Decomposing unpleasantness: Differential exogenous attention to disgusting and fearful stimuli

L. Carretié, E. Ruiz-Padial, S. López-Martín, J. Albert

Facultad de Psicología, Universidad Autónoma de Madrid, 28049 Madrid, Spain

Facultad de Humanidades, Universidad de Jaén, Spain

ABSTRACT

Negative stimuli have consistently been shown to efficiently attract exogenous attention. Two different types of unpleasant stimuli, disgusting and fearful, sharing similar arousal and valence, are usually employed as a single category. However, since they diverge in several important aspects (biological functionality, associated feelings, and central and peripheral physiological correlates), it may be expected that their potential to capture attention differs. Event-related potentials and behavioral indices were recorded while participants were engaged in a digit categorization task in response to three types of irrelevant, distracting pictures: disgusting, fearful and neutral. Disgusting trials were associated with worse performance than fearful trials in the digit categorization task as revealed by reaction times and number of errors. Moreover, P2-associated cuneus activation and scalp anterior P2 amplitude were greater for disgusting than for fearful distracters. All these indices reveal that, under the experimental conditions employed in the present study, disgusting distracters are more efficient at attracting exogenous attention than are fearful distracters.

Keywords: Fear Disgust ERPs P2 Cuneus Exogenous/automatic attention

1. Introduction

Negatively arousing visual stimuli have been shown to efficiently attract exogenous attention (also termed automatic or bottom-up attention), as revealed by electrophysiological and behavioral responses to emotional distracters while subjects are engaged in a cognitive task (Carretié et al., 2008, 2004, 2009b; Constantine et al., 2001; Doallo et al., 2006; Huang and Luo, 2007; Thomas et al., 2007; Vuilleumier et al., 2001; Yuan et al., 2007). This ability to automatically capture attention has obvious adaptive and evolutionary advantages: the consequences of not detecting a negative event are often much more dramatic than the consequences of ignoring or reacting slowly to neutral or even appetitive stimuli. An important issue is that, in these studies on exogenous attention, negatively arousing stimuli are treated as a single category. In part, this is due to the fact that some of the most prototypical negative stimuli (e.g. spiders or bloody scenes) elicit a mixture of negative emotions (Olatunji and Sawchuk, 2005). Nevertheless, this type of event could be divided into different subcategories.

Fear and disgust are two emotions that share the same emotional valence (negative) and high ability to arouse (higher than that elicited by other negative emotions such as sadness: Russell, 1980). In functional terms, both types of emotion also share the same scope: avoiding the event that is causing, or may cause, displeasure. However, they differ in several respects. First, the subjective feeling associated with each of these two emotional states is clearly different. Second, their biological meaning is also divergent: while disgust is primarily related to contamination (Rozin, 2000), fear facilitates avoidance of a broader type of danger that may cause harm at many levels. Third, they appear to preferentially activate different brain areas. Whereas fear-related stimuli have been reported to mainly activate amygdala, disgusting events preferentially activate the anterior insula when processes other than exogenous attention are explored (see a review in Calder et al., 2001; but see, e.g. Schienle et al., 2006; Stark et al., 2007). Fourth, it has been proposed that, at the peripheral level, disgust is mainly parasympathetically mediated, while fear is a sympathetically mediated process (Levenson et al., 1990).

Therefore, a relevant question that arises once these differences are taken into account is whether disgusting stimuli and fearful stimuli have the same uniform ability to capture attention as previously assumed. Since the main reason why negative stimuli efficiently capture automatic attention is biological, one could contend that threatening and repugnant events, which have diverse biological meaning, should differ in their ability to attract attention. To the best of our knowledge, only two studies, both of a behavioral nature (no physiological responses were recorded), have compared the differences between automatic attention to fearful...
and to disgusting stimuli. In one of them, the emotional Stroop task was presented to subjects using neutral, threat-related and disgust-related words (Charash and McKay, 2002). While disgust-related words interfered with the cognitive ongoing task to a greater extent than did neutral words, no differences were found between fear-related and neutral words. In the second study (Cisler et al., 2009b), “fear words”, “disgust words” and neutral words were presented to subjects during a cognitive task in which their emotional content was irrelevant. In this case, fear words were found to interfere with the cognitive task more than disgust words. Therefore, although fear- and disgust-related attention differences have been found, the question as to the direction of these differences remains unanswered. Since words tend to be less arousing than other types of visual emotional stimuli (Hinojosa et al., 2009; Keil, 2006; Kisllor et al., 2006; Mogg and Bradley, 1998; Vanderploeg et al., 1987), it would be advantageous to obtain additional data using pictorial stimulation.

