



Electrocortical responses to NIMSTIM facial expressions of emotion



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ARTICLE INFO

Article history:

Received 1 June 2012

Received in revised form 13 November 2012

Accepted 12 December 2012

Available online 30 December 2012

Keywords:

Emotion

Face

ERP

Self-report

NIMSTIM

ABSTRACT

Emotional faces are motivationally salient stimuli that automatically capture attention and rapidly potentiate neural processing. Because of their superior temporal resolution, scalp-recorded event-related potentials (ERPs) are ideal for examining rapid changes in neural activity. Some reports have found larger ERPs for fearful and angry faces compared with both neutral and other emotional faces, and a key aim of the present study was to assess neural response to multiple emotional expressions using the NIMSTIM. Importantly, no study has yet systematically evaluated neural activity and self-report ratings for multiple NIMSTIM expressions. Study 1 examined the time-course of electrocortical activity in response to fearful, angry, sad, happy, and neutral NIMSTIM faces. In Study 2, valence and arousal ratings were collected for the same faces in a separate sample. In line with previous findings, the early P1 was larger for fearful compared with neutral faces. The vertex positivity (VPP) was enhanced for fearful, angry, and happy expressions compared to neutral. There was no effect of expression on the N170. Marginally significant enhancements were observed for all expressions during the early posterior negativity (EPN). The late positive potential (LPP) was enhanced only for fearful and angry faces. All emotional expressions were rated as more arousing and more pleasant/unpleasant than neutral expressions. Overall, findings suggest that angry and fearful faces might be especially potent in terms of eliciting ERP responses and ideal for emotion research when more evocative images cannot be used.

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1. Introduction

Decoding facial expressions of emotion is crucial for inferring the states and intentions of others. In this regard, faces might be an especially salient type of emotional stimulus. Indeed, facial expressions of emotion increase cortical arousal and capture attention (Armony and Dolan, 2002; Jiang et al., 2009; Öhman, 2002; Vuilleumier, 2005; West et al., 2009; Whalen et al., 1998). Because emotional processing tends to be rapid and dynamic, the millisecond resolution of event-related potentials (ERPs) might be ideal for examining neural activity in the context of facial expressions of emotion (e.g., Hajcak et al., 2012).

For example, the time-course of neural response to emotional scenes (i.e., International Affective Picture System [IAPS]; Lang et al., 2005) is well documented (Cuthbert et al., 1999; Foti et al., 2009; Keil et al., 2002; Olofsson et al., 2008; Smith et al., 2003; Weinberg and Hajcak, 2010), and there is evidence that emotional scenes enhance neural processing beginning as early as 100 ms, with sustained increases in neural activity evident for the duration of stimulus presentation (e.g., Hajcak et al., 2010). Taken together, these findings suggest

that emotional scenes robustly impact neural activity across multiple processing stages.

However, many IAPS pictures include images of mutilated bodies, physical assault, and erotica, which may be inappropriate for certain populations (e.g., children and psychiatric patients). In these instances, stimulus sets using facial expressions of emotion—which have also been shown to potentiate ERPs—might be more appropriate. Indeed, many studies have examined ERPs in response to emotional and neutral faces; however, these studies vary widely in terms of the emotional expressions and stimulus sets employed, as well as the specific ERPs examined. The current study focused on the time-course of neural processing of fearful, angry, happy, sad, and neutral faces using the NIMSTIM facial stimulus set. NIMSTIM is large (i.e., there are more than 600 photos), freely available, full color, and is increasingly-used in studies of emotion (Tottenham et al., 2009). However, no study has systematically assessed ERP responses for multiple NIMSTIM expressions (cf. Blau et al., 2007). In terms of specific ERPs, we evaluated multiple components believed to be sensitive to emotional content (e.g., Eimer and Holmes, 2007): the P1/N1, Vertex Positive Potential (VPP)/N170, Early Posterior Negativity (EPN), and Late Positive Potential (LPP).

The P1/N1 complex presents as a positive-going ERP over occipital electrodes, and a negative-going ERP over frontocentral electrodes around 100 ms. The P1 and N1 putatively instantiate early selective attention, and are enhanced for stimuli presented in attended compared

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to unattended locations (Luck, 1995; Vogel and Luck, 2000). The P1/N1 is also larger/smaller for emotional compared to neutral scenes (Carretié et al., 2004; Delplanque et al., 2004; Foti et al., 2009; Hot et al., 2006; Keil et al., 2002; Smith et al., 2003), and the P1/N1 likely originates from regions of occipital and frontal cortex (Carretié, et al., 2004; Pessoa and Adolphs, 2010; Vuilleumier, 2005). However, evidence is less consistent in terms of whether emotional faces modulate the P1 and N1. Some reports observed a greater P1 for unpleasant faces compared to pleasant and neutral faces (i.e., a negativity bias; Bel-Bahar, 2008; Foti et al., 2010; Luo, et al., 2010; Williams et al., 2006), whereas other reports found an enhanced P1 for pleasant and unpleasant faces compared with neutral faces (Batty and Taylor, 2003; Esslen et al., 2004). The N1 is relatively understudied in terms of emotional faces. One study observed a more negative N1 for fearful compared to neutral and happy faces (Luo et al., 2010). Another report found a more negative N1 for neutral compared with fearful faces (Eimer and Holmes, 2002), and yet another observed no difference between emotional and neutral expressions for the N1 and the P1 (Eimer et al., 2003). Cross-study discrepancies could be due to variation in task demands (e.g., attention cues, Vogel and Luck, 2000) or stimulus luminosity (Johannes et al., 1995)—which influence the P1 and N1. Nonetheless, the literature as a whole suggests that under certain circumstances emotional faces can rapidly potentiate sensory and attention processing, and this effect may be especially robust for fearful or angry faces.

