In other words, due to the fact that sexual stimuli convey information more relevant to survival (reproduction) than sport/adventure images do, those images also elicit larger brain responses (Briggs & Martin, 2009). Furthermore, a study by Schupp et al. (2004) showed the presence of a greater LPP response to erotic images in the pleasant category (as compared with family and baby pictures) and mutilation image in the unpleasant category (in comparison with threat images) (Schupp et al., 2004).

Taken together, it seems that motivational salience may be the component of primary pertinence when evaluating the reactivity of the LPP. The Hajcak and Weinberg (2010) study contributes greatly to the literature in terms of delineating the LPP in response to specific semantic categories and in reevaluating a supposed negativity bias in the LPP. It also provides a framework for understanding the potential connection between the LPP and motivational salience, given that the LPP was greatest in response to images of mutilation and eroticism, which both convey information important to survival (Weinberg & Hajcak, 2010). However, questions remain about what constitutes motivational salience and relevance for different individuals.

The current study aims to evaluate the potential relationship between disgust sensitivity and LPP response to emotional images, as well as state and trait anxiety and the LPP. Given that the LPP seems to track with motivational salience, we hypothesize that results of previous studies will be replicated and that the LPP will be larger in response to unpleasant images versus neutral images (e.g., Hajcak et al., 2007; Schupp et al., 2000; Weinberg & Hajcak, 2010). Furthermore, we hypothesize that participants, regardless of disgust sensitivity, will elicit the lowest LPPs in response to neutral images. We also expect that participants, regardless of disgust sensitivity, will elicit the highest LPPs in response to threat images, which will be positively correlated with anxiety levels (Weinberg & Hajcak, 2010). However, we hypothesize that more disgust-sensitive individuals, as evidenced by self-report ratings, will elicit larger LPPs in response to disgust images than less disgust-sensitive individuals. Thus, it may be the case that motivational salience modulates the LPP response to emotional images; however, individual differences in emotional processing may modulate what is and is not motivationally salient to various individuals. These results could have implications for the understanding of mental illnesses typified by disgust sensitivity, namely obsessive-compulsive disorder (OCD).

Method

Participants

Twenty-eight healthy volunteers (16 females) took part in the study (mean age = 22.07 ± 3.62, range = 18-32 years). All participants had no history or signs of neurological, psychiatric (including substance and alcohol abuse/dependence in remission for less than one year), or medical illness, as confirmed by a phone screen based on the Structured Clinical Interview for the DSM-Non-Patient edition (SCID-NP; APA, 1994; First, Spitzer, Gibbon, & Williams, 1996). All participants gave written informed consent after explanation of the experimental protocol, as approved by the University of Michigan Institutional Review Board.

Self-Report

Immediately prior to the start of the session participants were asked to complete the Disgust Propensity and Sensitivity Scale – Revised (DPSS-R), a 16-item measure designed to test the frequency of experiencing disgust (propensity) and the emotional impact of those symptoms (sensitivity) using a five-point frequency rating scale (“never”, “rarely”, “sometimes”, "often", "always") (van Overveld, de Jong, Peters, Cavanagh, & Davey, 2006). We also collected participants' responses to the State Trait Anxiety Inventory (STAI; Spielberger, 1983), which is a 40-item questionnaire that measures reported state anxiety and trait anxiety based on 4-choice Likert scale ("not at all" to "very much so"). Scores range from 20-80 with higher scores representing higher anxiety (Tilton, 2008).

Visual Stimuli

Ninety pictures were chosen from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2008) and a proprietary set developed in the lab (50 IAPS, 40 from proprietary set). Images were classified into three valence categories: disgust (e.g., dirty toilets, vomit), n = 30; threat (e.g., weapons, angry faces), n = 30; and neutral (e.g., a clock, person reading), n =30. All pictures were matched in color composition, image complexity, and content.

Visual stimuli were presented on a computer screen using Presentation software (Neurobehavioral Systems, Inc.; Albany, CA). Participants viewed a white fixation cross on a black background prior to each trial.

Procedure

After completing the DPSS-R and the STAI, electroencephalograph (EEG) electrodes were attached and participants were given verbal instruction that they would be passively viewing pictures of varying emotional quality. Participants then viewed four blocks of images, each consisting of 15 trials of each picture type (i.e., disgust, threat, neutral) intermixed in random order and with each block initiated by the participant. Across the first two blocks each picture was shown once and then displayed for a second time across the last two blocks. Each picture was presented for 1 second with a jittered inter-trial interval (ITI) ranging from 500 ms – 5,000 ms.

