Emotionally negative pictures increase attention to a subsequent auditory stimulus

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Abstract
Emotionally negative stimuli serve as a mechanism of biological preparedness to enhance attention. We hypothesized that emotionally negative stimuli would also serve as motivational priming to increase attention resources for subsequent stimuli. To that end, we tested 11 participants in a dual sensory modality task, wherein emotionally negative pictures were contrasted with emotionally neutral pictures and each picture was followed 600 ms later by a tone in an auditory oddball paradigm. Each trial began with a picture displayed for 200 ms; half of the trials began with an emotionally negative picture and half of the trials began with an emotionally neutral picture; 600 ms following picture presentation, the participants heard either an oddball tone or a standard tone. At the end of each trial (picture followed by tone), the participants categorized, with a button press, the picture and tone combination. As expected, and consistent with previous studies, we found an enhanced visual late positive potential (latency range = 300–700 ms) to the negative picture stimuli. We further found that compared to neutral pictures, negative pictures resulted in early attention and orienting effects to subsequent tones (measured through an enhanced N1 and N2) and sustained attention effects only to the subsequent oddball tones (measured through late processing negativity, latency range = 400–700 ms). Number pad responses to both the picture and tone category showed the shortest response latencies and greatest percentage of correct picture-tone categorization on the negative picture followed by oddball tone trials. Consistent with previous work on natural selective attention, our results support the idea that emotional stimuli can alter attention resource allocation. This finding has broad implications for human attention and performance as it specifically shows the conditions in which an emotionally negative stimulus can result in extended stimulus evaluation.

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1. Introduction
A large and growing body of evidence demonstrates that attention is preferentially allocated to stimuli with negative emotional content (see Yiend, 2010). One explanation for this increased attention is an innate negativity bias which is reported to be an evolutionarily adaptive response that facilitates rapid subconscious processing of aversive and potentially threatening information (Leducx, 1995; Rozin and Royzman, 2001). On the other hand, the perspective of natural selective attention emphasizes the idea that affective stimuli – both pleasant and unpleasant – innately capture attention resources and command priority processing due to their high motivational relevance (Desimone and Duncan, 1995; Lang et al., 1997b; Olofsson et al., 2008; Schupp et al., 2006; Yiend, 2010). In this view, the salient nature of emotional environmental stimuli garners more attention resources to the exclusion of less salient environmental stimuli.

This capturing of processing resources by emotional stimuli can also extend in time to influence the processing of subsequent stimuli and is thought of as “affective” or “motivational” priming. Previous work in this area has shown that emotional stimuli will prime subsequent responses in a different sensory modality since stimuli in the same sensory modality are competing for limited processing resources (reviewed in Schupp et al., 2006). For example, cross modal studies show that emotional stimuli facilitate lexical decisions (Kissler and Koessler, 2010), reduce response times (Scott et al., 2009; De Houwer et al., 2002; Jiang et al., 2007), improve identification of visual targets (Brosch et al., 2007, 2008; Zeelenberg and Bocanegra, 2010; but see Weinberg and Hajcak, 2011), potentiate startle responses (Herbert and Kissler, 2010; reviewed in Lang et al., 1997b), augment the P1 ERP component during visual target detection (Brosch et al., 2009), and enhance touch sensation (Poliakoff et al., 2007). The motivational priming hypothesis expounded by Lang et al. (1997b) particularly posits that priming will occur when there is a link or association with the emotional activation network. For example, defensive startle reflexes are potentiated following aversive shock in humans and rats because the startle reflex and the shock both activate the aversive motivational system. This type of motivational priming for a startle reflex in humans can also be found when the aversive stimuli are emotional pictures and this effect is observed across a range of participant ages and across sensory modalities (Lang et al., 1990; Vrana et al., 1998).
Of note, however, a series of visual-auditory cross-modal studies showed that emotional pictures reduce the P3 event related potential (ERP) to an auditory probe (Cuthbert et al., 1998; Keil et al., 2007; Schupp et al., 1997, 2004, 2008). In other words, these studies show that there was not a motivational priming effect of the emotional pictures. Although these results are seemingly in contrast to the blink reflex and other results supporting the motivational priming hypothesis, Lang et al. (1997b) explain that although the auditory startle probe works on the same aversive motivational system as the emotional pictures, the enhanced attention to the emotional stimulus results in a reduction in attention processing resources available for the auditory stimulus since the emotional pictures are viewed as more complex than the neutral pictures. In this view, the P3 ERP, as a neural correlate of stimulus evaluation, may be reduced due to the ongoing evaluation of the complexity and arousal level of the emotional pictures. However, this ongoing stimulus evaluation can potentially be shared by a subsequent stimulus if the two stimuli are placed closely together in time, allowing for cross-modal spreading activation. 