Following the P1/N1 complex, the VPP is a positive-going ERP maximal over mid-central sites approximately 170 ms after the presentation of faces. Neural processing during the time window of the VPP is enhanced for faces compared with non-faces (Bentin et al., 1996; Sagiv and Bentin, 2001; Wheatley et al., 2011), and for emotional compared with neutral facial expressions (Ashley et al., 2004; Blau et al., 2007; Eger et al., 2003; Eimer et al., 2003; Eimer and Holmes, 2007). The VPP also has a lateralized counterpart—the N170—a negative-going ERP that is prominent over occipital-temporal sites when using a nose or average-electrode reference (see Joyce and Rossion, 2005, Fig. 1)¹. It has been suggested that the VPP is more sensitive to emotion in faces compared with the N170, and this might result from the VPP being better positioned to reflect contributions from frontal sources (e.g., Eimer and Holmes, 2007; Esslen et al., 2004; Kawasaki et al., 2001; Williams et al., 2006). Indeed, reports examining the VPP frequently observe enhancement in response to multiple emotional expressions (Ashley et al., 2004; Batty and Taylor, 2003; Eimer, et al., 2003; Foti et al., 2010; Luo et al., 2010), whereas the N170 was not sensitive to emotional content in at least three reports (Ashley et al., 2004; Eimer and Holmes, 2002; Eimer et al., 2003; cf., Blau et al., 2007). Moreover, similar to the other ERPs discussed herein, the VPP/N170 may be particularly enhanced for fearful or angry faces (Ashley et al., 2004; Batty and Taylor, 2003; Foti et al., 2010; Vuilleumier, 2005). Overall, the results suggest that processing enhancements in response to facial-affect are particularly evident for the VPP, and fearful expressions may increase processing even more than other emotional expressions.

The Early Posterior Negativity (EPN) follows the VPP/N170 and is a negative-going deflection in the waveform which becomes maximal at temporal-occipital sites between 175 and 275 ms (Foti et al., 2009; Schupp et al., 2006; Schupp et al., 2003). The EPN is enhanced for emotional compared with neutral stimuli (Foti et al., 2009; Schupp et al., 2004), including emotional faces (Leppänen et al., 2007; Mühlberger et al., 2009; Schupp et al., 2004). Emotional enhancement of the EPN putatively indexes enhanced visual processing in the occipital and temporal cortex (Schupp et al., 2003, 2006). Moreover,

the EPN may be preferentially sensitive to threatening faces (fear and anger) compared with both pleasant and neutral faces (Holmes et al., 2008; Schupp et al., 2004). As with the N170/VPP, both the EPN and LPP can be observed when using the non-optimal reference scheme, but they emerge more clearly when using the average-electrode or average-mastoid reference, respectively. Moreover, reference choices also impact the emotion enhancement effects on the EPN and LPP: emotional modulation is more prominent when using the optimal reference for a given ERP (Hajcak et al., 2012).

The LPP is a positive-going slow wave that is maximal over central-parietal sites around 300 ms. The LPP is associated with sustained attention to motivationally-salient visual scenes (Hajcak et al., 2009, 2010; Schupp et al., 2000; Weinberg and Hajcak, 2011). Importantly, emotional expressions, compared with neutral expressions, also enhance the magnitude of the LPP, suggesting that emotional expressions also cue attention and sustained processing (Eimer, et al., 2003; Krolak Salmon et al., 2001; Luo et al., 2010). However, some studies have observed differential enhancement of the LPP as a function of expression type, with fearful and angry faces eliciting a larger LPP than happy, sad, or neutral faces (Foti et al., 2010; Morel et al., 2009; Schupp et al., 2004; Williams et al., 2006). Altogether, LPP enhancements are often observed in response to emotional faces, and in some cases, fearful and angry faces may be especially potent in terms of enhancing the LPP (e.g., Eimer, et al., 2003; Krolak Salmon et al., 2001; Luo et al., 2010; Schupp et al., 2004).

Altogether, the literature suggests that fearful and angry faces may be especially salient emotional expressions that capture attention and processing resources automatically, similar to emotional scenes containing fearful or threatening images (e.g., Schupp et al., 2004; Vuilleumier, 2005; Weinberg and Hajcak, 2010). By contrast, processing enhancements for other emotional expressions (i.e., happy, sad) might be less robust, and result from task demands and attention-emotion interactions. For example, passive viewing designs often report increased neural processing across the entire time-course of picture presentation for fearful and angry faces (Eimer and Holmes, 2002; Foti et al., 2010; Schupp et al., 2004; Williams, et al., 2006), whereas emotion discrimination or categorization tasks result in processing enhancements for other emotional expressions (Batty and Taylor, 2003; Bel-Bahar, 2008; Eimer et al., 2003; Krolak Salmon et al., 2001; Luo et al., 2010). Finally, referencing choices also impact ERP findings, and non-optimal reference schemes can attenuate the effect of emotion on ERPs (Hajcak et al., 2012; Joyce and Rossion, 2005).

In the current study, we utilized a passive viewing paradigm to evaluate the P1/N1, VPP/N170, EPN and LPP in response to angry, sad, happy, fearful, and neutral NIMSTIM faces. A passive viewing design was used to assess which emotional expressions automatically capture attention and enhance neural processing without added task demands. This approach is akin to psychophysiological studies of passively viewed emotional scenes (IAPS; see Bradley et al., 2001, for a review). Given prior reports on face processing and ERPs, we expected all emotional expressions to differ from neutral for the VPP, but fearful and angry expressions were expected to elicit greater processing enhancements than happy, sad, and neutral faces for other ERPs.

Study 2 collected arousal and valence self-report ratings to verify that the emotional faces used in Study 1 were perceived as more emotional than neutral, and to record normative valence and arousal ratings for the NIMSTIM set. Although normative ratings exist for angry, fearful, and happy NIMSTIM faces (Adolph and Alpers, 2010; Blau et al., 2007), self-report ratings have not been collected for sad NIMSTIM expressions, despite their increasing use in studies on depression (e.g., Wisco et al., 2012; Hankin et al., 2010). Based on previous reports for the NIMSTIM (Adolph and Alpers, 2010; Blau et al., 2007), and on previous reports for other facial stimulus sets (e.g., Goeleven et al., 2008), all emotional expressions were expected to be rated as more arousing and pleasant/unpleasant than neutral faces.

