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Affective ERP Processing in a Visual Oddball Task: Arousal, Valence, and Gender

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Abstract

Objective—To assess affective event-related brain potentials (ERPs) using visual pictures that were highly distinct on arousal level/valence category ratings and a response task.

Methods—Images from the International Affective Pictures System (IAPS) were selected to obtain distinct affective arousal (low, high) and valence (negative, positive) rating levels. The pictures were used as target stimuli in an oddball paradigm, with a visual pattern as the standard stimulus. Participants were instructed to press a button whenever a picture occurred and to ignore the standard. Task performance and response time did not differ across conditions.

Results—High-arousal compared to low-arousal stimuli produced larger amplitudes for the N2, P3, early slow wave, and late slow wave components. Valence amplitude effects were weak overall and originated primarily from the later waveform components and interactions with electrode position. Gender differences were negligible.

Conclusion—The findings suggest that arousal level is the primary determinant of affective oddball processing, and valence minimally influences ERP amplitude.

Significance—Affective processing engages selective attentional mechanisms that are primarily sensitive to the arousal properties of emotional stimuli. The application and nature of task demands are important considerations for interpreting these effects.

Keywords

International Affective Picture System; IAPS; event-related potentials (ERPs); P300; valence; arousal; gender

1. Introduction

1.1. Arousal and valence

The International Affective Picture System (IAPS) often is used to provide visual images for assessing emotional responses (Lang et al., 1999). These pictures are rated for valence (unpleasant to pleasant) and arousal (calm to exciting) level. Both dimensions have been

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assessed using event-related potentials (ERPs), with valence effects typically observed for early (100–250 ms) and arousal effects observed for later (250–850 ms) components (Codispoti et al., 2007; Olofsson et al., 2008). Affective ERP modulations have been obtained from passive viewing, active discrimination tasks, and for images presented as distracting or target stimuli in an oddball paradigms (Delplanque et al., 2004, 2005; Keil et al., 2002; Mini et al., 1996; Schupp et al., 2000). As these affectively potent stimuli can alter ERP morphology even when presented subconsciously, these effects appear to occur automatically (Bernat et al., 2001; Cuthbert et al., 2000; Delplanque et al., 2006; Roschmann and Wittling, 1992).

In addition, negative affective valence produces stronger ERP modulation than positive affective valence pictures (Cacioppo et al., 1999; Öhman and Mineka, 2001). The potency of negative affect may reflect the rapid processing of aversive information by the amygdala and related structures (Crawford and Cacioppo, 2002; LeDoux, 1995; Morris et al., 1998). Hence, affective processing can occur automatically without conscious awareness if emotional stimuli are passively encountered (Esteves et al., 1994; Kunst-Wilson and Zajonc, 1980; LeDoux, 1989; Öhman and Soares, 1998). Affective ERP effects also are obtained when a performance task is used to elicit a behavioral response to affective stimuli, although the relative strength and stability of valence and arousal effects are unclear (Conroy and Polich, 2007; Delplanque et al., 2004; Olofsson and Polich, 2007).

1.2. Affect processing

A general affective processing hypothesis stems from findings indicating that valence category influences early selective attention capture by salient (appetitive, fearful, sexual) stimulus factors, especially for negative valence items that generate a negativity-bias (Cacioppo and Bernston, 1994; Cacioppo et al., 1999). The strength of stimulus arousal level further governs emotional picture processing by modulating the amount of attentional resource allocation engaged (Bradley et al., 1992; Lang et al., 1993), such that P3 amplitude is larger for high arousal affective pictures presented in both passive and active paradigms (Delplanque et al., 2005; Keil et al., 2002; Mini et al., 1996; Schupp et al., 2000). Taken together, these findings suggest that affective picture stimuli elicit selective attention and influence the motivational system via arousal and resource allocation mechanisms (Cuthbert et al., 2000; Dolcos and Cabeza, 2002; Schupp et al., 2004).

In this context, another factor that can contribute to affective ERP outcomes is gender. Several reports suggest females react more to unpleasant valence pictures (harmful, threatening scenes), whereas males react more to arousing pleasant pictures (nudes, sexuality). These results imply that the genders may differentially process affective stimuli (Fujita et al., 1991; Kring and Gordon, 1998; Lang et al., 1998; Meyers and Smith, 1987). To control for such effects, emotion studies sometimes employ only females (Bradley et al., 2001; Conroy and Polich, 2007; Morita et al., 2001; Yamamoto et al., 2001), who may be more responsive than males to valence manipulations thereby biasing ERP arousal and valence effects (Cahill, 2006; Lang et al., 1993).