It is very likely that there was not a motivational priming effect of the emotional pictures, the enhanced attention to the emotional stimulus, can prime attention in the auditory modality when the two stimuli are placed closely together in time and whether auditory stimuli of different saliency levels are differentially influenced by the emotional pictures. We specifically hypothesized that, following negative, but not neutral pictures, there would be enhanced automatic, or natural, selective attention to the subsequent tones—especially to the attention-capturing oddball tones. Attention to the tones was assessed by ERP components that are sensitive to selective attention: the N1 and processing negativity (Naatanen, 1992); Processing negativity is thought to be generated in the superior temporal auditory cortex and is associated with orienting attention to a relevant stimulus (Arthur et al., 1991; Hari et al., 1989; Naatanen and Michie, 1979). We specifically focused on the late processing negativity which is thought to be influenced by frontal lobe processing, and here, likely reflects further auditory stimulus evaluation (Alho, 1992). The auditory N2 was included in the analyses since this component is sensitive to priming tasks and stimulus orientation (Fring and Grob-Bordin, 2007; Hinojosa et al., 2009). Finally, the P3 auditory component was assessed since this component is robustly elicited when emotional stimuli are presented and is sensitive to emotional stimuli (Keil et al., 2007).

2. Material and methods

2.1. Participants

Eleven right-handed college students were tested including 2 males and 9 females (M age = 24.5, SD = 10.6). All participants had normal or corrected-to-normal vision. Each subject received a thirty dollar gift certificate to a local bookstore as compensation for participation. Testing procedures were carried out according to a protocol approved by the Nova Southeastern University Institutional Review Board (IRB).

2.2. Stimuli and procedure

A dual sensory modality EEG ERP paradigm was employed in which visual ERP were elicited from participants while they viewed a subset of negative and neutral pictures selected from the International Affective Picture System (IAPS) (Lang et al., 1997a). A picture presentation and timing were controlled through the use of Presentation software (Neurobehavioral Systems, LLC).

