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Danger and disease: Electrocortical responses to threat- and disgust-eliciting images

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ABSTRACT

Previous research suggests facilitated processing of evolutionarily significant stimuli (e.g., depictions of erotica, mutilation, threat), as reflected by augmented event-related potentials (ERPs), including the early posterior negativity (EPN) and late positive potential (LPP). Evolutionary models suggest that images that evoke disgust should be high in motivational salience, but evidence that the EPN and LPP are enhanced by disgusting images is lacking. Prior studies have employed only a small number of disgusting images that were limited in the types of content depicted. In the current study, participants viewed larger sets of disgusting, threatening, and neutral images with more varied content while electroencephalography (EEG) was recorded. Results showed that disgusting and threatening images elicited equivalent LPPs, which were both significantly increased relative to LPPs elicited by neutral images. EPN amplitudes were augmented for both disgusting and threatening relative to neutral images, though significantly more for disgust. These findings offer initial evidence that the EPN and the LPP are sensitive to disgust-eliciting pictures and that these pictures may receive processing that is at least on par with that of threatening images. Limitations of the current study and implications for future research are discussed.

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1. Introduction

Evolutionary accounts suggest that stimuli relevant to survival (e.g., detection of food, mating partners and potential danger signals) should be particularly effective at capturing attention (Lang et al., 1997) and at motivating potentially adaptive physiological and behavioral changes (e.g., fighting, fleeing, procreating; Bradley, 2009). For example, erotic stimuli may signal an increased likelihood of procreation. Increased attention towards threatening stimuli can prioritize and potentiate escape-related behaviors (Hajcak et al., 2007). Similarly, disgust, an emotion characterized by revulsion in the face of noxious stimuli, may function to protect the individual from disease (Olatunji and Sawchuk, 2005). For example, bodily fluids and rotten food, which are strong disgust elicitors, are associated with the potential for infection and sickness (Rozin et al., 2000).

Laboratory studies of emotion processing have employed pictorial depictions of emotionally evocative contents, with electrophysiological measurement demonstrating increased event-related potential (ERP) components for emotional stimuli relative to neutral stimuli (Cacioppo et al., 1994; Cuthbert et al., 2000). Preferential processing of emotional stimuli has been demonstrated during both the early and later periods of attentional capture and processing, as demonstrated by specific ERP components. For example, in the early stages of attention capture, the early posterior negativity (EPN), an occipital negativity maximal at about 230 ms post picture presentation, has been found to be larger for emotional relative to neutral images (Foti et al., 2009; Schupp et al., 2003, 2006; Weinberg and Hajcak, 2010). During later stages of stimulus presentation, the late positive potential (LPP), a positive-going centro-parietal ERP beginning approximately 300 ms after stimulus onset, emerges as larger for emotional compared to neutral stimuli, reflecting sustained attention and the elaborated processing of stimulus meaning (Dillon et al., 2006; Hajcak and Olvet, 2008; Hajcak et al., 2011; Weinberg and Hajcak, 2010).

While initial affective ERP work focused on identifying and characterizing electrocortical indices that were reliably larger for emotional compared to non-emotional stimuli, more recent investigations have examined the effects of specific picture contents on ERPs. In line with motivational accounts of attention (Lang et al., 1997) these studies

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have generally found preferential processing of images that depict content relevant to biological imperatives — specifically, the need to reproduce and to fight/flee (Bradley et al., 2001; Briggs and Martin, 2009; Schupp et al., 2004; Weinberg and Hajcak, 2010). For example, erotic images elicit larger EPNs and LPPs compared to other pleasant emotional stimuli (Schupp et al., 2003, 2004; Weinberg and Hajcak, 2010). Similarly, for unpleasant images, both the EPN and LPP are most strongly elicited by depictions of mutilation and threat relative to those of grief or loss (Schupp et al., 2003, 2004; Weinberg and Hajcak, 2010).

The sensitivity of both the EPN and LPP to threatening images (e.g., individuals pointing weapons, venomous animals) has been interpreted as an adaptive allocation of attention to danger (Weinberg and Hajcak, 2010). Despite the fact that disgust may also function to signal danger, existing studies have not found disgusting images to strongly enhance either the EPN or the LPP. Importantly, however, these studies have tended to employ disgusting stimuli with a limited range of content (i.e., only "contamination" pictures) and have sometimes pooled these images with stimuli that may be perceived as less dangerous, such as images of grief and loss. For example, Schupp et al. (2003) recorded electroencephalographic (EEG) activity while participants viewed a large set (N = 700) of pictures drawn from the International Affective Picture System (IAPS; Lang et al., 2008). The authors did not specifically report on the EPN elicited by disgusting images, but instead assigned "contamination" images to a category of negative valenced pictures of low evolutionary significance (including grief and accidents) and reported that this category was associated with smaller EPNs than mutilation and threat-related pictures (Schupp et al., 2003).