After finishing the EEG recording, all participants viewed each of the 90 picture stimuli previously seen during the EEG session and were asked to subjectively rate the valence ("How unpleasant does this picture make you feel?"), arousal ("How intense is your emotion when you are looking at this image?"), disgust ("How disgusted do you feel when you looking at this picture?"), and threat ("How afraid do you feel when looking at this picture?") evoked by each image on a 9-point scale (1, "not at all"; 5, "somewhat"; 9, "extremely so"); their responses were self-paced, and we instructed them to take as much time as needed to perform these ratings.

Electroencephalographic Recording and Data Processing

Continuous EEG recordings were collected using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Thirty-four electrode sites (standard 32 channel setup plus Iz and FCz), based on the 10/20 system were used, as well as one electrode on each of the left and right mastoids. Electrooculogram (EOG) generated from eye movements and eye-blinks was recorded using four facial electrodes: horizontal eye movements were measured using two electrodes located approximately 1 cm beyond the outer edge of each eye; vertical eye movements and blinks were measured with two electrodes placed approximately 1 cm above and below the right eye. The EEG signal was preamplified at the electrode to improve the signal-to-noise ratio and amplified with a gain of 16x by a BioSemi ActiveTwo system (BioSemi, Amsterdam). The data were digitized at 24-bit resolution with a sampling rate of 512 Hz using a low-pass fifth order sinc filter with a half-power cutoff of 102.4 Hz. Each active electrode was measured online with respect to a common mode sense (CMS) active electrode producing a monopolar (nondifferential) channel. Offline, all data was referenced to the average of the left and right mastoids and band-pass filtered with low and high cutoffs of 0.1 and 30 Hz, respectively; eyeblink and ocular corrections were conducted per (Gratton, Coles, & Donchin, 1983).

A semiautomatic procedure was used to distinguish and reject artifacts. The specifications applied were a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100-ms intervals. These intervals were rejected from individual channels in each trial. Visual inspection of the data was then conducted to detect and reject any remaining artifacts.

The EEG was segmented for each trial beginning 200 ms prior to picture onset and ending 1700 ms following picture onset, and the 200 ms window prior to the picture onset served as the baseline. ERPs were constructed by separately averaging the three image categories (disgust, threat, and neutral). The LPP is maximal at centro-parietal sites (Foti & Hajcak, 2008; Hajcak et al., 2007; Keil et al., 2002; Schupp et al., 2000; Weinberg & Hajcak, 2010) and was scored as the mean activity from four centro-parietal sites (Pz, Cz, CP1, and CP2) between 400-1,000 ms (Figure 1).

Data Analysis

All behavioral and ERP data were statistically evaluated using SPSS (Version 19.0) General Linear Model software and were analyzed using a within-subject ANOVA and post-hoc comparisons using paired *t* tests performed after a significant overall *F* ratio was obtained. We used a significance threshold of $p < 0.05$ (two-tailed), corrected for multiple comparisons using Bonferroni correction. The Pearson correlation coefficient (r) was also used to examine the relationship between subjective measures and LPP-related brain activity.

Results

Behavioral Data

Table 1 shows means and standard deviations for self-report ratings of arousal, valence, disgust, and threat for each picture type, and Figure 2 shows means and standard deviations for these self-report ratings, graphically. There was a main effect of picture type on ratings of arousal ($F_{(2,54)} = 41.29$, $p < 0.001$), valence ($F_{(2, 54)} = 226.64$, $p < 0.001$), disgust ($F_{(2, 54)} = 234.68$, $p < 0.001$), and threat ($F_{(2, 54)} = 86.91$, $p < 0.001$). Post-hoc comparisons confirmed that both threat and disgust images were significantly more unpleasant, emotionally arousing, disgusting, and threatening than neutral images ($p < 0.001$ for all comparisons). Disgust and threat images were not rated significantly differently in terms of arousal ($t_{(27)} = 0.915$, $p > 0.05$), however, disgust images were rated as significantly more unpleasant ($t_{(27)} = 5.15$, $p < 0.001$) and disgusting ($t_{(27)} = 15.50$, $p < 0.001$) than threat images, and threat images were rated as more threatening than disgust images ($t_{(27)} = 9.46$, $p < 0.001$).

LPP

The grand average ERPs elicited by each picture type (e.g., disgust, threat, and neutral) at the central-parietal cluster are presented in Figure 3 (right), and mean LPP area measures are presented in Table 1. As shown in Figure 3 (right), the overall magnitude of the LPP differed as a function of picture category ($F_{(2, 54)} = 24.91$, $p < 0.001$). Specifically, the LPP elicited by threat ($t_{(27)} = 4.86$, $p < 0.001$) and disgust ($t_{(27)} = 6.01$, $p < 0.001$) images were both significantly greater than that elicited by neutral images. Interestingly, the difference in average LPP magnitude between disgust and neutral images was greater than that between threat and neutral images ($t_{(27)} = 2.83$, $p = 0.009$). Figure 3 (left) shows topographic maps of voltage differences (in μV) for disgust minus neutral images (left) and threat minus neutral images (right) across all participants from 400-1,000 ms following picture onset.