1.3. Present study

The present study was designed to address these issues by selecting IAPS images that strongly differed on their rated arousal and valence levels. A tractable response was obtained to target picture stimuli in an oddball paradigm. Requiring the same simple button-press for all affective stimuli will produce unambiguous ERP components and minimize processing variability. Both female and male subjects also were assayed to characterize gender differences. Based on previous findings, valence should modulate the early ERP components, and arousal should modulate the later ERP components. Females should elicit stronger valence effects than males, and males should evince stronger arousal effects than females.

2. Method

2.1. Participants

A total of 32 (16F, 16M) right-handed undergraduates served as participants. All reported being free of neurological/psychiatric disorders and having normal or corrected-to-normal vision. All provided informed written consent and received course credit or \$10 per hour.

2.2. Stimuli and procedure

Table 1 lists the means and standard deviations of the standardized ratings for each of the four stimulus categories that varied in valence and arousal (9 point scale). The means of the female and male ratings were used to select images that were perceived as having the same affective content level. The specific images were selected to maximize the rating differences for both valence and arousal levels. The Appendix lists the specific IAPS stimulus numbers of the IAPS images used.

Valence and arousal ratings were assessed with separate two-factor (2 valence $\times$ 2 arousal) analyses of variance. Negative valence pictures were rated more negative than positive valence pictures, $F(1,60)=971.8$, $P<.00001$; low arousal pictures were rated lower than high arousal pictures, $F(1,60)=4242.1$, $P<.00001$; no interactions were obtained ($P>0.40$, both cases). These pictures served as target stimuli and were presented to each subject in an oddball task with a probability of $p=0.40$. A red and white checked pattern of equal size was the standard image and occurred with a probability of $P=0.60$. This procedure provided similar visual spatial frequencies across stimulus types and was adapted from previous reports (Delplanque et al., 2004; Olofsson and Polich, 2007).

The subjects sat in a chair 75 cm from the computer screen. All stimuli were 9×12 cm, displayed for a duration of 1000 ms at the center of a computer screen on a light grey background at normal viewing luminance. A 2000 ms inter-stimulus interval was used. Participants were instructed to respond with a mouse-click when a target picture stimulus was presented and to refrain from responding when the standard stimulus was presented. The 64 target pictures (16 in each arousal/valence category) occurred randomly among 96 presentations of the standard image, resulting in a total of 160 trials. The same task conditions were presented twice with a random order to yield 32 target presentation trials for each stimulus category. Error rate and response time were recorded.

2.3. Recording conditions

Electroencephalographic (EEG) activity was recorded from 21 electrode sites including Fz, Cz, Pz, Fp1/2, F3/4, F7/8, C3/4, T7/8, P3/4, P7/8, O1/2, referenced to physically linked earlobes, a forehead ground, and impedances of 10K Ω or less, with the reference electrodes balanced. Additional electrodes were placed at the outer canthi as well as above and below the left eye to assess electro-ocular (EOG) activity with a bipolar recording. The bandpass was 0.01–30 Hz (6 dB/octave), and the EEG was digitized at 256 Hz (4.0 ms/point) for 1024 ms, with a 100 ms pre-stimulus baseline. Waveforms were averaged off-line, such that trials on which the EEG or EOG exceeded $\pm 100 \mu\text{V}$ were rejected. Individual subject data were filtered with a 15 Hz low-pass digital filter. Single-trial data also were subjected to an EOG correction procedure using spectral frequency analysis to remove any remaining artifact (Semlitsch et al., 1986).

3. Results

3.1. Behavioral Data

Error rate was defined as the percent of incorrect responses and was less than 1% for all conditions; it is not considered further. Response time was defined as the time from stimulus onset to the button press response. Mean response time was computed over stimulus trials for each condition across blocks and was assessed with a three-factor (2 arousal $\times$ 2 valence $\times$ 2 genders) analysis of variance. Response time did not differ among stimulus categories (negative-low=509, positive-low=502, negative-high=504, positive-high=502 ms ($P>.15$) or between genders ($P>.45$); no reliable interactions were obtained. Task performance was therefore similar across affective stimulus categories and subject gender.