¹ There is evidence suggesting that the VPP and N170 are opposite ends of the same dipole, and their presentation is a function of referencing montage. The VPP is prominent over the vertex when using an earlobe, mastoid, and non-cephalic reference, whereas the N170 is prominent over occipital-temporal sites when using a nose and average-electrode reference (see Fig. 1 Joyce and Rossion, 2005).

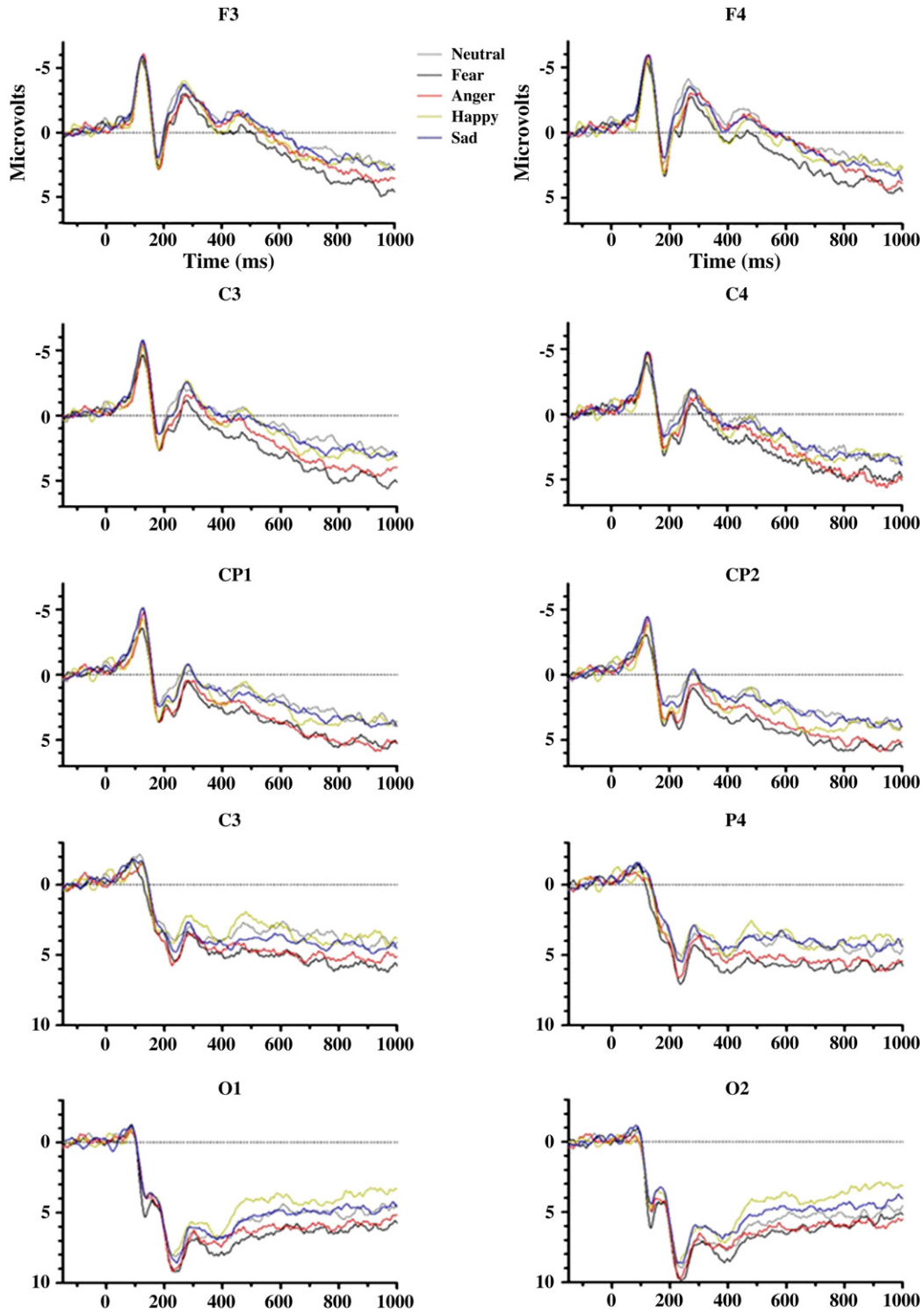


Fig. 1. Study 1 participants' ($N = 41$) ERPs time-locked to the onset (0 ms) of neutral (gray), fearful (black), angry (red), happy (yellow), and sad (blue) NIMSTIM faces from frontal (top) to occipital (bottom) recording sites. ERPs for Fig. 1 are average-mastoid referenced and negative is plotted upwards. The P1 is apparent at O1/2 at about 100 ms, the N1 at F3/4 around 100 ms, the VPP at C3/4 and CP1/2 at approximately 190 ms, and the LPP appears at CP1/2 beginning around 300 ms.

2. Method

2.1. Stimuli

One hundred and thirty images from the NIMSTIM collection (Tottenham et al., 2009) were selected. Specifically, 26 different actors (13 female) portrayed each of five expressions: neutral, angry, fearful, happy, and sad (see Appendix A). All facial stimuli were

presented in full-color, against a black background, on a Windows-based computer.

2.2. Participants

In Study 1, 46 healthy participants (19 male, 27 female) gave informed consent, and performed multiple computer-based tasks while EEG was recorded. The order of tasks was counterbalanced

across subjects; other tasks did not contain facial stimuli, and the results of other tasks are reported elsewhere (healthy controls were aggregated for the current study from: Foti, et al., 2010; Weinberg et al., 2010; MacNamara and Hajcak, 2010). Participants in Study 1 were identified as healthy via a phone screening prior to their arrival, and reported no history of psychopathology on the Structured Clinical Interview for DSM-IV Diagnosis (SCID-I; Spitzer et al., 1992). Data from five participants were excluded because of poor quality EEG recording or too few artifact-free trials (less than 20 trials per condition). The final sample was composed of 41 participants (15 male, 26 female; mean age of 35.2 years, SD = 13.3 years). All participants were paid \$20.00 per hour for their participation, and most experiments were completed in one hour.

Participants in Study 2 were 28 college students (13 females, 15 males). Three females and two males were excluded from this sample because of missing data. The final sample for this group consisted of 10 females and 13 males (mean age = 19.9, SD = 3.3). All participants received course credit for participation in the study. Data from all participants (Study 1 and Study 2) were collected in accord with Stony Brook University IRB protocol for human subject research.