Self-Report Data

As shown in Figure 4, the sensitivity subscale of the DPSS-R was significantly and positively correlated with the LPP elicited by disgust compared to neutral images (right) ($r_{(28)}$ = 0.37, p = 0.05), and the LPP elicited by threat compared to neutral images (left) ($r_{(28)}$ = 0.04, p = 0.01). However, we did not find any significant correlations with the LPP elicited by any of the picture types and the propensity subscale of the DPSS-R or the STAI (e.g., state, trait) ($p > 0.05$). Two participants were left out of the average STAI measures due to incomplete responses.

Discussion

The current study investigated electrocortical response to viewing images of varying emotional quality (i.e., disgust, threat, and neutral). Results showed that the LPP elicited by unpleasant images (i.e., disgust and threat) was greater than that elicited by neutral images. More specifically, the LPP elicited by disgust images was greater than that elicited by threat images. Analyses showed a positive correlation between the sensitivity subscale of the DPSS-R and the LPP elicited by disgust images as well as threat images.

Results of the current study demonstrating a larger LPP in response to unpleasant images versus pleasant images reinforce those in the literature that the LPP is an observable ERP component responsive to emotional stimuli, in general (see Hajcak et al., 2007; Schupp et al., 2000; Weinberg & Hajcak, 2010). Thus, our first hypothesis confirming the presence of the LPP was supported.

Interestingly, in the current study disgust images generated a larger LPP than threat images, which is not consistent with results of previous studies (e.g., Schupp et al., 2004;

Weinberg & Hajcak, 2010), nor is it consistent with a model of LPP tracking most closely with motivational salience. Although, while existing research often takes into account valence and arousal measures, most does not include data on the accuracy of emotional stimuli. That is, in the current study participants rated stimuli on scales of disgust and threat as well as valence and arousal so as to validate that the disgust stimuli were, in fact, disgusting, and that the threat images evoked feelings of threat. It was validated that the disgust images were rated by participants as most disgusting of the three picture types, followed by threat and neutral images, respectively, and threat images were rated as most threatening, followed by disgust and neutral images, respectively. Thus, the images categories matched the participants' ratings, ensuring that the images evoked the intended emotion.

However, data also suggested that the disgust stimuli used were more disgusting to participants than the threat images were threatening. Following this, perhaps the greater LPP response to disgust images was due to the fact that those stimuli were more "true to form" in evoking what they were meant to evoke. Thus, in the widely used IAPS set, it may be difficult to tell whether participants may also feel disgusted by images of mutilation, for example. In this case, drawing a distinct conclusion about whether the LPP is reactive to feelings of threat induced by images of mutilation or to feelings of threat induced by disgust is difficult to declare without further data. Perhaps some collections of IAPS disgust images are more effective at conveying disgust than others. Therefore, an interesting point of further research could involve taking measures of evoked emotion for all stimulus categories to verify that each category is conveying what it is meant to convey. This way, the character of LPP reactivity could be more clearly delineated. It should be mentioned that the image sets used in the current study were not balanced with respect to source. That is, the disgust images included proportionately more images from the proprietary set than did the threat images or the neutral images. Thus, it may be difficult to draw concrete conclusions about the qualities of the images in a general sense, as normative ratings are not available for the proprietary set.

In terms of the idea of motivational relevance being conveyed through disgust sensitivity, for example, the current study showed that scores on the sensitivity subscale of the DPSS-R positively correlated with the LPP generated by both disgust and threat images. Since the correlation was present with both disgust and threat images, this result does not flawlessly support the hypothesis that disgust sensitivity may convey the motivational salience of disgust, in particular, and in turn, predict LPP response to disgust images; however, there are various interpretations of this data.

For example, since the LPP seems to track with motivational salience and disgust images elicited a large LPP in comparison with neutral images and with threat images, then it follows that disgust is motivationally relevant. Perhaps, like threatening images, disgusting images represent a threat signal or the potential for harm (Curtis, 2011; Davey, 2011). While threatening images may convey the potential for external physical harm, perhaps disgusting images convey the potential for internal harm, such as that from disease, as described in Curtis (2011) and Davey (2011) (Curtis, 2011; Davey, 2011). Furthermore, perhaps disgust sensitivity is also related to threat sensitivity, considering that contamination could be considered threatening to disgust-sensitive individuals.

Alternatively, since the participants represented a pool of healthy individuals, perhaps the range of disgust sensitivity does not span wide enough to draw any clear conclusions about disgust sensitivity and its relation to LPP in response to emotional images. Further research could compare different populations of individuals; for example, healthy controls could be compared with people suffering from obsessive-compulsive disorder (contamination subtype). This may provide a more distinct example of LPP response to individuals with heightened disgust sensitivity versus a control group of healthy volunteers.