3.2. ERP Analyses

After excluding error and artifact trials, ERP averages for each stimulus condition contained a mean of 30.3, 29.7, 30.2, 30.1 trials for the (arousal-valence) low-negative, high-negative, low-positive, and high-positive, respectively. A 3-factor (2 valence $\times$ 2 arousal $\times$ 2 genders) analysis of variance performed on the number of trials found no differences for valence ($F=1.8$, $P>0.15$), arousal ($F<1$, $P>0.50$), or gender ($F=3.7$, $P>0.10$). The number of trials did not differ among stimulus conditions or gender groups.

Figure 1 illustrates the grand averages for each stimulus category and gender group, with arousal level overlapped for each of the midline electrodes. The ERP components were measured from recording electrodes for each subject by obtaining the mean waveform amplitude relative to the pre-stimulus baseline. The latency windows were: P1=80–120 ms, N1=120–160 ms, P2=160–220, N2=220–300, P3=300–450 ms, early slow wave (SW1)=550–700, late slow wave (SW2)=700–850 ms. The P1 yielded only electrode placement effects, and these data are not considered further. Preliminary analyses of amplitude data from the lateral electrodes found no interpretable hemispheric effects related to affect or gender. These are not considered further.

Figure 2 illustrates the mean amplitude of the ERP components for each experimental variable as a function of the midline electrode location. The main analysis was performed by applying a four-factor mixed repeated measure analysis of variance to the mean amplitude from each subject (2 valence $\times$ 2 arousal $\times$ 2 genders $\times$ 3 midline electrodes) for each component. This method yields statistically independent assessment of the potential's responsivity to the independent variables. Greenhouse-Geisser corrections were applied to the df as needed, with the corrected probabilities and partial eta-squared (η^2) effect-size statistic reported. Newman-Keuls means comparison procedures were employed to assess interactions as needed.

Midline electrode outcomes—All components demonstrated highly significant main effects for the electrode factor, which were produced by the consistent increase in amplitude from the frontal to parietal electrodes, $F(2,60)>50.0+$, $P<0.001$ (all cases), $\epsilon=.57$ to $.73$, $\eta^2=0.65$ to 0.86 . These results will not be considered further. Reliable interactions among the electrode and other variables are detailed below for each component.

N1 component (120–160 ms)—No main effects of arousal, valence, or gender on N1 amplitude were observed. A three-way interaction among these factors was obtained, $F(1,30)=7.94$, $P<.01$, $\eta^2=0.21$. Post-hoc evaluation found that for the females the amplitudes from the low- and high-arousal and positive valence stimuli were marginally different ($P<.06$). For the males amplitudes from the low- and high-arousal negative valence stimuli ($P<.08$) and the high-arousal stimuli difference between positive and negative valence were marginally different ($P<.10$). Detailed assessment of individual data points indicated that outlier subjects

were the source of these statistically weak valence effects. A three-way interaction among arousal $\times$ gender $\times$ electrode also was significant, $F(2,60)=3.44$, $P<.05$, $\eta^2=0.10$. Post-hoc decomposition indicated that electrode location was the source of the statistical effect.

P2 component (160–220 ms)—No effects of arousal, valence, or gender on P2 amplitude were obtained. None of the interactions were reliable.

N2 component (220–300 ms)—Component amplitude was larger for the high- compared to low-arousal stimuli, $F(1,30)=4.93$, $P<.05$, $\eta^2=0.14$. This effect was larger for frontal than central compared to parietal electrodes and yielded a significant interaction between arousal and electrode, $F(2,60)=5.77$, $P<.01$, $\varepsilon=.79$, $\eta^2=0.16$. No other outcomes were statistically reliable.

P3 component (300–450 ms)—Component amplitude was larger for the high- compared to low-arousal stimuli, $F(1,30)=32.46$, $P<.001$, $\eta^2=0.52$. Negative valence stimuli were associated with amplitudes that were larger over the parietal electrode relative to positive valence stimuli and produced a significant interaction between valence level and electrode location, $F(2,60)=5.82$, $P<.01$, $\varepsilon=.87$, $\eta^2=0.16$. Post-hoc evaluation found that this interaction stemmed from about a 0.5 μ V amplitude increase for negative compared to positive valence stimuli at the parietal electrode ($P<.002$). No other valence-related outcomes were significant.