1 IAPS pictures with negative valence: 2095, 2120, 2205, 2410, 2491, 2694, 2751, 2800, 3000, 3010, 3015, 3053, 3060, 3062, 3064, 3069, 3071, 3100, 3102, 3110, 3120, 3130, 3140, 3146, 3170, 3180, 3200, 3230, 3261, 3266, 3281, 3300, 3350, 3360, 4005, 4500, 5400, 5972, 6150, 6210, 6213, 6241, 6242, 6243, 6300, 6311, 6313, 6350, 6415, 6530, 6540, 6570, 6821, 6838, 7035, 7036, 7037, 7040, 7050, 7110, 7110, 7119, 7138, 7172, 7283, 7675, 8231, 8475, 9007, 9040, 9041, 9090, 9190, 9171, 9220, 9250, 9252, 9253, 9331, 9410, 9421, 9423, 9470, 9472, 9560, 9625, 9680, 9810, 9810, 9812, 9921. IAPS pictures with neutral valence: 1019, 1022, 1200, 1230, 1240, 1270, 1310, 1390, 1410, 1930, 1931, 1945, 2095, 2190, 2191, 2200, 2206, 2214, 2221, 2370, 2560, 2681, 2690, 2695, 2700, 2749, 2751, 2752, 2780, 2795, 2800, 2810, 2830, 2840, 2850, 2880, 2890, 2905, 3010, 3030, 3053, 3062, 3063, 3068, 3080, 3100, 3102, 3110, 3110, 3130, 3140, 3168, 3170, 3210, 3230, 3261, 3266, 3300, 3350, 3360, 4004, 4042, 4233, 4302, 4561, 4563, 4770, 5120, 5130, 5395, 5500, 5510, 5521, 5532, 5534, 5570, 6900, 6930, 7002, 7004, 7005, 7009, 7010, 7020, 7025, 7031, 7034, 7038, 7080, 7090, 7096, 7100, 7140, 7150, 7160, 7161, 7175, 7180, 7182, 7184, 7185, 7187, 7207, 7211, 7217, 7224, 7233, 7234, 7283, 7285, 7491, 7493, 7560, 7590, 7595, 7930, 9360, 9402, 9405, 9411, 9421.
There were 350 trials which were broken up into 7 blocks of 50 trials to allow for short (about 2 min) breaks for the participants during the experiment. Fig. 1 depicts a visual representation of the experimental trial. Each trial lasted 1200 ms and began with a 200 ms randomized presentation of either a negative (n = 175, 50%) or neutral (n = 175, 50%) picture. Following the picture presentation, the participants viewed a black screen with a fixation point which was on for the rest of the trial. A tone was presented 600 ms following the picture which consisted of randomized presentation of an oddball (n = 70, 20%) or a standard (n = 280, 80%) tone. The sinusoidal tones consisted of a randomized sequence of 1000 Hz low pitch tones and 2000 Hz high pitch tones. The low pitch tones were used as the standard tones and the high pitch tones were used as the oddball tones. The stimulus intensity was 70 dB and was 100 ms in duration. The frequency of oddball and standard tones was split evenly between negative and neutral picture categories so that oddball tones occurred on 10% of neutral picture trials and 10% of negative picture trials. Due to the high number of trials (350), it was necessary to repeat some of the pictures throughout the paradigm. However, this type of repeated exposure to the emotional pictures does not lead to habituation of the affective response (Bradley et al., 1993; Smith et al., 2005). The IAPS normative ratings (Lang et al., 1997a) were used to select the emotional category of each picture. The average negative picture normative rating was 2.32 (SD = 0.69) and the average neutral picture normative rating was 4.94 (SD = 0.62). The average normative arousal rating of the negative pictures was 6.08 (SD = 0.85) and the average normative arousal rating for the neutral pictures was 3.92 (SD = 1.15).

In order to ensure that the participants attended to both the picture and tone categories and to index behavioral responses to the picture and tone categories, the participants were instructed to categorize each picture-tone combination on a computer keyboard at the end of each picture-tone trial. Possible combinations included a negative picture followed by an oddball tone, a negative picture followed by a standard tone, a neutral picture followed by an oddball tone, or a neutral picture followed by a standard tone. Participants were given 3000 ms to categorize the picture–tone combination before the next trial began. Participants were given a practice session with non-experimental pictures to categorize the picture tone combination before the next trial began. For the rest of the trial, a tone was presented 600 ms following the picture which consisted of randomized presentation of an oddball (n = 70, 20%) or a standard (n = 280, 80%) tone. The sinusoidal tones consisted of a randomized sequence of 1000 Hz low pitch tones and 2000 Hz high pitch tones. The low pitch tones were used as the standard tones and the high pitch tones were used as the oddball tones. The stimulus intensity was 70 dB and was 100 ms in duration. The frequency of oddball and standard tones was split evenly between negative and neutral picture categories so that oddball tones occurred on 10% of neutral picture trials and 10% of negative picture trials. Due to the high number of trials (350), it was necessary to repeat some of the pictures throughout the paradigm. However, this type of repeated exposure to the emotional pictures does not lead to habituation of the affective response (Bradley et al., 1993; Smith et al., 2005). The IAPS normative ratings (Lang et al., 1997a) were used to select the emotional category of each picture. The average negative picture normative rating was 2.32 (SD = 0.69) and the average neutral picture normative rating was 4.94 (SD = 0.62). The average normative arousal rating of the negative pictures was 6.08 (SD = 0.85) and the average normative arousal rating for the neutral pictures was 3.92 (SD = 1.15).