This research could have far-reaching implications for the study of OCD. OCD is an Axis-I anxiety disorder typified by recurrent, undesired thoughts (obsessions) and repeated practices to decrease anxiety elicited by those thoughts (compulsions) (APA, 1994; Gehring, Himle, & Nisenson, 2000). Most commonly, OCD obsessions center on concerns about contamination, for instance, the fear of contracting an illness from germs (APA, 1994; Olatunji, Sawchuk, Lohr, & de Jong, 2004). A common compulsion in response to this type of OCD is repeated hand washing to decrease the agitation related to the fear (APA, 1994).

A study by Woody and Tolin (2002) showed that those with OCD scored higher on the Disgust Scale (DS; Haidt, McCauley, & Rozin, 1994) than a non-clinical sample, suggesting that these individuals are more sensitive to disgust (Woody & Tolin, 2002) and, presumably, that disgust is motivationally relevant to these individuals. If the LPP tracks with motivational salience and, as a result, with disgust sensitivity then perhaps the pathophysiology of the illness could be better understood. Furthermore, if disgust sensitivity is a hallmark of OCD, specifically, and not of other anxiety disorders, then the LPP could potentially serve as an electrophysiological marker for this illness. Additional studies could evaluate other anxiety disorders, for example post-traumatic stress disorder (PTSD), in order to assess the reactivity of the LPP in response to stimuli evoking emotions relevant to this disorder (e.g., threat) to determine the specificity of the LPP as a potential endophenotype for various disorders.

In all, the LPP seems to be most reactive to motivational salience. However, motivational salience may differ on an individual level and may be related to pathology when expressed in extremes. If the LPP can predict some of the emotional processing discrepancies between mentally healthy people and those suffering from psychiatric disorders, then perhaps more can be understood about the pathophysiology of these illnesses. In these terms, further research involving the LPP and motivational salience will be important in promoting our comprehension of mental disorders and the brain.

References

APA (1994). *Diagnostic and Statistical Manual of Psychiatry, 4th edition* (4th ed.). Washington D.C.: American Psychiatric Publishing, Inc.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1*(3), 276-298.

Bradley, M. M., Sabatinelli, D., Lang, P. J., Fitzsimmons, J. R., King, W., & Desai, P. (2003). Activation of the visual cortex in motivated attention. *Behavioral Neuroscience, 117*(2), 369-380.

Briggs, K. E., & Martin, F. H. (2009). Affective picture processing and motivational relevance: Arousal and valence effects on ERPs in an oddball task. *International Journal of Psychophysiology, 72*(3), 299-306.

Curtis, V. (2011). Why disgust matters. *Philosophical Transactions of the Royal Society of London.Series B, Biological Sciences, 366*(1583), 3478-3490.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology, 52*(2), 95-111.

Darwin, C. (1872/1965). *The expression of the emotions in man and animals*. London: J. Murray.

Davey, G. C. L. (2011). Disgust: The disease-avoidance emotion and its dysfunctions. *Philosophical Transactions of the Royal Society of London.Series B, Biological Sciences, 366*(1583), 3453-3465.

Dillon, D. G., Cooper, J. J., Grent-'t-Jong, T., Woldorff, M. G., & LaBar, K. S. (2006). Dissociation of event-related potentials indexing arousal and semantic cohesion during emotional word encoding. *Brain Cognition, 62*(1), 43-57.

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. (1996). *Structured clinical interview for the DSM-IV Axis I disorders (SCID I/P, Version 2.0)*. New York: Biometrics Research Department, New York State Psychiatric Institute.

Flykt, A., & Caldara, R. (2006). Tracking fear in snake and spider fearful participants during visual search: A multi-response domain study. *Cognition & Emotion, 20*(8), 1075-1091.

Foti, D., & Hajcak, G. (2008). Deconstructing reappraisal: Descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience, 20*(6), 977-988.

Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology, 46*(3), 521-530.

Gehring, W. J., Himle, J., & Nisenson, L. G. (2000). Action-monitoring dysfunction in obsessive-compulsive disorder. *Psychological Science, 11*(1), 1-6.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55*(4), 468-484.

Haidt, J., McCauley, C., & Rozin, P. (1994). Individual differences in sensitivity to disgust: A scale sampling seven domains of disgust elicitors. *Personality and Individual Differences, 16*(5), 701-713.

Hajcak, G., Dunning, J. P., & Foti, D. (2007). Neural response to emotional pictures is unaffected by concurrent task difficulty: An event-related potential study. *Behavioral Neuroscience, 121*(6), 1156-1162.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: Time-course of the late positive potential. *Clinical Neurophysiology, 120*(3), 505-510.

Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective, Behavioral, Neuroscience, 6*(4), 291-297.

Hajcak, G., & Olvet, D. M. (2008). The persistence of attention to emotion: Brain potentials during and after picture presentation. *Emotion, 8*(2), 250-255.

Hajcak, G., Weinberg, A., MacNamara, A., & Foti, D. (in press). ERPs and the study of emotion. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford handbook of ERP components*. New York: Oxford University Press.

Hayes, D. J., & Northoff, G. (2011). Identifying a network of brain regions involved in aversion-related processing: A cross-species translational investigation. *Frontiers in Integrative Neuroscience, 5*(49), 1-21.

Holmes, A., Nielsen, M. K., Tipper, S., & Green, S. (2009). An electrophysiological investigation into the automaticity of emotional face processing in high versus low trait anxious individuals. *Cognitive, Affective, & Behavioral Neuroscience, 9*(3), 323-334.

Huang, Y. X., & Luo, Y. J. (2006). Temporal course of emotional negativity bias: An ERP study. *Neuroscience Letters, 398*(1-2), 91-96.

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, 75*(4), 887-900.

James, W. (1894). Discussion: The physical basis of emotion. *Psychological Review, 1*(5), 516-529.

Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology, 39*(5), 641-649.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation, and action. In P. J. Lang, R. F. Simons, & M. Balaban (Eds.). *Attention and orienting: Sensory and motivational processes* (pp. 97-137). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). Emotion, motivation, and anxiety: Brain mechanisms and psychophysiology. *Biological Psychiatry, 44*(12), 1248-1263.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual.* Gainsville, FL: University of Florida.

MacNamara, A., & Hajcak, G. (2009). Anxiety and spatial attention moderate the electrocortical response to aversive pictures. *Neuropsychologia, 47*(13), 2975-2980.

MacNamara, A., & Hajcak, G. (2010). Distinct electrocortical and behavioral evidence for increased attention to threat in generalized anxiety disorder. *Depression and Anxiety, 27*(3), 234-243.

Michalowski, J. M., Melzig, C. A., Weike, A. I., Stockburger, J., Schupp, H. T., & Hamm, A. O. (2009). Brain dynamics in spider-phobic individuals exposed to phobia-relevant and other emotional stimuli. *Emotion, 9*(3), 306-315.

Olatunji, B. O., Sawchuk, C. N., Lohr, J. M., & de Jong, P. J. (2004). Disgust domains in the prediction of contamination fear. *Behaviour Research and Therapy, 42*(1), 93-104.

Phan, K. L., Fitzgerald, D. A., Nathan, P. J., Moore, G. J., Uhde, T. W., & Tancer, M. E. (2005). Neural substrates for voluntary suppression of negative affect: A functional magnetic resonance imaging study. *Biological Psychiatry, 57*(3), 210-219.

Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional neuroanatomy of emotion: A meta-analysis of emotion activation studies in PET and fMRI. *NeuroImage, 16*(2), 331-348.

Phillips, M. L., Young, A. W., Scott, S. K., Calder, A. J., Andrew, C., Giampietro, V., . . . Gray, J. A. (1998). Neural responses to facial and vocal expressions of fear and disgust. *Proceedings.Biological Sciences / the Royal Society, 265*(1408), 1809-1817.

Schienle, A., Schafer, A., & Naumann, E. (2008). Event-related brain potentials of spider phobics to disorder-relevant, generally disgust- and fear-inducing pictures. *Journal of Psychophysiology, 22*(1), 5-13.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology, 37*(2), 257-261.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Hillman, C. H., Hamm, A. O., & Lang, P. J. (2004). Brain processes in emotional perception: Motivated attention. *Cognition and Emotion, 18*(5), 593.

Shapira, N. A., Liu, Y., He, A. G., Bradley, M. M., Lessig, M. C., James, G. A., . . . Goodman, W. K. (2003). Brain activation by disgust-inducing pictures in obsessive-compulsive disorder. *Biological Psychiatry, 54*(7), 751-756.

Spielberger, C. (1983). *Manual for the State-Trait Anxiety Inventory, STAI (Form Y) ("Self-Evaluation Questionnaire")*. Palo Alto, CA: Consulting Psychologists Press.

Sprengelmeyer, R., Rausch, M., Eysel, U. T., & Przuntek, H. (1998). Neural structures associated with recognition of facial expressions of basic emotions. *Proceedings.Biological Sciences / the Royal Society, 265*(1409), 1927-1931.

Tilton, B. S. R. (2008). Review of the State-Trait Anxiety Inventory (STAI). *Journal of Personality*, *48*(2). Retrieved from http://www.theaaceonline.com/stai.pdf

van Overveld, W. J. M., de Jong, P. J., Peters, M. L., Cavanagh, K., & Davey, G. C. L. (2006). Disgust propensity and disgust sensitivity: Separate constructs that are differentially related to specific fears. *Personality and Individual Differences, 41*(7), 1241-1252.