In a subsequent report, Schupp et al. (2004) found that threatening images and images depicting mutilation were associated with larger LPPs compared to contamination images. Contamination images elicited LPPs that were equivalent in magnitude to those elicited by images of sadness and loss, which tend to be rated quite low in emotional intensity (Lang et al., 2008). In a more recent study, Weinberg and Hajcak (2010) expanded on Schupp et al.'s (2004) results by including a larger set of disgusting images (N = 15 disgusting pictures compared to N = 5 contamination images), as well as erotic, affiliative, threatening and mutilation pictures. Results showed that the largest LPPs were elicited by mutilation and erotic images, with threatening images also eliciting relatively large LPPs. In contrast, disgusting images elicited significantly smaller LPPs than erotic, mutilation and threatening images. Likewise, the EPN was also more strongly elicited by both mutilation and threat compared to disgusting images (Weinberg and Hajcak, 2010).

A limitation of the studies reviewed above is that they have used relatively small selections of disgusting images that contained pictures which may not have been especially strong disgust elicitors (e.g., images of used cigarette butts, a sickly looking kitten, a slice of pie with superimposed flies); moreover, prior work has relied on normative image ratings and did not collect subjective ratings of disgust for the stimuli employed. Therefore, it is possible that the stimuli used in prior studies were not strong disgust elicitors (or that these stimuli were combined with less evolutionarily significant images) and that more potent stimuli would have succeeded at strongly modulating ERP responses.

In the present study we therefore sought to further investigate the LPP and EPN elicited by disgusting images. We included a large number of disgusting images chosen for their depiction of disease-inducing agents. Some of these images were created in-house and were supplemented by images from the IAPS (Lang et al., 2008); participants viewed the pictures during a passive viewing task while EEG responses were recorded. In order to draw comparisons with prior work, and to better understand both early and later processing of specific picture contents (Weinberg and Hajcak, 2010), we measured both the EPN and the LPP elicited by disgusting, threatening and neutral pictures. We also asked participants to provide subjective ratings of the images in order to ensure that the disgusting pictures succeeded at being highly evocative of disgust. As a point of comparison, we employed threatening images, which should also be highly motivationally salient (e.g., Schupp et al., 2004), as well as neutral images.

2. Method

2.1. Participants

Twenty-eight undergraduate volunteers (16 female) took part in the study (age $M = 22.07$; $SD = 3.62$; range = 18–32 years). Participants had no history or signs of neurological, psychiatric or medical illness, as confirmed by a phone screen based on the Structured Clinical Interview for the DSM-IV (SCID; First et al., 1996). Potential participants who were taking psychotropic/psychoactive medications were excluded. The study was reviewed and approved by the University of Michigan Institutional Review Board and all participants provided written informed consent.

2.2. Visual stimuli

Ninety pictures were used: 30 threatening, 30 neutral and 30 disgusting. All picture categories contained a combination of images that had been created in-house and IAPS images (Lang et al., 2008)[2]. Disgusting images included several themes of disgusting content, including depictions of bodily secretions (vomit, excrement), infections (nasal, ear), and contaminated food; threatening images depicted animal and human threat (e.g., angry faces, weapons, lunging dogs) and neutral images depicted neutral people, landscapes and neutral animals (e.g., scenes of people working, computers, birds).

2.3. Procedure

After completing the informed consent procedure, EEG electrodes were attached and participants were oriented to the task. Visual stimuli were presented in color at the full size of the computer monitor (which measured 34 × 27 cm), using presentation software (Neurobehavioral Systems, Inc.; Albany, CA). Participants viewed four blocks of images; each consisting of 15 trials of each picture type (i.e., disgusting, threatening, neutral) intermixed in random order. Across the first two blocks each picture was shown once and then displayed for a second time across the last two blocks for a total of 180 trials. Each picture was presented for 1 s with a jittered inter-trial interval ranging from 500 ms–5000 ms, during which time a white fixation cross was shown on a black background.

After finishing the EEG recording, all participants rated the valence and arousal of each image. Participants also rated their emotional response to each image in terms of disgust ("How disgusting do you find this picture?") and perceived threat ("How threatening do you find this picture?"). Valence ratings used a 9-point scale from "unpleasant" to "pleasant." Arousal, disgust and threat ratings were made using a 9-point scale from "not at all" to "extremely."