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2.3. EEG data acquisition and analysis

EEG assessment was conducted using Contact Precision Instruments’ Psychlab EEG amplifying and recording equipment. Electrodes were attached with electrode paste at Fz, Cz, Pz, C3, C4, O1 and O2 in accordance with the International 10–20 System and as previously described (Tartar et al., 2004). Signals were referenced to linked electrodes attached to earlobes. Electrode impedance was maintained at less than 5 kΩ. Procedures for infection control specified by the Society for Psychophysiological Research were followed in attaching and removing electrodes (Putnam et al., 1992). The EEG amplifier was set at a gain of 30,000 and the sampling rate of the EEG was 500 Hz. High pass filters were set to 1 Hz and low pass filters were set to 40 Hz. A 60 Hz notch filter was active. The data were analyzed offline through the use of Psylab8 software (Contact Precision Instruments, Cambridge, MA). For the purposes of data analysis, and to maximize the number of artifact free trials, the visual and auditory ERPs were separately baseline corrected and analyzed. For the visual and auditory ERP analyses, 1000 ms of raw EEG data were epoched to the respective stimulus presentation including 100 ms of pre-stimulus baseline in each modality. The LPP was measured as the average voltage 300–800 ms following picture onset. The N1 was measured as the peak amplitude 75–150 ms following tone onset. The N2 was measured as the peak amplitude 225–325 ms following tone onset, the late processing negativity was defined as the average voltage 400–700 ms post tone onset, and the P3 was defined as the mean amplitude 320–420 ms following tone onset. Trials in which the EOG exceeded ±75 mV were excluded from the final averaged ERP. The average number of artifact free trials going into each analysis did not significantly differ by picture category (negative picture average = 149, SD = 20; neutral picture average = 160, SD = 16).

2.4. Statistical analyses

In order to examine the effect of picture category on the visual LPP across electrodes, we carried out a 2 × 7 general linear model (GLM) with repeated measures (RM). The within factors were picture category (negative vs. neutral) and electrode locations (Cz, Fz, Pz, C3, C4, O1 and O2). The tone condition was excluded from this analysis because at the time of picture presentation the tone had not yet occurred and thus could not impact the picture processing. To examine the effects of picture category (negative vs. neutral) and tone condition (oddball vs. standard) on the auditory ERPs (auditory N1, N2, late processing negativity, and P3) and electrode locations (Cz, Fz, Pz, C3 and C4) we performed three additional 2 × 2 × 5 general linear models (GLM) with repeated measures—one for each ERP auditory dependent measure (N1, N2, P3, and late processing negativity). Electrode locations Fz, Cz, Pz, C3 and C4 were included in the auditory ERP analyses since they are the primary sites for yielding maximum amplitude of the auditory ERP. The within subject factors were visual category, tone type, and electrode location. GLM analyses include a measure of partial eta² as effect size. Post-hoc pairwise comparisons were carried out using a Bonferroni adjustment for multiple comparisons. Interaction and main effects were followed up with paired samples t-tests since these tests provide a conservative approach to post-hoc testing (given the fact that RM ANOVA provides additional degrees of freedom in testing simple effects).

In addition to the ERP analyses, we also carried out a series of t-tests on the behavioral responses to the picture and tone categorization procedure with Cohen’s d as the calculated effect size. In these analyses, we measured reaction time to categorize the picture–tone combination (measured as the latency to respond following tone onset). Although each numerical button press incorporated the participant’s judgment of both the picture and tone category, we analyzed separately whether the participant was correct in the picture and tone categorization. For example, if the participant was told to press “1” on a negative picture followed by an oddball tone trial and pressed “1” on a negative picture followed by a standard tone trial, that would be counted as correct for picture categorization but incorrect for tone categorization. We compared the behavioral responses to each picture category separately for oddball and standard tone trials. All calculations were conducted using an SPSS statistical package (version 19, SPSS inc., IBM company). In instances where the sphericity assumption was not met, the reported p-values associated with the F statistics are adjusted via Greenhouse–Geisser. All reported p values are two-tailed with an a priori significance level of p<0.05.