Weinberg, A., & Hajcak, G. (2010). Beyond good and evil: The time-course of neural activity elicited by specific picture content. *Emotion, 10*(6), 767-782.

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in my insula: The common neural basis of seeing and feeling disgust. *Neuron, 40*(3), 655-664.

Woody, S. R., & Tolin, D. F. (2002). The relationship between disgust sensitivity and avoidant behavior: Studies of clinical and nonclinical samples. *Journal of Anxiety Disorders, 16*(5), 543-559.

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I would like to thank my mentors, Dr. K. Luan Phan and Dr. William Gehring, for their extensive help and guidance through this project. Dr. Phan provided me with vast opportunities to learn and grow as a student and as a researcher. Likewise, Dr. Gehring was instrumental in helping me pursue this research and write my thesis. I would also like to thank Christine Davie- her direction was critical to analyzing my data and writing my paper. Furthermore, I would like to thank the entire Phan Lab for their help through this project with special thanks to Mike Angstadt and Kelly Kreger, as this project would not have been possible without their help. I would additionally like to thank my parents and Claude LeRose for their tireless support.

Table 1

Mean (SD) Arousal, Valence, Disgust, and Threat Ratings (Self-Report) for Each Picture Type, as well as Mean Area Measures (μV) for the LPP (400-1,000 ms) When Viewing Each Picture Type

Picture Type	Arousal	Valence	Disgust	Threat	LPP
Neutral	2.53 (1.26)	5.82 (0.52)	1.36 (0.62)	1.40 (0.71)	2.41 (2.20)
Threat	4.98 (1.96)	2.74 (1.00)	2.36 (1.28)	5.85 (1.93)	4.27 (2.21)
Disgust	4.81 (2.03)	2.04 (0.72)	6.95 (1.68)	2.72 (1.78)	5.35 (2.43)

LPP, late positive potential

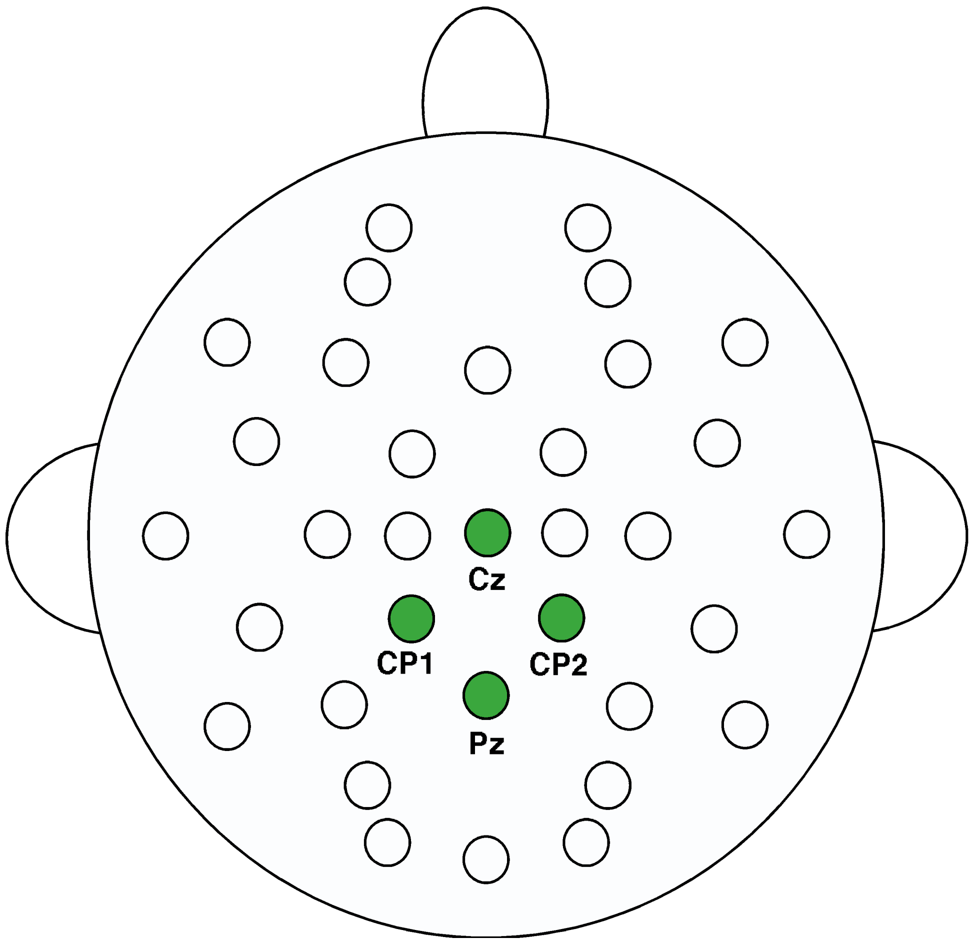

Figure 1. Diagram of 32 electrode sites. Highlighted are the four centro-parietal sites used to define the LPP (Pz, Cz, CP1, CP2).