No studies on brain activity yet exist on the differential ability of fearful and disgusting stimuli to capture attention, although event-related potentials (ERPs) have been shown to be good indices of exogenous attention. More specifically, the P2 component of ERP’s shows significant amplitude increments when a negative stimulus automatically attracts attention in a wide variety of tasks (Carretié et al., 2004; Doallo et al., 2006; Huang and Luo, 2007; Thomas et al., 2007; Yuan et al., 2007), in contrast to other components such as late positive potentials, which reflect top-down attention to emotional events (see the review by Olofsson et al., 2008; see also Hajckal et al., 2009). In previous experiments on attention to emotional pictures, P2 has been shown to originate in the visual cortex (Carretié et al., 2001; Carretié et al., 2004). This is an important issue, since Schienle et al. (2006), presenting disgusting and fearful pictures (but not exploring automatic attention: participants were asked explicitly to direct processing resources to pictures), found that maximal disgust > fear differences were produced in visual areas of the brain (fear > disgust was not explored). Stark et al. (2007) also explored brain responses to disgusting and fearful pictures that participants attended to in a top-down fashion. Again, disgust > fear contrasts yielded significant effects in visual areas, along with the insula. Fear > disgust analyses revealed extensive areas of visual cortices as the most sensitive, in statistical terms, to this contrast. Therefore, the role of P2 in automatic attention and its visual cortex origin make this component especially interesting for the scope of this study.

The present experiment was aimed at exploring whether a similar or differential pattern of exogenous attention exists in response to fear- and disgust-related distractors while subjects were engaged in a cognitive task. Both behavioral and neural indices of exogenous attention were recorded. Behavioral measures consisted of reaction times and number of errors in the cognitive task. Automatic capture of attention by distractors is reflected in poorer performance in the ongoing cognitive task. The neural index of attentional capture was P2, which, as explained, has been reported to reflect automatic attention to emotional stimuli. Analyses on this component involved source localization in order to spatially characterize possible experimental effects. Although fearful stimuli have been studied much more than disgusting stimuli in emotional attention research, thus becoming the prototypical negative category, the few existing data comparing both types of unpleasant events suggest that the latter are powerful attractors of exogenous attention. Moreover, some of the most frequently used fearful stimuli, such as threatening animals (e.g. spiders or snakes) or physical injury scenes, may be more associated with disgust than with fear (Olatunji and Sawchuk, 2005), so part of the attentional effect traditionally attributed to “negativity” may have been related to disgust processing. Therefore, we expected behavioral and neural indices of exogenous attention to be significantly modulated by disgustingness of distracters. In line with previous data described above, this disgust modulation of automatic attention could be even greater than fear modulation in several areas of the visual cortex.

2. Methods

2.1. Participants

Twenty-six subjects (21 women, age range of 19–30 years, mean = 22.73) participated in this experiment. All of them were students of Psychology at the Universidad Autónoma de Madrid and voluntarily took part in this experiment after providing their informed consent to participate, reporting normal or corrected-to-normal visual acuity.

2.2. Stimuli and procedure

Subjects were placed in an electrically shielded, sound-attenuated room. Three types of pictures were presented to participants, in a single run, through RGB projection on a back projection screen: fearful (F), disgusting (D), and emotionally neutral (N). There were 40 trials of each type (20 different pictures presented twice). The size for all stimuli was 75.17◦ (width) x 55.92’ (height). Each of these pictures contained two central digits (49.3’ height) colored in yellow and outlined in solid black so they were clearly distinguished from the background. The complete set of stimuli may be seen at http://www.uam.es/carretie/grupo/FearDisgust09.htm. Each picture was displayed on the screen for 350 ms, and stimulus onset asynchrony was always 3000 ms.