3. Results

3.1. Visual LPP analyses

Fig. 2 presents the grand average visual ERPs separated by electrode location and picture category (emotionally negative vs. neutral). We analyzed the visual LPP using a 2 (picture category) × 7 (electrode location) GLM repeated measures ANOVA. This analysis revealed a significant main effect for picture category (F(1,110) = 20.18, partial eta² = 0.67, p<0.01); the LPP was larger on negative pictures trials (mean = 6.61, standard error = 0.89) compared to neutral picture trials (mean = 5.60, standard error = 0.85). There was also a main effect for electrode location (F(6, 60) = 53.30, partial eta² = 0.84, p<0.001). Bonferroni post hoc test correction for multiple comparisons showed that the average LPP at O1 and O2 was smaller compared to the five other
The electrode×picture category interaction was also significant (F(6,60)=7.09, partial \( \eta^2 = 0.42 \), \( p < 0.01 \)). Post hoc analyses revealed that the LPP was significantly different between negative and neutral picture categories at Fz, Cz, C3, and C4 electrode locations (all \( p < 0.05 \)).

3.2. Auditory P3 analyses: oddball effects

Fig. 3 presents the grand average auditory ERPs for oddball and standard tones separated by electrode location and picture category (emotionally negative vs. neutral). The 2 (picture category)×2 (tone

Fig. 1. Trial depiction. Each trial began with either a negative or a neutral picture — each of which occurred on 50% of the trials. 600 ms following picture exposure, participants received an auditory stimulus which was either an oddball (occurring on 20% of the trials) or a standard (occurring on 80% of the trials) tone. The frequency of oddball and standard tones was split evenly between negative and neutral picture categories so that oddball tones occurred on 10% of the neutral picture trials and 10% of the negative picture trials. Participants were instructed to rate (keyboard press) the picture and tone category from that trial immediately after hearing the tone.

Fig. 2. Visual LPP ERPs. Participants were exposed to an emotionally negative or neutral picture for 200 ms (black bar on x axis). Visual ERP analyses showed that compared to emotionally neutral picture trials, negative picture trials resulted in a larger visual late positive potential (LPP) at Fz, Cz, C3 and C4 electrode locations (all \( p < 0.05 \)).
category) × 5 (electrode location) GLM with repeated measures of the auditory P3 showed a main effect for picture category ($F(1,10) = 5.54$, partial $\eta^2 = 0.36$, $p < 0.05$); the P3 was smaller for negative (mean = 0.81, standard error = 1.24) compared to neutral (mean = 2.44, standard error = 1.05) pictures. There was no main effect for electrode location ($F(4,7) = 1.59$, $p > 0.05$) or standard vs. oddball tone ($F(1,10) = 1.59$, $p > 0.05$). There was a significant electrode location × picture category interaction ($F(4,7) = 8.28$, partial $\eta^2 = 0.83$, $p < 0.01$). No other interactions were significant (all $p's > 0.05$). Post hoc analyses revealed that the P3 amplitude was significantly smaller on trials when an oddball tone followed a negative picture at electrode locations Cz ($t(10) = 2.36$, $p = 0.04$) and Pz ($t(10) = 3.15$, $p = 0.01$).

### 3.3. Auditory N1, N2, and late processing negativity analyses: attention and orienting effects

Fig. 3 shows that following negative compared to neutral pictures, there is an enhanced N1 to both oddball and standard tones but extended processing negativity to only the oddball tones. A 2 (picture category) × 2 (tone category) × 5 (electrode location) repeated measures GLM analysis was conducted on the N1 and late processing negativity. The analyses revealed that for the N1 early attention effects measure there was a main effect for electrode location ($F(4,40) = 3.46$, partial $\eta^2 = 0.26$, $p < 0.05$). Bonferroni post hoc tests, however, did not reveal any significant differences between

![Auditory ERPs on standard and oddball tone trials.](image)