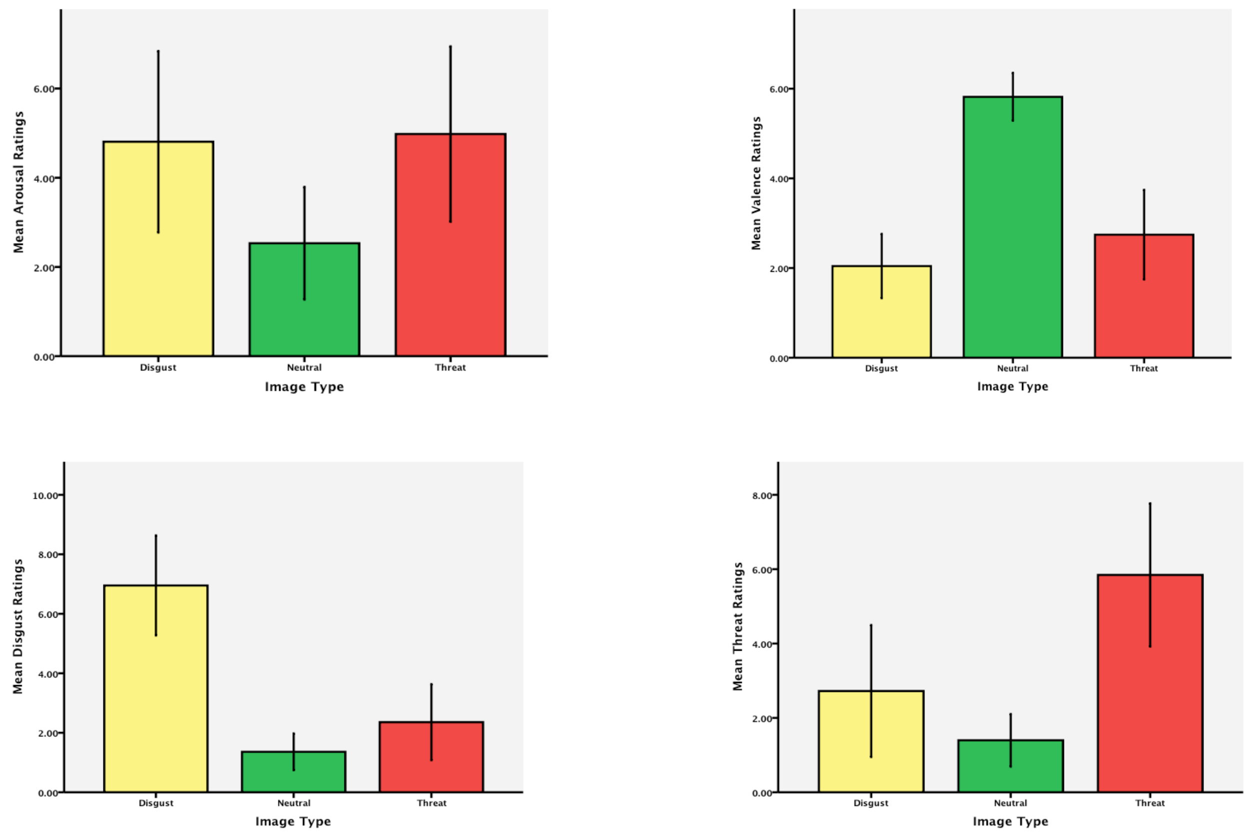

Figure 2. Mean Arousal, Valence, Disgust, and Threat Ratings (Self-Report) for Each Picture Type. Bars represent standard error of the mean.