2.3. Procedure

In Study 1, participants were given a brief description of the experiment, and then informed consent was obtained orally and in writing. EEG and electrooculogram (EOG) sensors were then attached to the subject. Presentation software (Neurobehavioral Systems, Inc., Albany, CA) was used to control the presentation and timing of all stimuli. Each photograph was displayed in color and occupied 7.5 × 10 in. (19 × 25 cm) of a 19-in. (48.26 cm) monitor. At a viewing distance of approximately 24 in. (60.96 cm), each face occupied approximately 40° of visual angle horizontally and vertically. To familiarize participants with the procedure, they initially viewed 10 images from the NIMSTIM collection that were not among the experimental stimuli. The actual experiment consisted of 130 trials with a short break in the middle. Each face was presented once, and the order of face presentation was randomized for each participant. At the beginning of the experiment and between the two blocks, the computer instructed the participant to “Simply view these faces.” Faces were presented for 1000 ms, and a fixation mark (+) was presented during the inter-trial interval, which varied randomly between 1000 and 1500 ms.

In Study 2, participants were given a brief description of the experiment, and then informed consent was obtained orally and in writing. Participants were then asked to view faces, and were instructed to rate each face on the valence and arousal dimensions using a visual analog scale, the self-assessment manikin (SAM; Lang, 1980). As in Study 1, faces were presented for 1000 ms and a fixation mark (+) was presented during the inter-trial interval. Participants were allowed as much as time as necessary to rate faces. The arousal

scale consists of five characters depicting a range of visceral responses from calm to excited; the numbers 1 through 9 were presented below the characters, with 1 corresponding to a strong bodily response (e.g., stimulated, jittery, wide-awake) and 9 corresponding to no bodily response (e.g., relaxed, calm, dull, sleepy). Participants were told to rate only their level of arousal on this scale, rather than the affective quality of their response. The valence scale also consisted of five characters depicting a range from happy to unhappy, with the numbers ‘1’ through ‘9’ again presented below the characters. Participants were instructed to use this scale to rate the extent to which they felt pleasant or unpleasant emotions in response to the picture. The number ‘1’ corresponded to the happiest figure, and ‘9’ corresponded to the unhappiest figure. On both of the scales, ‘5’ represented the midpoint, and participants were encouraged to use any point on the scale. For presentation purposes here (Table 1), both sets of ratings have been reverse-scored so that a score of 9 represents pleasant valence and high arousal.

2.4. EEG recording and analysis

The continuous EEG was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 34 scalp electrodes based on the 10/20 system, as well as from two electrodes that were placed on the left and right mastoids. The electrooculogram (EOG) generated from blinks and eye movements was recorded from two electrodes approximately 1 cm above and below the subject’s right eye, and two electrodes approximately 1 cm outside the canthi, aligned with the pupil. The EEG signal was preamplified at the electrode to improve the signal-to-noise ratio and amplified with a gain of 1 × by a BioSemi ActiveTwo system (BioSemi, Amsterdam). The data were digitized at 24-bit resolution with a LSB value of 31.25 nV and a sampling rate of 1024 Hz, using a low-pass fifth order sinc filter with -3dB cutoff point at 208 Hz. As designed by BioSemi, each active electrode was measured online with respect to a common mode sense (CMS) active electrode producing a monopolar (non-differential) channel. All the bioelectric signals were digitized on a laboratory microcomputer using ActiView software (BioSemi, Amsterdam, The Netherlands) and were analyzed off-line using Brain Vision Analyzer (Brain Products, Germany). Off-line, ERPs were re-referenced either to the numeric mean of the mastoids, or to an average-electrode reference, and all data were band-pass filtered between 0.1 and 30 Hz.

A semi-automated procedure was employed to detect and reject artifacts. The criteria 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 electrodes for each trial. Any additional artifacts identified visually were rejected from individual electrodes for each trial. Participants included in the average-mastoids reference analyses (N = 41) had at least 100 artifact-free trials (20 artifact-free trials per emotion condition)

Table 1
Descriptive statistics for ERPs (μV) across five facial expressions.

Study 1	Neutral M (95% CI)	Fear M (95% CI)	Anger M (95% CI)	Happy M (95% CI)	Sad M (95% CI)
<i>Average-mastoids referenced ERPs</i>					
P1	1.83 (1.33–2.34)	2.86 (2.37–3.35)	1.94 (1.44–2.44)	2.03 (1.55–2.51)	1.75 (1.21–2.29)
N1	-5.14 (-5.58 to -4.70)	-4.36 (-4.81 to -3.91)	-4.85 (-5.29 to -4.41)	-4.58 (-5.11 to -4.05)	-5.20 (-5.61 to -4.79)
VPP	1.38 (.89–1.88)	2.64 (2.09–3.20)	2.32 (1.81–2.83)	2.32 (1.79–2.83)	1.50 (.94–2.06)
LPP	2.53 (2.21–2.85)	4.41 (4.02–4.80)	3.94 (3.59–4.29)	2.69 (2.31–3.01)	2.84 (2.46–3.22)
<i>Average-electrodes referenced ERPs</i>					
N170	-.05 (-.43 to -.34)	-.52 (-.89 to -.14)	-.38 (-.76 to -.01)	-.47 (-.86 to -.08)	-.30 (-.66 to .06)
EPN	5.67 (5.26–6.08)	4.91 (4.46–5.36)	5.12 (4.67–5.57)	5.06 (4.64–5.48)	5.00 (4.59–5.41)

The P1, N1, VPP, and LPP are reported here using an average-mastoids reference. The N170 and EPN are reported using an average-electrodes reference. Results for analyses using the alternative reference scheme are presented in footnotes 2 and 3. For a review of the effects of reference on affective-modulated ERPs, see Hajcak et al. (2012) and Joyce and Rossion (2005).

for each analyses-relevant electrode; participants included in the average-electrode reference analyses ($N=38$) had at least 100 artifact-free trials for all electrodes (i.e., all electrodes are analyses-relevant when data is re-referenced to the common average).