The cognitive task concerned the central digits: participants had to press, “as accurately and rapidly as possible”, one key if both digits were even or if both were odd (ie., if they were “concordant”), and a different key if one central digit was even and the other was odd (ie., if they were “discordant”). Forty combinations of digits were composed, half of them being concordant and the other half discordant. The same combination of digits was repeated across emotional conditions in order to ensure that task difficulty was the same for F, N, and D stimuli. Stimuli were presented in semi-random order in such a way that there were never more than two consecutive trials of the same emotional category and that either the discordant or discordant condition never appeared more than twice consecutively. Participants were instructed to continuously look at a fixation mark located in the center of the screen until they blinks only after a beep that sounded 1300 ms after each stimulus onset. Pictures were taken both from the International Affective Picture System (APS; Lang et al., 2005) and from our own emotional picture database (EmoMadrid; http://www.uam.es/carretie/EmoMadrid.htm). These images were selected according to objective criteria (valence and arousal assessments, which were similar for Fear and Disgust categories) and subjective criteria (trying to select “pure” fear and disgust, and avoiding stimuli in which the emotions could be mixed). After the recording session, participants filled out a multidimensional scale for each picture so their assessments on the valence, arousal, fearfulness and disgustingness content of the stimulation were obtained (Table 1). Wilcoxon’s Chi-squared analyses were performed to test significance of pairwise contrasts, due to the non-parametric nature of measures. Fearfulness was significantly higher for F than for D stimuli, and disgustingness was significantly higher for D than for F stimuli (p < 0.05 in both cases). Valence and Arousal were higher for F than for D pictures (p < 0.05 in both cases) but, as explained later, these dimensions were controlled for in statistical contrasts. N stimuli were significantly lower in fearfulness, disgustingness, valence and arousal than were F and D stimuli (p < 0.05).

2.3. Recording

Electroencephalographic (EEG) activity was recorded using an electrode cap (ElectroCap International) with tin electrodes. Thirty electrodes were placed at the scalp following a homogeneous distribution. All scalp electrodes were referenced to the nose. Electrooculographic (EOG) data were recorded supra- and infraorbitally (vertical EOG) as well as from the left versus right orbital rim (horizontal EOG). Electrode impedances were always kept below 5 kΩ. A bandpass filter of 0.3–40 Hz was applied. Recordings were continuously digitized at a sampling rate of 200 Hz throughout the recording session. The continuous recording was divided into 1000 ms epochs for each trial, beginning 200 ms before stimulus onset. Trials for which subjects responded either out-of-time (>2400 ms) or erroneously were eliminated. Epochs containing eye movements or blinks over 100 μV in amplitude were deleted. For the rest of the epochs, the EOG-artifact removal procedure described by Gratton et al. (1983) was applied whenever EOG activity was observed. This artifact and error rejection led to the average admission of 79.32% F trials, 80.28% N trials, and 74.13% D trials. The minimum number of trials accepted for averaging was 86 (2011) 247–253
2.4. Data analysis

2.4.1. Detection, spatio-temporal characterization, and quantification of P2

Detection and quantification of P2 was carried out through a covariance-matrix-based temporal principal component analysis (tPCA), a strategy that has repeatedly been recommended for these purposes (e.g., Chapman and McCrary, 1995; Dien et al., 2005). In brief, tPCA computes the covariance between all ERP time points, which tend to be high between those time points involving in the same component and low between those belonging to different components. Temporal factor scores, the tPCA derived parameter in which extracted temporal factors can be quantified, is equivalent to amplitude. The decision on the number of factors to select was based on the scree test (Cliff, 1987). Extracted factors were submitted to promax rotation (Dien et al., 2005).