2.4. 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)

[2] IAPS images in each picture category were as follows: disgusting — 7380, 9008, 9031, 9300, 9301, 9302, 9320, 9322, 9325, 9570; neutral — 1450, 1500, 1590, 2102, 2104, 2107, 2191, 2305, 2372, 7003, 7006, 7025, 7026, 7045, 7052, 7100, 7211; threatening — 1050, 1120, 1300, 1525, 1726, 1930, 2811, 3500, 6020, 6231, 6244, 6250, 6300, 6312, 6313, 6315, 6370, 6520, 6550, 6560, 6563, 6830, 6840. Twenty of the disgusting images, seven of the threatening images and thirteen of the neutral images were created in-house and are available upon request.

Table 1
Mean (S.D.) subjective ratings and mean area measures (μV) for the EPN and LPP.

Picture type	Arousal	Valence	Disgust	Threat	EPN	LPP
Neutral	2.53 (1.26)	5.82 (0.52)	1.36 (0.62)	1.40 (0.71)	6.20 (3.43)	0.78 (4.09)
Threatening	4.98 (1.96)	2.74 (1.00)	2.36 (1.28)	5.85 (1.93)	3.99 (3.85)	2.64 (3.09)
Disgusting	4.81 (2.03)	2.04 (0.72)	6.95 (1.68)	2.72 (1.78)	2.97 (3.76)	2.63 (3.86)

were used, as well as one electrode on each of the left and right mastoids. The electrooculogram 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. The data were digitized at 24-bit resolution with a Least Significant Bit (LSB) value of 31.25 nV and a sampling rate of 1024 Hz, using a low-pass fifth order sync filter with a −3 dB cutoff point at 208 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. Brain Vision Analyzer (Brain Products, Gilching, Germany) was used for processing and data analysis.

The EEG was segmented for each trial beginning 200 ms prior to picture onset and ending 1000 ms following picture onset; the 200 ms window prior to the picture onset served as the baseline. Eyeblink and ocular corrections were conducted (Gratton et al., 1983). Artifact analysis identified voltage steps 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. Trials were also inspected visually for any remaining artifacts; these intervals were rejected from individual channels in each trial.

The EEG was averaged separately for the three image categories (disgust, threat, and neutral). The EPN was scored as the mean activity at Oz between 200 and 300 ms after picture onset. The LPP was scored as the mean activity at site Cz[3] between 400 and 1000 ms after picture onset.

3. Results

3.1. Picture ratings

Table 1 shows means and standard deviations for subjective ratings for each picture type. There were main effects of picture type on ratings of arousal, $F_{(2,26)} = 41.29$, $p < 0.001$, valence, $F_{(2,26)} = 226.64$, $p < 0.001$, disgust, $F_{(2,26)} = 234.68$, $p < 0.001$, and threat, $F_{(2,26)} = 86.91$, $p < 0.001$. Post-hoc comparisons indicated that both threatening and disgusting images were rated as significantly more unpleasant, emotionally arousing, disgusting, and threatening than neutral images, p's < 0.001. Disgusting and threatening images were not rated significantly differently in terms of arousal, $t_{(27)} = 0.92$, $p > 0.05$. Disgusting images were rated as significantly more unpleasant, $t_{(27)} = 5.15$, $p < 0.001$ and disgusting, $t_{(27)} = 15.50$, $p < 0.001$ than threatening images. Threatening images were rated as more threatening than disgusting images, $t_{(27)} = 9.46$, $p < 0.001$.

[3] Analysis pooling 4 centro-parietal sites (Pz, Cz, CP1 and CP2) yielded a similar pattern of results to site Cz analyzed alone. Specifically, pooling these four sites yielded the following LPP means (in μV): Neutral = 2.67 ± 3.36; Threatening = 4.45 ± 2.29; Disgusting = 5.18 ± 3.55. Paired sampled t-tests revealed that LPP was larger for both threatening $t_{(27)} = 2.67$, $p = .013$ and disgusting, $t_{(27)} = 3.77$, $p = .001$, pictures compared to neutral pictures. There was no significant difference between LPPs associated with threatening and disgusting images, $t_{(27)} = 1.1$, $p > .28$.

3.2. EPN

Fig. 1 (top) depicts grand-average waveforms from site Oz elicited by each picture type, and mean EPN amplitudes are presented in Table 1. Fig. 1 (bottom) shows topographic maps of voltage differences from 200–300 ms following picture onset, for disgusting minus neutral images as well as threatening minus neutral images. A repeated measures ANOVA revealed that the magnitude of the EPN differed as a function of picture content, $F_{(2,26)} = 40.83$, $p < .001$. Post hoc comparisons revealed that the EPN was greater (i.e., more negative) for both threatening, $t_{(27)} = 4.8$, $p < .001$ and disgusting, $t_{(27)} = 9.2$, $p < .001$, pictures compared to neutral pictures. Moreover, the EPN elicited by disgusting pictures was significantly larger than that elicited by threatening pictures, $t_{(27)} = 2.55$, $p = .017$.