The EEG was segmented for each trial beginning 200 ms prior to picture onset and continuing for 1000 ms (i.e., picture presentation duration). For each trial, the baseline was defined as the 200 ms prior to picture onset. ERPs were constructed by separately averaging the 5 picture types (neutral, angry, fearful, happy, and sad). All analyses of ERPs were conducted on the mean amplitude (μV) for a given ERP's time-window. The ERPs reported below were analyzed with either an average-mastoids reference (P1, N1, VPP, and LPP)², or an average-electrodes reference (N170 and EPN)³, and the referencing choices for reported components were based on prior reports (Hajcak et al., 2012; Joyce and Rossion, 2005).

The P1 was analyzed as the mean activity at Pz, PO3/O4, and O1/Z/2 from 100–150 ms, where it is typically maximal (Foti et al., 2010; Luo et al., 2010; Batty and Taylor, 2003), and where we observed the greatest variation between emotional and neutral expressions. During the 100–150 ms time window emotional enhancements were also evident over frontal and central electrodes, consistent with reports of the N1 (e.g., Luo et al., 2010), and the N1 was analyzed at FC1/2, Fz, Cz, and FCz. VPP activity was analyzed at C3/Z/4 and CP1/2 from 150–200 ms, similar to where it has been observed in previous studies (Eimer et al., 2003; Wheatley et al., 2011). The N170 was observable over T7/8, P7/8, PO3/4 electrodes from 150–200 ms, similar to where it has been found in previous reports (Blau et al., 2007; Eimer et al., 2003). The EPN was assessed at lateral parietal and occipital sites (O1/Z/2, P7/8, PO3/4) from 200 to 300 ms, in line with previous work (Foti et al., 2009; Schupp et al., 2004). The LPP was scored as the average activity between 300 and 1000 ms over central and parietal electrodes (C3/Z/4, CP1/2, P3/Z/4) and previous researchers have used similar sites and time windows when assessing the LPP (Foti et al., 2009; Hajcak et al., 2007; Keil et al., 2002, 2005; Schupp et al., 2000).

Region \times Expression mixed-linear models (MLMs) were computed for each ERP component (MIXED-command, PASW software v. 18). Pairwise post-hoc comparisons were conducted to decompose significant main effects. Descriptive statistics for ERPs are presented in Table 1 and descriptive statistics for SAM ratings are presented in Table 2; grand-averaged waveforms at illustrative electrode sites for average-mastoid referenced ERPs (P1, N1, VPP, LPP) are presented in Fig. 1, and grand-averaged waveforms for average-electrode referenced ERPs (N170, EPN) are presented in Fig. 2.

² To examine the impact of referencing choices on ERPs, we conducted additional analyses of the P1/N1, VPP, and LPP using data re-referenced to an average-electrodes montage. There was no main effect of Expression or Expression \times Region interaction for the P1 ($F_s < 1$). The P1 was greatest at O1 and O2 ($F(5, 337) = 100.16, p < .01$). There was no main effect of Expression, Region, nor Expression \times Region interaction for the N1 ($F_s < 1$). There was a significant effect of Expression for the VPP, however ($F(4, 319) = 2.77, p < .05$). Fearful ($t(368) = 3.12, p < .01$), angry ($t(367) = 2.02, p < .05$), and happy ($t(367) = 2.45, p < .05$) faces elicited a larger VPP than neutral faces. The main effect of Region revealed that the VPP was maximal at CP1 and CP2 ($F(4, 347) = 22.48, p < .01$). There was no Region \times Expression interaction for the VPP ($F < 1$). The LPP was also modulated by Expression ($F(4, 486) = 9.05, p < .01$); fearful ($t(576) = 4.58, p < .01$), angry ($t(572) = 5.70, p < .01$), and happy ($t(550) = 2.43, p < .05$) faces elicited a larger LPP than neutral faces. The LPP was largest over the Pz, P3, and P4 electrodes ($F(7, 291) = 41.90, p < .01$), there was no significant Expression \times Region interaction ($F < 1$).

³ We also evaluated the N170 and EPN using an average-mastoid reference. There was no significant effect of Expression ($F(4, 340) = 1.40, p > .20$). The N170 was most prominent at the T7 and T8 electrodes ($F(5, 344) = 59.20, p < .01$), the Expression \times Region interaction for the N170 was not significant ($F < 1$). The EPN was significantly modulated by Expression ($F(4, 466) = 3.57, p < .01$). Fearful faces trended towards a more positive (smaller) EPN than neutral ($t(416) = 1.90, p < .10$). A main effect of region indicated that the EPN was largest (most negative) at P7 ($F(6, 375) = 57.07, p < .01$). There was no significant Region \times Expression interaction for the EPN ($F < 1$). The more positive EPN for fearful compared to neutral faces is a product of average-mastoids referencing: the average mastoids reference inverts the EPN so emotional content elicits a more positive EPN (see Hajcak et al., 2012).

3. Results

3.1. Event-related potentials

3.1.1. Average-mastoid referenced ERPs

3.1.1.1. P1. There was a significant main effect of Expression on the P1 ($F(4, 434) = 3.14, p < .05$). Pairwise comparisons revealed that only fearful faces elicited a P1 greater than neutral ($t(484) = 2.94, p < .01$). In fact, fearful faces also elicited a larger P1 than angry ($t(477) = 2.66, p < .01$), happy ($t(477) = 2.41, p < .05$), and sad ($t(472) = 3.13, p < .01$) faces. A main effect of Region ($F(5, 356) = 58.92, p < .01$) revealed that the P1 was greatest over the PO4 electrode. There was no significant Region \times Expression interaction ($F < 1$).

3.1.1.2. N1. The N1 also varied with Expression ($F(4, 368) = 2.55, p < .05$). The N1 was significantly more negative after the presentation of neutral faces compared to fearful faces ($t(406) = 2.46, p < .05$); sad faces also elicited a more negative N1 than fearful faces ($t(404) = 2.75, p < .01$). There was no significant effect of Region, nor Region \times Expression interaction ($F_s < 1$).