Once quantified in temporal terms, and prior to statistical contrasts on experimental effects, P2 factor scores were submitted to two kinds of spatial analyses. The first one aimed at detecting the main source underlying P2 via the standardized low-resolution brain electromagnetic tomography (sLORETA) applied to P2 temporal factor scores. sLORETA is a 3D, discrete linear solution for the EEG inverse problem (Pascard-Marqui, 2002). The solution is projected onto the Montreal Neurological Institute (MNI) standard brain. Subsequently, this main source was defined as region of interest (ROI) through the ad hoc sLORETA algorithm, using the single voxel approach, in order to compute its current density per subject and condition.

The second type of spatial analyses consisted of decomposing the P2 topography at the scalp level into its main spatial regions via a spatial PCA (sPCA) performed on P2 temporal factor scores. This spatial decomposition is an advisable strategy prior to statistical contrasts, since ERP components frequently behave differently in some scalp areas than they do in others (e.g. they present opposite polarity or react differently to experimental manipulations). sPCA provides a reliable division of the scalp into different regions or spatial factors. Basically, each spatial factor is formed with the scalp points where recordings tend to covary. Moreover, each spatial factor can be quantified through the spatial factor score, a single parameter that reflects the amplitude of the whole spatial factor. Also in this case, the decision on the number of factors to select was based on the scree test, and extracted factors were submitted to promax rotation.

Both levels of analysis (3D and scalp) were linked via multiple regression analysis in order to test the association of each of the extracted spatial factors with the main source found by sLORETA. Thus, ROI current densities were used as the dependent variable in a multiple regression analysis, and amplitudes (spatial factor scores) of each extracted spatial factor were used as independent variables, using the “enter” procedure.

2.4.2. Analyses on experimental effects on P2 and behavior

Experimental effects on P2 were also tested at two levels, 3D and scalp. The first one focused on the P2 main source provided by sLORETA. Thus, ROI current densities (or activations) were submitted to a repeated-measures ANOVA using Emotion as factor (three levels: N, F and D). The second level of analyses was scalp-related. ANOVA exploring the effect of Emotion was performed on factor scores (or amplitudes) corresponding to the P2 spatial factor/s that the multiple regression analysis mentioned above significantly associated with the P2 main source. With respect to behavior, performance in the digit categorization task was analyzed. To that aim, reaction times (RTs) and number of errors were submitted to repeated-measures ANOVAs introducing Emotion as a factor. In the case of RTs, outliers, defined as responses over 2400 or below 200 ms, were ignored in the analyses (three trials, all within two subjects). The Greenhouse–Geisser (GG) epsilon correction was applied to adjust degrees of freedom when necessary. Effect sizes were computed using the partial eta-square ($\eta^2_p$) method. Post-hoc comparisons to determine the significance of pairwise contrasts with respect to the factor Emotion were made using the Bonferroni correction procedure, which accounts for multiple comparisons (e.g. SPSS Inc., 2006).

In order to test the extent to which these effects were strictly due to the idiosyncratic characteristics of D stimuli (i.e., those strictly related to their disgusting nature), additional “control” ANOVAs were carried out. These analyses included two types of control. First, the influence of other affective characteristics of D stimuli such as their negative valence or high arousing power (both shared, though to a different extent, with F stimuli: see Section 2.2), was neutralized by introducing valence and arousal as covariates. Second, differences between D and N trials (Dn), as well as between F and N trials (Fn), were computed and introduced in ANOVAs as the two levels of the within-subject factor. The scope of this task was to subtract the effect of non-emotional factors such as color or onset abruptness, among others, that favor attentional capture (see, e.g. Simons, 2000; Simons and Ambinder, 2005).

3. Results

3.1. Detection, spatiotemporal characterization, and quantification of P2

Fig. 1 shows a selection of grand averages once the baseline value (prestimulus recording) had been subtracted from each ERP. These grand averages correspond to frontal areas, where the critical ERP component (anterior P2, as explained later) is prominent. The first analytical step was detecting and quantifying P2 (see Section 2.4). Seven temporal factors were extracted by tPCA and submitted to promax rotation (Fig. 2). Factor peak-latency and topography characteristics associated FT6 with P2. This component presented polarity inversion at occipital sites, where it was negative (Fig. 3).