**Fig. 3.** Auditory ERPs on standard and oddball tone trials. The auditory ERPs were separately analyzed by the preceding picture (negative vs. neutral) and tone classification (oddball vs. standard). a. When a negative, but not a neutral picture, was followed by a standard tone, there was an increase in the N1 and N2 amplitude to the tone. Analyses of the standard tone trial late processing negativity showed no significant differences between the preceding emotionally neutral picture trials compared to negative picture trials at any electrode site. b. Analyses of the oddball tone trials showed that like the standard tone trials, there was greater attention to the tones when participants saw a negative picture then heard and oddball tone compared to when the participants saw a neutral picture then heard an oddball tone. However, different from the standard tone trials, the negative picture–oddball tone trials resulted in late processing negativity at midline Fz, Cz, Pz and lateral C3, C4 electrode locations. Bottom: The gray box on the oddball Pz graph depicts the analyzed latency range for the late processing analyses. Y axis represents voltage (μV) and x axis represents time (ms).
individual electrode locations. There was also a main effect for picture category (F(1,10) = 5.83, partial eta² = 0.37, p < 0.05); the N1 amplitude to the tone was greater following a negative (mean = −9.38, standard error = 0.87) compared to a neutral (mean = −7.63, standard error = 1.13) picture (see Fig. 3). In addition, there was a main effect for the standard vs. oddball tone category (F(1,10) = 17.88, partial eta² = 0.64, p < 0.05). The auditory N1 amplitude was larger on standard tone trials (mean = −9.26, standard error = 0.93) compared to oddball tone trials (mean = −7.74, standard error = 0.99). There were no significant interactions (all p’s > 0.05).

A 2 (picture category) × 2 (tone category) × 5 (electrode location) repeated measures GLM analysis was conducted on the auditory N2 ERP. The analyses revealed a significant main effect for picture category (F(1,10) = 36.53, partial eta² = 0.79, p < 0.001). The N2 was greater when tones followed a negative (mean = −2.30, standard error = 0.76) compared to neutral tones (mean = 0.20, standard error = 0.51) picture. Post-hoc analyses showed that compared to emotionally neutral pictures, negative pictures resulted in significantly larger N2 amplitudes for both the oddball and standard tones at Cz and Pz electrode locations (p’s < 0.05).

In the measures of late processing negativity there was a significant main effect for electrode location (F(1,69,16.86) = 5.23, partial eta² = 0.34, p < 0.05), but the Bonferroni post hoc tests, however, did not reveal any significant differences between individual electrode locations. In addition, there was a main effect for picture category (F(1,10) = 6.65, partial eta² = 0.40, p < 0.05); there was a larger auditory processing negativity following negative picture trials (mean = −2.31, standard error = 0.96) compared to neutral picture trials (mean = −0.67, standard error = 0.49). Tests of interaction effects revealed a significant picture category × tone category interaction (F(1,10) = 14.44, partial eta² = 0.59, p < 0.01) as well as a significant electrode location × picture category × tone category (F(4,40) = 3.13, partial eta² = 0.24, p < 0.05). No other interactions were significant (all p’s > 0.05). Post hoc analyses showed that compared to emotionally neutral pictures, negative pictures resulted in a significantly larger late auditory processing negativity for the oddball tones at Fz, Cz, Pz, C3; and C4 electrode locations (all p’s < 0.05). In the standard tone trials, there was no significant difference in the late processing negativity in negative compared to neutral picture conditions at any electrode location (all p’s > 0.05).

4.2. Auditory P3

The additional processing requirements of a dual sensory (picture-plus-tone) task as opposed to a single sensory (tone-only) task results in a reduction in the P3 associated with the second stimulus within each trial (Nash and Fernandez, 1996). In agreement, previous studies which examined the influence of emotional pictures on tone processing showed that the P3 ERP response was reduced when participants were exposed to an emotional picture with intermittent auditory probes (Cuthbert et al., 1998; Keil et al., 2007; Schupp et al., 1997, 2004). Findings from these studies suggest that the P3 was reduced because the emotional pictures consumed processing resources at the expense of auditory stimulus processing. In agreement with these studies, we also find that the P3 is reduced when an auditory tone follows and emotionally negative compared to an emotionally neutral picture. However, it appears that the reduced P3, at least in the present study, does not reflect decreased attention to the tones since the attention-sensitive N1 and processing negativity ERP measures are augmented following an emotionally negative compared to neutral picture. The P3 is a sensitive measure of stimulus evaluation and categorization and is thought to reflect context updating, rather than attention per se (Donchin, 1981). Accordingly, it appears that in our study the negative pictures work to reduce auditory processing resources associated with context updating. Although we used an auditory oddball paradigm to elicit our auditory ERPs, we did not observe any differences in P3 measures between tone type (oddball vs. standard) which is a typical finding in the oddball task. It is possible that in our study the rapid presentation of the tones following the pictures, combined with the continual presentation of pictures with varying emotional intensities blunted the classic oddball tone P3 effect. Alternatively, the relatively long inter-tone interval of 3.9 s blunted the novelty effect of the oddball tones.