3.3. LPP

Fig. 2 (top) depicts grand-average waveforms from electrode Cz elicited by each picture type, and mean LPP amplitudes are presented in Table 1. Fig. 2 (bottom) shows topographic maps of voltage differences from 400–1000 ms following picture onset, for disgusting minus neutral images as well as threatening minus neutral images. A repeated measures ANOVA revealed that the magnitude of the LPP differed as a function of picture content, $F_{(2,26)} = 4.14$, $p < .03$. Post hoc comparisons revealed that the LPP was larger for both threatening $t_{(27)} = 2.62$, $p = .014$ and disgusting, $t_{(27)} = 2.57$, $p = .016$, pictures compared to neutral pictures. However, there was no significant difference between LPPs associated with threatening and disgusting images, $t_{(27)} = .03$, $p > .97$.

3.4. Correlations

Mean LPP and EPN amplitudes were not significantly correlated with self-report ratings of picture characteristics (arousal, valence, disgust and threat), lowest $p > .07$.

4. Discussion

We evaluated electrocortical and subjective response to disgusting images. Picture ratings obtained for disgusting images suggest that they were perceived as highly disgusting, unpleasant and arousing. Furthermore, disgusting images augmented both the EPN and LPP relative to neutral images. Disgusting and threatening images yielded LPPs of comparable magnitude, whereas the EPN elicited by disgusting images was larger than that elicited by threatening images. These results suggest that disgusting stimuli receive prioritized processing at least on par with that of other biologically relevant images (i.e., threatening images) and support the notion that disgust conveys survival-relevant information, such as the possibility of infection (Rozin et al., 2000).

Our results contrast with previous studies, in which disgusting images were found to elicit smaller EPNs and LPPs than threatening images (Schupp et al., 2003, 2004; Weinberg and Hajcak, 2010). This inconsistency could be related to the larger number of stimuli employed in the present study, as well as their potency in eliciting disgust (as evidenced by picture ratings). Additionally, although we collected subjective ratings of perceived threat ("How threatening do you find this picture?"), we did not specifically ask participants if these disgust and threat images elicited the feeling of "fear", and it is

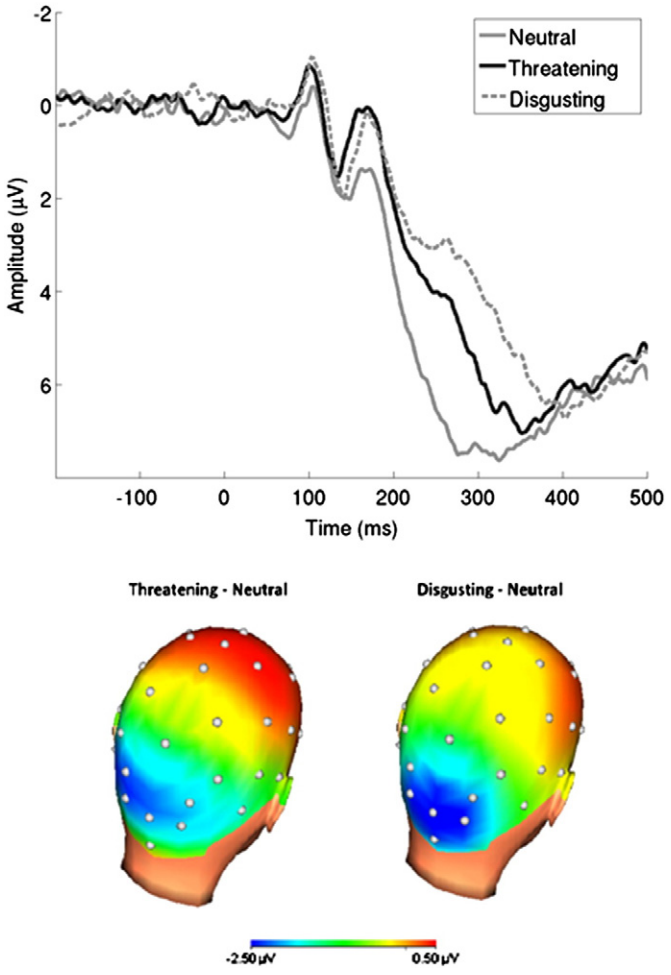

Fig. 1. Above: grand-averaged waveforms at Oz for the three picture types from −200 ms to +500 ms post-picture presentation showing the early posterior negativity (EPN). Below: voltage differences (in μV) for threatening minus neutral images and disgusting minus neutral images in the time range of the EPN (200–300 ms post-picture presentation).