3.1.1.3. VPP. The VPP differed across Expressions ($F(4, 348) = 4.28, p < .01$), and pairwise comparisons indicated that fearful ($t(401) = 3.34, p < .01$), angry ($t(406) = 2.62, p < .01$), and happy ($t(405) = 2.56, p < .05$) faces elicited a larger VPP than neutral faces. Sad faces and neutral faces did not significantly differ ($t(400) = .30, p > .70$). A main effect of Region indicated that the VPP was maximal over CP1 and CP2 ($F(4, 350) = 3.50, p < .01$), but there was no significant Region \times Emotion interaction ($F < 1$).

3.1.1.4. LPP. There was also a main effect of Expression during the LPP ($F(4, 617) = 20.47, p < .01$). Fearful ($t(624) = 7.32, p < .01$) and angry ($t(638) = 5.92, p < .01$) faces elicited a larger LPP than neutral faces. Fearful faces also elicited a larger LPP than happy faces ($t(635) = 6.40, p < .01$), sad faces ($t(641) = 5.80, p < .01$), and angry faces (at a trend-level, $t(633) = 1.73, p < .10$). Happy, sad, and neutral faces elicited similar magnitude LPPs ($p_s > .50$). The LPP was greatest at the Pz, P3, and P4 electrodes (main effect of Region; $F(7, 400) = 15.05, p < .01$), but there was no significant Region \times Emotion interaction ($F < 1$).

3.1.2. Average-electrode referenced ERPs

3.1.2.1. N170. As suggested by Fig. 2, there was no main effect of Expression for the N170 ($F < 1$). A main effect of Region indicated that the N170 was largest (most negative) at the T7 electrode ($F(5, 318) = 92.65, p < .01$). The Expression \times Region interaction for the N170 was not significant ($F_s < 1$).

3.1.2.2. EPN. There was a marginally significant main effect of Expression on the EPN ($F(4, 486) = 1.98, p = .10$). Fearful ($t(402) = 3.09, p < .01$), happy ($t(396) = 2.19, p < .05$), sad ($t(394) = 2.57, p < .05$) and angry ($t(418) = 2.07, p < .05$) expressions elicited a more negative EPN than neutral expressions. The EPN was maximal (most negative) at P7 ($F(6, 336) = 75.98, p < .01$); there was no significant Expression \times Region interaction ($F < 1$).

3.2. Arousal and valence ratings

The descriptive statistics for valence and arousal SAM ratings are presented in Table 2—self-reported arousal differed across Expressions ($F(4, 46) = 7.21, p < .01$). Pairwise comparisons indicated that fearful ($t(38) = 4.21, p < .01$), angry ($t(40) = 4.29, p < .01$), happy ($t(35) = 2.41, p < .05$), and sad ($t(42) = 3.40, p < .01$) faces were rated as more

Table 2
Descriptive statistics for SAM ratings across five facial expressions.

Study 2	Neutral M (95% CI)	Fear M (95% CI)	Anger M (95% CI)	Happy M (95% CI)	Sad M (95% CI)
Arousal	1.25 (0.76–1.74)	3.13 (2.36–3.90)	3.07 (2.36–3.78)	2.42 (1.56–3.28)	2.59 (1.96–3.22)
Valence	3.80 (3.67–3.94)	2.78 (2.33–3.23)	2.63 (2.20–3.05)	5.70 (5.27–6.14)	2.74 (2.40–3.07)

Self-Assessment Manikin (SAM) arousal and valence ratings for Study 2. Ratings have been reversed scored—high scores indicate high pleasantness and high arousal.