Subsequently, as already explained, the sLORETA algorithm was applied to P2 temporal factor scores. As shown in Fig. 4, the average source across subjects and conditions yielded by sLORETA was the cuneus (BA19, x = 5, y = −85, z = 25). This location was defined as region of interest (ROI) in order to compute its current density per subject and condition. The second spatial analysis, this time at the scalp level (see section on Data Analysis), consisted of applying an sPCA to P2 temporal factor scores. Two spatial factors were obtained: one anterior and the other posterior. Regression analysis described in section on Data Analysis testing the linkage between 3D and scalp data (corrected $R^2 = 0.243$, $F(2,75) = 13.336$, $p < 0.001$) detected a strong association of P2-related cuneus activation with anterior P2 ($\beta = 0.527$, $p < 0.001$), but not with posterior P2 ($\beta = −0.147$, $p > 0.05$).

3.2. Experimental effects on P2

Table 1 shows means and standard error of means of P2 parameters. As may be observed, maximal values corresponded to D trials. Contrasts detailed in section on Data Analysis showed significant differences in P2 cuneus activation as a function of Emotion, as revealed by the ANOVA performed to that aim ($F(2,50) = 5.772$, $GG$ corrected $p = 0.01$, $n^2_p = 0.188$). Post hoc contrasts yielded significant differences between D and both N and F trials, the rest of pairwise comparisons being non-significant. Parallel to this, the ANOVA on anterior P2 amplitudes (spatial factor scores) also revealed an effect of Emotion ($F(2,50) = 4.042$, $p < 0.025$, $n^2_p = 0.147$).
Post hoc comparisons revealed that D trials evoked greater cuneus current densities and anterior amplitudes than did F trials; the other pairwise comparisons did not reach significance.

Control analyses (see Section 2.4) revealed that the experimental effects observed in P2 anterior amplitudes were mainly due to the idiosyncratic characteristics of D stimuli: Dn was significantly greater than Fn ($F(1,48) = 5.551, p < 0.01, \eta^2_p = 0.104$). However, P2 cuneus activation failed to show significant differences between Dn and Fn levels ($F < 1$).

### 3.3. Experimental effects on behavior

As shown in Table 1, RTs and number of errors were maximal in D trials. Repeated-measure ANOVAs yielded significant effects both for RTs ($F(2,50) = 13.568, \text{GG corrected } p < 0.001, \eta^2_p = 0.352$) and number of errors ($F(2,50) = 5.399, \text{GG corrected } p < 0.01, \eta^2_p = 0.178$). According to post hoc tests, RTs to D stimuli were significantly longer than to N and F (N and F did not differ). Additionally, number of errors to D was significantly higher than to N ($F$ values not differing from D and N).
Also in this case, control analyses were carried out using valence and arousal as covariates, and subtracting the performance in response to N trials from that recorded in D and F trials. These additional ANOVAs showed that Dn reaction times were significantly longer than Fn ($F(1,48) = 6.777, p < 0.05, \eta^2_p = 0.124$), but number of errors failed to show Dn vs Fn differences ($F < 1$).

Interestingly, the two responses which survived control analyses, RTs and anterior P2 spatial factor scores, were significantly correlated ($r = 0.189, p < 0.05$, unilateral), even when controlling for both valence and arousal ($r = 0.198, p < 0.05$, unilateral).