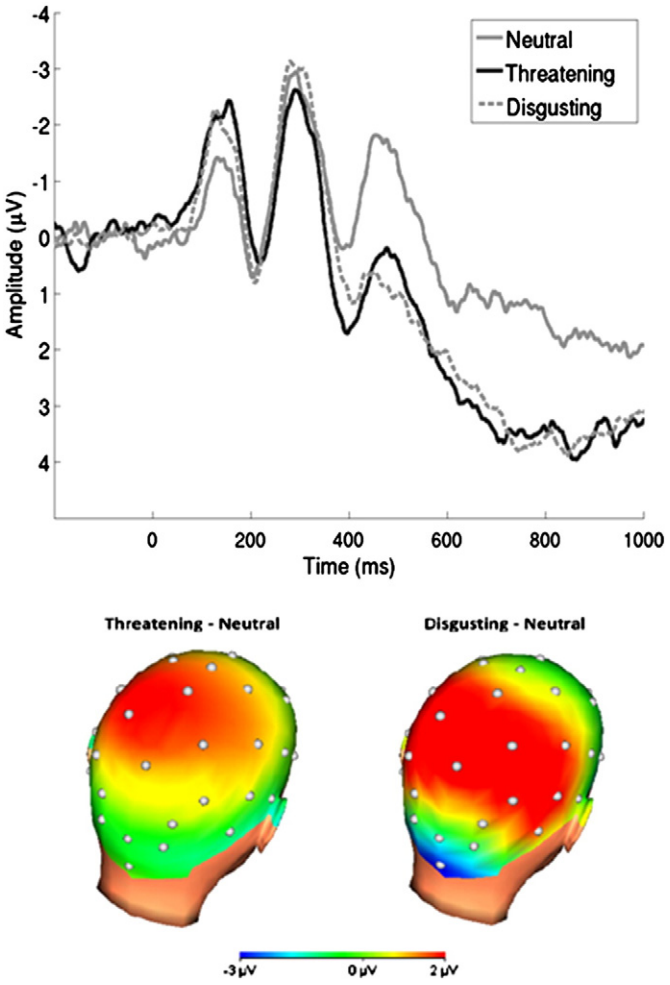

Fig. 2. Above: grand-averaged waveforms at Cz for the three picture types from −200 ms to +1000 ms post-picture presentation showing the late positive potential (LPP). Below: voltage differences (in μV) for threatening minus neutral images and disgusting minus neutral images in the time range of the LPP (400–1000 ms post-picture presentation).

possible that the disgusting stimuli used in the present study elicited more fear than in prior work (see Krusemark and Li, 2011). Finally, the disgusting images used in prior work contained few depictions of humans (e.g., 3 of 15 images in Weinberg and Hajcak, 2010), a factor known to increase the motivational salience of pictures, whereas in the present study, nearly 50% of the disgusting pictures contained people (in line with the neutral and threatening categories).

Disgust processing has been posited to play a role in several forms of psychopathology, most notably obsessive compulsive disorder (OCD; Olatunji and Sawchuk, 2005). Although the current study employed a nonpatient, undergraduate sample, these results suggest that these ERPs might be useful tools in the study of OCD and other conditions involving clinically significant disgust reactions and heightened disgust sensitivity. Previous studies have reported that OCD patients display abnormal evoked potentials for somatosensory and auditory stimuli (Shagass et al., 1984; Towey et al., 1994). Although visual stimuli have been used to probe disgust-processing in anxiety (Krusemark and Li, 2011), to our knowledge no previous studies have yet used visual emotional stimuli in an ERP paradigm in order to probe emotional processing in OCD.

Limitations of the present study should be noted and raise questions for future research. Due to the limited range of disgust-eliciting stimuli used in previous studies, we created many of our images in-house. While these images did not differ systematically from the IAPS images used (e.g. size on screen, resolution, number of people depicted), they were unequally distributed across the three image categories. Therefore, while the current results are suggestive of the enhanced electrocortical processing of disgusting stimuli, this work requires replication using a more balanced stimulus set. An additional limitation of the current study is the sole focus on disgusting, threatening and neutral images. We did not include mutilation images because they tend to elicit a combination of disgust and threat (Wright et al., 2004). Nevertheless, future work may wish to perform additional comparisons (such as with erotic images) in order to quantify disgust-related ERP modulation as it compares to other motivationally salient image categories.

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