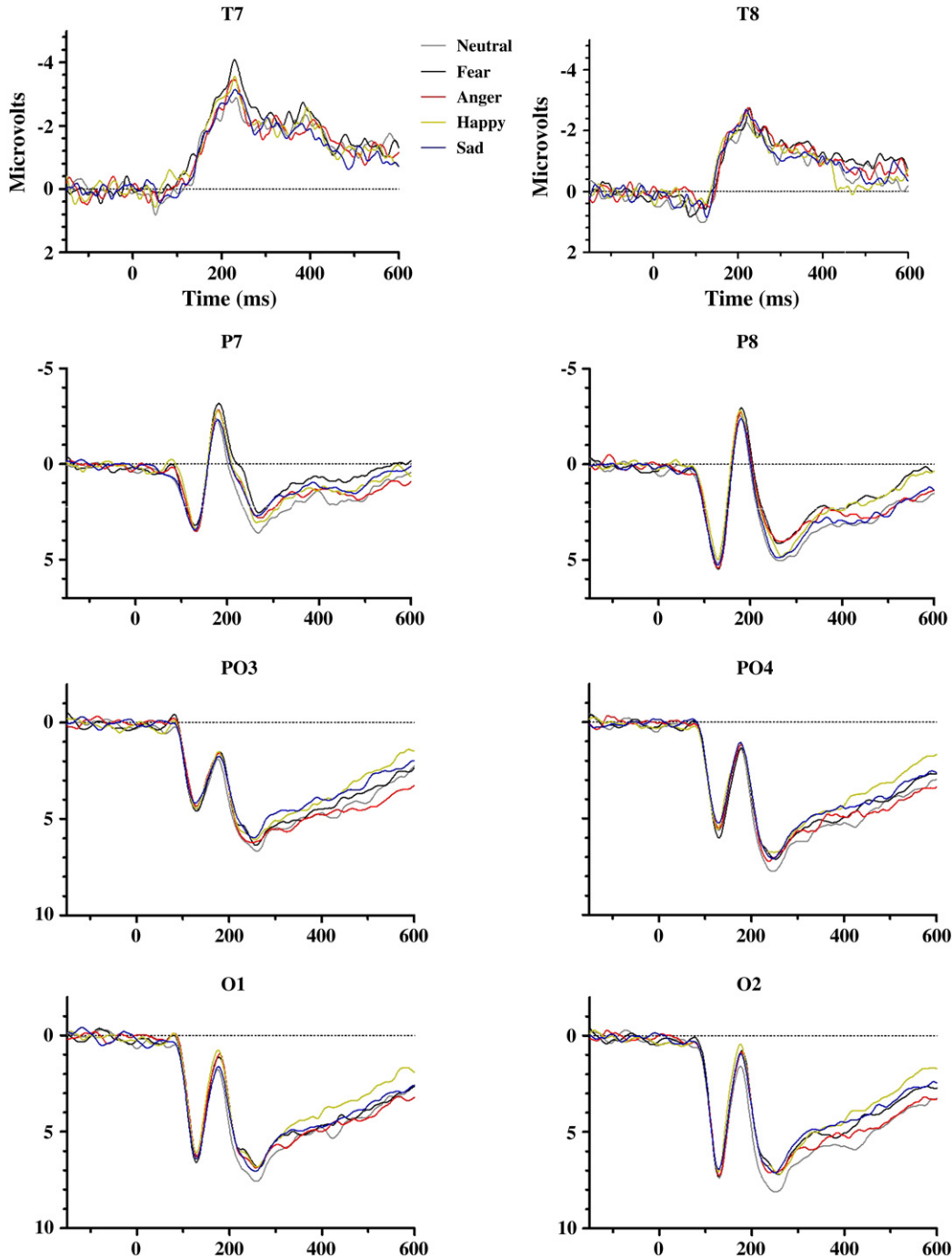


Fig. 2. Study 1 participants' (N = 38) ERPs time-locked to the onset (0 ms) of neutral (gray), fearful (black), angry (red), happy (yellow), and sad (blue) NIMSTIM faces from temporal (top) to occipital (bottom) recording sites. ERPs for Fig. 2 are average-electrode referenced and negative is plotted upwards. The N170 is apparent at T7/8 and P7/8 around 190 ms, the EPN at PO3/4 and O1/2 at approximately 250 ms.

arousing than neutral; however, fearful, angry, happy, and sad faces had similar arousal ratings ($ps > .25$).

Results for valence ratings indicated that pleasantness ratings varied with Expression ($F(4, 44) = 39.60, p < .01$). Post-hoc tests indicated that pleasantness ratings were in expected directions: happy faces were rated as more pleasant than neutral faces ($t(26) = 8.10, p < .01$), neutral faces were rated more pleasant than sad faces ($t(28) = 6.02, p < .01$), and there was no difference in pleasantness ratings between sad, angry and fearful faces ($ps > .60$).

4. Discussion

Our primary aim was to examine a range of electrocortical responses and self-report ratings for NIMSTIM faces. Although emotional expressions enhanced neural processing throughout the time course of picture presentation, this effect was not uniform across expression types: fearful and angry faces led to substantially greater neural responses across the time-course examined, whereas happy expressions modulated the VPP and EPN, and sad faces only enhanced the EPN. These findings converge with other reports, indicating that motivationally salient content—in this case, fear and anger—elicit robust processing enhancements compared to less salient facial expressions (Britton et al., 2006; Schupp et al., 2000; Vuilleumier, 2005; Weinberg and Hajcak, 2010; Williams et al., 2006).

Enhancement of the P1 in response to a fearful face has been observed previously (e.g., Batty and Taylor, 2003; Foti et al., 2010; Luo et al., 2010), and probably indexes automatic attention processing and prioritization of visual information (e.g., Foti et al., 2009; Olofsson et al., 2008; Pourtois et al., 2004). The P1 was not enhanced in response to happy, sad, or angry faces in this report, but prior reports of an enhanced P1 for multiple expressions have been found when using target detection (Batty and Taylor, 2003) or emotion induction tasks (Esslen et al., 2004). In this regard, the results suggest that processing enhancements for fearful faces may be somewhat automatic; by contrast, processing enhancements for other expressions depend on cues for attention (the P1 is larger for attended than unattended locations Luck, 1995). These results converge with behavioral (West et al., 2009) and neuroimaging reports (Öhman, 2002) indicating that fearful faces rapidly capture attention and enhance visual processing (see Vuilleumier, 2005, for a review). Emotional enhancement of the P1 is likely driven by low-level features specific to fearful faces (i.e., eye-whites) which are rapidly transmitted to subcortical structures implicated in orienting attention and potentiating vision processing (Feng, et al., 2009; Leppänen et al., 2008; Pessoa and Adolphs, 2010; Pourtois et al., 2005; Vuilleumier, 2005; Vuilleumier et al., 2003). Moreover, because the P1 is especially sensitive to low-level visual features of stimuli (e.g., luminance; Johannes, et al., 1995) and these visual features were not controlled for, it may be the case that fearful faces are more luminous than other faces and in turn, elicit an enhanced P1. Differences in low-level features between emotional and neutral faces might be an unavoidable confound, and may be more of a threat to internal than external validity.

Results for the N1 (an enhanced N1 to neutral compared to fearful faces) coincide with some reports (Eimer and Holmes, 2002), but not others (Luo et al., 2010; Holmes et al., 2003). Notably, reports of a more negative N1 to fearful than neutral faces tend to utilize tasks that explicitly cue participants' attention to faces (Luo et al., 2010; Holmes et al., 2003; cf. Eimer et al., 2003), whereas when participants are allowed to freely view stimuli, an enhanced N1 for neutral faces has been observed (Eimer and Holmes, 2002, present results). This may not be surprising given findings on the N1 from visual attention studies—cues to attend to a given stimulus enhance the N1 to that stimulus (Luck, 1995; Vogel and Luck, 2000). Thus, the present results suggest that emotional cues do not automatically enhance the selection processes believed to be indexed by the N1. An alternative possibility is that the larger N1 for neutral than fearful faces reflected an

increased occipital P1 for fearful faces (i.e., contamination of the frontal N1 by effects on the P1).