4. Discussion

The present results indicate that fearfulness and disgustingness differ in the way they influence exogenous attention. Such a conclusion is based on both neural and behavioral responses. The correlation between both types of responses suggests their functional association. At the behavioral level, disgusting distracters were those interfering maximally with the ongoing cognitive task, as revealed by reaction times and number of errors: participants responded slower and more inaccurately to the digit categorization task whenever disgusting distracters appeared on the screen. Reaction times were significantly longer than in neutral and fearful trials, and number of errors were greater than in neutral trials. These results are in line with those of Charash and McKay (2002), who also observed enhanced interference through disgust-related words in an emotional Stroop task. They found significant disgust > neutral differences, but not fear > neutral nor disgust > fear differences. The fact that disgust > fear differences were also significant in our study may be due to the use of pictorial events, more powerful than words at eliciting emotion (Hinojosa et al., 2009; Vanderploeg et al., 1987). Disgusting trials showed longer reaction times than fearful even in the control analysis made to neutralize the influence of their valence/arousal (shared with other non-disgusting unpleasant stimuli) and non-emotional characteristics (shared with neutral stimuli). This result signals reaction time as a behavioral parameter sensitive to the specific or idiosyncratic characteristics of disgusting pictures.

At the neural level, cuneus activity, the main source of P2, was greater in response to disgusting distracters than to fearful and neutral distracters. This finding is not surprising. First, previous ERP data on automatic attention to emotional pictures have also revealed cuneus as the main source of P2 (Carretié et al., 2004). Second, the involvement of cuneus in automatic attention to non-emotional stimuli has previously been reported in diverse studies (Hahn et al., 2006; Peelen et al., 2004). And third, Schienle et al. (2006) found greater activation in the cuneus (and other visual areas) after the presentation of disgusting pictures than after the presentation of fearful pictures (although they did not explore automatic attention). Indirectly, this finding reflects enhanced attention to disgusting events. Indeed, afferences from structures in charge of evaluating salient/emotional situations, such as amygdala or ventromedial prefrontal cortex, to visual cortices (including cuneus), are well documented (see a review in Carretié et al., 2009a). Analyses at the scalp level on anterior P2 also revealed disgust > fear significant differences in the present experiment. The amplitude of anterior P2 (i.e., a component positively peaking between 150 and 250 ms at anterior scalp, although it is labeled in different ways) has been reported to increase when a stimulus attracts attention in a bottom-up fashion (Carretié et al., 2004; Kenemans et al., 1989, 1992). Control analyses showed that anterior P2 amplitudes reflected the disgust advantage even when controlling for valence, arousal and non-emotional factors common to neutral distracters.

The question arises as to why disgusting events have been shown to be more efficient at capturing automatic attention than fearful events, since the latter involve imminent threat or danger for the individual, and would require urgent and fast withdrawal responses (e.g. LeDoux, 2000; Ohman and Mineka, 2001). Before interpreting this finding, it is important to note that part of the small amount of data distinguishing fear from loathing points in the same direction. As already indicated, Charash and McKay (2002) found disgusting stimuli to engage more attention than fearful stimuli in a bottom-up fashion during an emotional Stroop task. In line with this, other indirect data support the present findings: disgusting pictures have consistently been found to cause larger heart rate deceleration than fearful and neutral pictures (see reviews

**Fig. 4.** sLORETA solution for P2 temporal factor scores across subjects and conditions. The peak voxel ($x = 5, y = -85, z = 25$) was subsequently defined as ROI for statistical contrasts.
on the idea that emotional states are well explained by valence and arousal (e.g. Lang et al., 1993; Osgood et al., 1957; Russell, 1980), and the discrete approach, that defends the study of each emotion separately (e.g. Ekman, 1992; Izard, 1992; Panksepp, 1982), are both necessary and complementary for accounting for the effect of negative emotion on automatic attention. In relation to this, it is important to notice that further “decomposition of negativity” is possible and worth being explored. For example, Rozin (2000) suggests a four-factor model of disgust: core, animal-reminder, interpersonal, and socio-moral disgust elicitors. Finally, the present results along with those obtained in previous experiments (e.g. Stark et al., 2007; Schienle et al., 2006) suggest that cortical areas other than insular should be considered as regions of interest in the study of processing differences between fear and disgust. In the particular case of automatic attention, cuneus has been revealed as a critical area.

Acknowledgements

This work was supported by the grants PSI2008-03688 and PSI2009-12368 from the Ministerio de Ciencia e Innovación (MICINN) of Spain. MICINN also supports Jacobo Albert through a Juan de la Cierva contract (JCI-2010-07766).

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