4.3. Auditory early and late negativities

We found that following a negative, but not a neutral picture, there was increased extended negativity to the subsequent tone. In the negative picture followed by standard tone trials, there was an increase in the N1 component which is sensitive to attention (Woldorff et al., 1993) and a robust N2 component. The robust central-posterior N2 effect observed here on rare and standard tone trials following negative compared to neutral picture trials reflects the role of the N2 in the “general alerting system” network (Suwazono et al., 2000). This interpretation of the N2 emphasizes its role in stimulus orienting as opposed to its role in mismatch detection which is
typically found at frontal electrode locations (reviewed in Folstein and Van Petten, 2008). Following the enhanced N1 and N2 components, the increase in attention following negative pictures was sustained throughout the analyzed auditory ERP timeframe only when the subsequent tone was rarely occurring. Here, the processing negativity in the negative picture-oddball tone trials is within the latency range reported by Naatanen and colleagues with an early onset of waveform displacement (70 ms) and extended negativity (Naatanen and Michie, 1979). Since the processing negativity in the negative picture-oddball tone trials overlies the N1, N2 and P3, these components might not be completely independent of the overlying processing negativity. However, the N1 is reported to be independent of the overlying processing negativity (Hillyard et al., 1973).

Although selective attention is typically shown in a single modality auditory attention dichotic listening task (reviewed in Naatanen, 1992), dual modality paradigms show that selective attention can spread across sensory modalities (Eimer and Schröger, 1998; Talso et al., 2007; Talsma and Kok, 2001). In both types of experimental paradigms, however, the processing negativity is derived from instructions to the participant to attend to a specific stimulus or stimulus location (Alho, 1992). The experimental set up of the present study was quite different in that participants were instructed to attend to both stimulus modalities (picture and tone) and subcategories (negative vs. neutral picture and standard vs. oddball tone).

The oddball tones had enough stimulus significance to benefit from the natural attention priming of the negative pictures without instructions to attend to this combination and ignore all other picture-tone combinations. Accordingly, the late processing negativity derived from the present study is interesting in that it appears to reflect automatic, or natural, selective attention.

4.4. Behavioral responses

The behavioral findings here complement the ERP findings – both the ERP and behavioral data show the greatest attention effects on the trials in which an oddball tone follows a negative picture. However, a previous study which examined response latencies to different oddball emotion categories (neutral, positive and negative IAPS pictures) in a P3 paradigm reported no differences in response time across arousal categories (Olofsson and Polich, 2007). It is perhaps the difference in the experimental protocol between this study and ours that results in the seemingly disparate findings in response latency to negative stimuli. Here, faster reaction time to the negative pictures occurred only after the rarely-occurring second stimulus. Specifically, when participants viewed a negative picture and then heard an oddball tone, the response time was significantly faster compared to when they viewed a neutral picture and then heard an oddball tone. These findings are also reflected in the correctly identified tone and picture responses.

**Fig. 4.** Behavioral responses. Negative pictures enhance behavioral classification measures only when they are followed by an oddball tone a) Compared to the neutral picture-oddball tone trials, the negative picture-oddball tone trials resulted in a faster reaction time to classify the to the picture and tone category (top) as well as a significant increase in correct responses to the tone (middle) and picture (bottom) categories. b) Similar to the auditory ERP findings, there was no significant difference in any of the behavioral measures (latency to respond or correct responses to tone or picture categories) on neutral picture-standard tone trials compared to negative picture-standard tone trials. * Indicates p<0.05, ** Indicates p<0.01.
picture categories — only the oddball tone trials significantly increased the correct identification of the tone and picture category. Casual observation of the latency and correct response measures suggests that the behavioral measure for neutral picture, oddball tone trials are similar to both the negative and neutral picture standard tone trials (Fig. 4). However, it is difficult to make any meaningful comparisons between the standard and oddball tone responses since behavioral reaction times to standard tones are reported to be faster than reaction times to oddball tones (Linden et al., 1999).