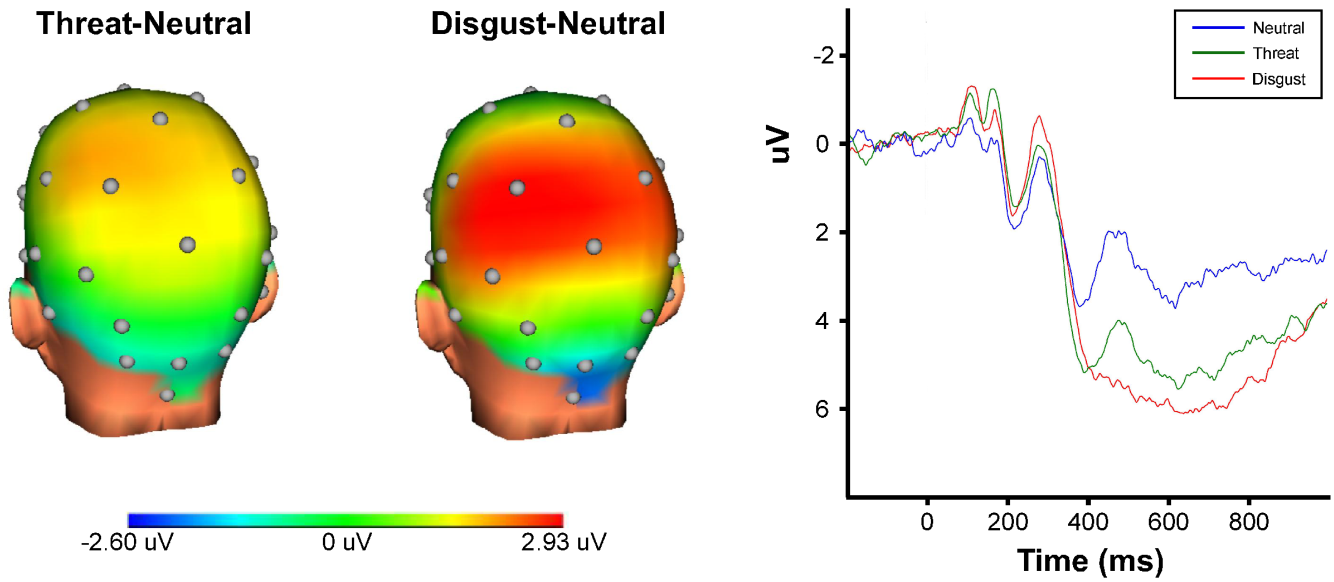

Figure 3. Topographic maps (left) illustrating voltage differences (in μV) for threat minus neutral images and disgust minus neutral images in the time range of the LPP (400-1,000 ms post-picture presentation). Also shown are stimulus-locked ERPs averaged from four centro-parietal sites (Pz, Cz, CP1, and CP2; right) for the three stimulus categories (neutral, threat, disgust).

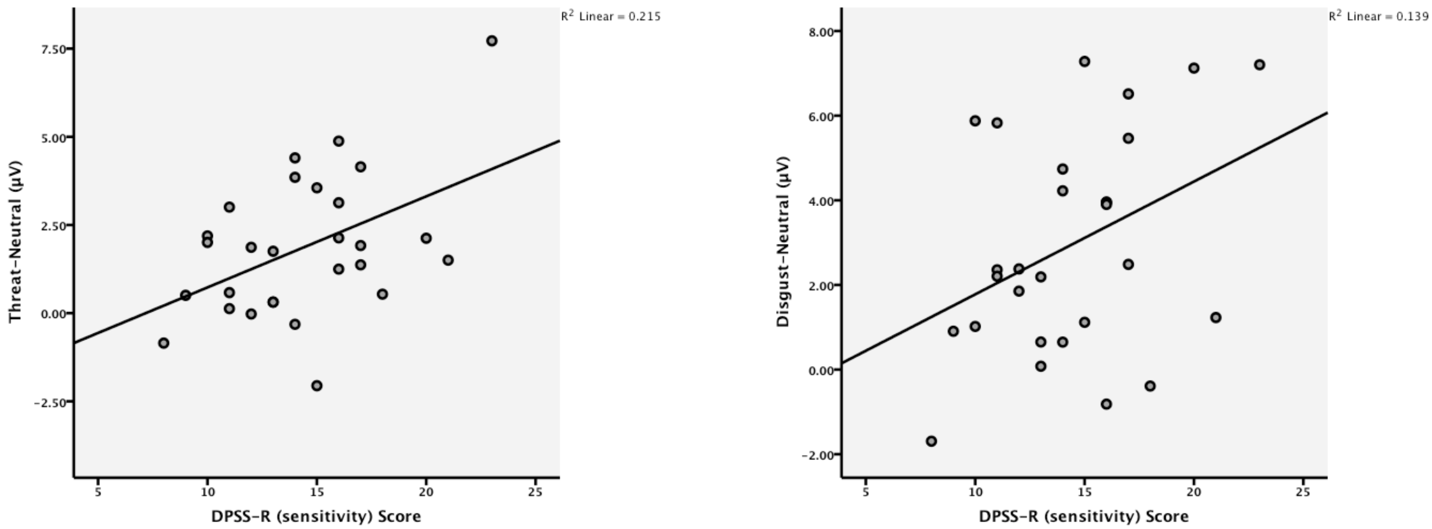

Figure 4. Correlations between DPSS-R (sensitivity) and voltage differences (in μV) for threat minus neutral images (left) and disgust minus neutral images (right) in the time range of the LPP (400-1,000 ms post-picture presentation).