Findings for the VPP were largely concordant with prior literature: happy, angry, and fearful faces prompted a larger VPP than neutral faces (Eimer and Holmes, 2002; Eimer et al., 2003; Luo et al., 2010). The VPP and N170 are indicators of face processing (see Eimer and Holmes, 2007 for a review), and the VPP may be more sensitive to the effect of emotion in faces than the N170 (Eimer and Holmes, 2002; Eimer et al., 2003; Eimer and Holmes, 2007). For example, emotional enhancement during the time window of the VPP (150–200 ms) may partially result from sources in frontal cortex (e.g., Esslen, et al., 2004; Kawasaki et al., 2001; Williams et al., 2006), and compared with the N170, the VPP may be better positioned to reflect the contribution of these frontal sources. In the current study, sad faces did not enhance the VPP or N170 (cf., Eimer et al., 2003). It is possible that task-related differences impact emotional modulation of the VPP/N170: Eimer et al. (2003) had participants indicate whether faces were neutral or emotional, and observed enhanced ERPs for all expressions after 180 ms (see also Ashley et al., 2004; Luo et al., 2010). Future studies might combine passive viewing and emotional discrimination paradigms to further examine the role of task demands on emotional processing in the time window of the VPP/N170.

The main effect of expression on the EPN was only marginally significant although pairwise comparisons indicated that all emotional faces elicited a more negative EPN compared to a neutral face. The findings support the interpretation of the EPN as an index of an early discrimination between emotional and neutral stimuli (Junghöfer et al., 2001; Schupp et al., 2003). Moreover, prior reports have observed statistically reliable modulation of the EPN as a function of emotion (Mühlberger et al., 2009), especially fear and anger (Leppänen et al., 2007; Schupp et al., 2004). Similar to the present results, one report found a larger (i.e., more negative) EPN for fearful, angry, and happy than neutral faces using a passive viewing design (Mühlberger et al., 2009). It is worth noting that ERPs in the study by Mühlberger et al. (2009) were based on substantially more trials than the current report (256 vs 130), increasing the statistical power of their analyses. Given that we observed reliable effects of emotion on other ERPs, it may be the case that the EPN is especially variable between participants (e.g., Holmes et al., 2008; Mühlberger et al., 2009). Thus, future studies will assess relationships between individual differences and ERPs elicited by emotional faces.

The LPP was larger only for fearful and angry faces,² similar to some (Schupp et al., 2004; Williams et al., 2006), but not other reports (Eimer et al., 2003; Luo et al., 2010). LPP modulation has been linked to the motivational relevance of images (Schupp et al., 2000; Weinberg and Hajcak, 2010), and to sustained elaborative processing (Hajcak et al., 2009, 2010; Weinberg and Hajcak, 2011). The present evidence suggests that fearful and angry faces are especially motivationally relevant compared with other expressions (e.g., Schupp et al., 2004). Moreover, arousal ratings for happy and sad images were lower than fearful and angry images, and the LPP is larger for more arousing images (Cuthbert et al., 1999). In this regard, the LPP is especially sensitive to subtleties between various emotional stimuli (Weinberg and Hajcak, 2010). It might also be the case that happy faces are more frequently observed in day-to-day life, and because the magnitude of the LPP is inversely related to stimulus frequency (Codispoti et al., 2006; Hajcak et al., 2012; Olofsson and Polich, 2007; Weinberg et al., 2012), happy faces fail to enhance the LPP.

Results from Study 2 indicated that all NIMSTIM emotional expressions were rated as more arousing and pleasant/unpleasant than neutral expressions. In contrast, fearful and angry faces were much more likely to enhance ERPs than sad and happy faces; similar dissociations between self-report ratings, peripheral psychophysiology (Alpers et al., 2011), and hemodynamic response (Britton et al., 2006), have been observed previously. Notably, self-report ratings and ERPs were collected from different samples, and this was a limitation of the current study. However, a cautious interpretation of the

present results would be that variability in ERP responses may require relatively intense emotional stimuli. Therefore, it remains a possibility that more intense expressions of happiness or sadness could elicit more robust neural changes than observed in the present report. Future studies will assess self-report ratings and ERPs within-subjects to clarify the impact of stimulus intensity on stimulus processing.

Standardized stimulus sets like the NIMSTIM or IAPS are often used in emotion research and are useful insofar as they can be used to study physiological and self-report responses across laboratories. Convergent evidence indicates that IAPS pictures are rated as more arousing, and more pleasant/unpleasant than faces, and IAPS images evoke greater psychophysiological responses than faces (Alpers et al., 2011; Britton et al., 2006; Ferri et al., 2012). However, the salience of IAPS images also has disadvantages: IAPS images may be inappropriate for, or poorly tolerated by, children and psychiatric patients. In comparison, NIMSTIM facial expressions may be better suited for a wide spectrum of participants. Moreover, the current study suggests that NIMSTIM are also clearly differentiated in terms of arousal and valence ratings.

Although many reports have found enhanced ERPs in response to fearful and angry faces, modulation by other emotional faces appears to be less robust, and as suggested above, discrepant findings could reflect differences in experimental designs. For example, designs that require participants to discriminate between objects and faces (Batty and Taylor, 2003), to rate characterological features of faces (Bel-Bahar, 2008), to categorize faces as emotional or neutral (Eimer et al., 2003), or to remember rapidly presented faces (Luo et al., 2010), have demonstrated large ERPs for multiple emotional expressions compared with neutral. However, reports using passive viewing designs have reported emotional enhancement of ERPs mostly to fearful and angry faces (Foti et al., 2010; Schupp et al., 2004; Williams et al., 2006; present results). Fearful and angry faces may be especially robust at capturing attention and mobilizing physiology because they signal potential threat (e.g., Öhman et al., 2001; Schupp et al., 2004; Vuilleumier, 2005). Thus, it is possible that motivational relevance might be a key factor influencing neural processing: inherently motivationally-salient expressions (i.e., fear and anger) might enhance processing automatically, whereas enhancement for less salient expressions (i.e., happy and sad) might depend on explicit cues for attention or task-demands. To clarify the impact of experimental design, future research might directly compare passive viewing and emotion discrimination tasks within-subjects. Overall, the present results suggest that fearful and angry faces are especially robust in terms of capturing attention and potentiating the electrocortical response (e.g., Öhman et al., 2001; Schupp et al., 2004; Vuilleumier, 2005).

Acknowledgments

Thanks to Maria Rienzi for assistance with data collection and data analysis. Also, thanks to Tarik Bel-Bahar, and John J.B. Allen for manuscript suggestions.

Appendix A

The NIMSTIM models used were: 1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 14, 17, 18, 20, 22, 23, 24, 25, 26, 27, 30, 34, 37, 38, 39, and 40.

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