4.5. Dual task, emotion and attention sharing

One explanation for ability of the negative pictures to result in increased attention to the subsequent tones is that sensory integration of the two stimuli (visual and auditory) might occur, leading to shared attention resources. Previous work clearly demonstrates that a stimulus in one modality can drive the perceptual processing of a stimulus in a second sensory modality (Colignon et al., 2008; Donchin, 1981; Fendrich and Corballis, 2001; Gebhard and Mowbray, 1959; Keil et al., 2007; Sekuler and Sekuler, 1999; Shams et al., 2001; Shipley, 1964). This makes good ecological sense as well — when a human or other animal is faced with a stimulus with high motivational relevance, it is crucial to increase perceptual resources across sensory modalities. Indeed, work on multi-sensory integration supports this idea and has shown that temporally proximate visual and auditory information can result in perceptual integration (reviewed in Koelewyn et al., 2010). Compared to other senses, audition in particular offers precision in perceptual judgments of event timing, and as a consequence, can govern the perceptual segmentation and interpretation of visual events (Fendrich and Corballis, 2001; Gebhard and Mowbray, 1959; Sekuler and Sekuler, 1999; Shams et al., 2001; Shipley, 1964). Moreover, visual stimuli can drive the emotional perception of auditory stimuli (Colignon et al., 2008). Although the inter-stimulus interval here (600 ms) is longer that typical perceptual integration studies (50–100 ms), it is possible that emotional stimuli expands the time window of perceptual integration (Angrilli et al., 1997; Drits-Volet and Gil, 2009; Nouhiane et al., 2007).

4.6. Limitations

One potential limitation in the present study is that the neurophysiological processing of the picture is not quite over before the onset of the tone, and as a consequence, the baseline correction could artificially augment the tone measures. However, the finding that in the standard tone trials, the difference in the baseline offset does not produce the processing negativity supports the idea that the auditory ERP is not influenced or contaminated by the baseline correction. Also, in a post hoc analysis of covariance the N1 and late processing negativity effects are still significant when the visual LPP is used as a covariate. In general, our desire to measure the two stimuli (picture and tone) as dual task, forces the ERPs, to some extent, to overlap. This is also ecologically relevant to a condition wherein two stimuli occur in immediate temporal proximity to each other where the first stimulus is not completely processed before the second stimulus occurs. An additional potential implication in the study was the relatively small sample size (n = 11). However, even with this limited sample, the major findings were sufficiently robust as to yield statistical significance at the conventional levels and large effect sizes. One final consideration is that our primary manipulated variable of interest was the valence of the pictures. However, the arousal level of the pictures is also a major determinant of attention processing in an oddball paradigm (Rozenkrants and Polich, 2008). It was not possible to select negative and neutral pictures with common arousal levels. Consequently, the findings reported here do not represent changes associated purely with valence category (negative vs. neutral) since the valence categories overlap with the arousal effects.

5. Conclusions

In sum, we find that in accord with previous research, affectively negative pictures; compared to neutral pictures, show a significantly enhanced visual LPP. We also find that when a tone in placed subsequent to the pictures with a short delay (600 ms), the auditory ERP measures of attention and orienting are enhanced for negative compared to neutral picture conditions. This is particularly true for the oddball tones, which show enhanced processing negativity and behavioral measure of improved attention. This suggests that on negative picture conditions, the tones, and especially the unexpected oddball tones, share the increased attention resources allocated to the negative pictures. Given that the oddball tones in the present experiment are relatively easy to detect, we plan on conducting future studies aimed at testing whether negative picture trials can significantly increase correct responses to a more difficult cross modal task.

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