Early slow wave (550–700 ms)—Component amplitude was larger for the high- compared to low-arousal stimuli, $F(1,30)=66.89$, $P<.001$, $\eta^2=0.69$. This effect was more prominent frontally for female compared to male subjects and produced a significant interaction between gender and electrode, $F(2,60)=6.81$, $\varepsilon=.73$, $\eta^2=0.18$. The relationship between gender and electrode also was modulated by arousal, such that high- compared to low-arousal stimulus amplitudes were smaller over the parietal site for the female compared to male subjects, $F(2,60)=5.55$, $P<.01$, $\varepsilon=.85$, $\eta^2=0.16$. No other outcomes were significant.

Late slow wave (700–850 ms)—Component amplitude was larger for the high- compared to low-arousal stimuli, $F(1,30)=42.67$, $P<.001$, $\eta^2=0.59$. This effect was larger for frontal than central and parietal electrodes, with a significant interaction between arousal and electrode obtained, $F(2,60)=3.68$, $P<.05$, $\varepsilon=.93$, $\eta^2=0.11$. Negative valence compared to positive valence stimuli were associated with larger amplitudes over the parietal electrode to yield a significant interaction between valence and electrode, $F(2,60)=3.66$, $P<.05$, $\varepsilon=.77$, $\eta^2=0.11$. Post-hoc evaluation found that this interaction stemmed from about a 1 μ V increase in amplitude for negative compared to positive valence stimuli over the parietal electrode ($P<.001$). In addition, differences in frontal amplitude were more prominent for female compared to male subjects and demonstrated a reliable interaction between gender and electrode, $F(2,60)=6.61$, $P<.01$, $\varepsilon=.67$, $\eta^2=0.18$. No other outcomes were significant.

4. Discussion

4.1. Arousal, valence, and gender

The major finding was that high-arousal stimuli demonstrated larger ERP amplitudes compared to low-arousal stimuli. This effect began approximately with the N2 (220–300 ms), became appreciably stronger for the P3 (300–450 ms) through the early SW (550–700 ms) potentials, and was still robust for the late SW (700–850 ms) component (Delplanque et al., 2006; Olofsson and Polich, 2007). The high- vs. low-arousal amplitude differences accounted for about 50–60% of the experimental variance for each of the late component measures (P3, SW1, SW2), which was at least three times the variance attributable to any other factor or interaction. Small but statistically viable valence effects were observed for the P3 and late SW components, with

negative stimuli yielding somewhat larger amplitudes than positive stimuli over the parietal area (Conroy and Polich, 2007; Delplanque et al., 2004, 2005). Thus, stimulus arousal level rather than valence category of IAPS images produces stronger affective amplitude outcomes when these pictures are used as target stimuli in an oddball task.

No gender differences were obtained outside of interactions with the electrode factor. As the sample sizes for each group were reasonable ($n=16/\text{gender}$), similar affective processing occurred for IAPS stimuli across genders. The strongest gender-related finding was found for N1 amplitude within two interactions (arousal $\times$ valence $\times$ gender, arousal $\times$ gender $\times$ electrode). The gender effects were not robust or consistent across the components, implying that female/male differences from arousal/valence manipulations may be paradigm dependent and mitigated when a performance task is required (Bradley et al., 2001; Meyers and Smith, 1987).

4.2. Theoretical perspective

Each target stimulus required the same button-press response to indicate that a picture had been presented, so that the obtained affective ERP amplitude effects were elicited automatically (Carretie et al., 2004; Olofsson and Polich, 2007; Pizzagalli et al., 1999). The present study purposefully employed stimuli that were rated very different between arousal/valence categories. High-arousal produce larger amplitudes compared to the low-arousal stimuli in a fashion similar to biological arousal effects, which increase P300 size in relation to attentional resource availability (Polich, 2007). Given the salient difference between the target pictures and repetitive standard pattern, accurate oddball discrimination should engage minimal sensory processing. Imposition of a target-stimulus task unrelated to the affective image content would therefore attenuate early ERP valence effects, because no judgment of emotional content would be needed. However, such target task processing would facilitate resource allocation to produce arousal effects for the later ERPs in a fashion related to biological variables (Polich and Kok, 1995). Thus, ERP waveform modulations from affective stimuli originate from attentional mechanisms that are sensitive to task demands (cf. Carretie et al., 2001; Conroy and Polich, 2007; Olofsson et al., 2008; Schupp et al., 2006, 2007).

4.3. Conclusion

Arousal and valence stimulus characteristics are defined by rating scale judgments for IAPS images. Image differences can systematically alter ERP components in partially overlapping latency ranges (Codispoti et al., 2006; Delplanque et al., 2007; LeDoux, 1995; Olofsson et al., 2008). Arousal effects begin just before the P3 potential occurs and continue through generation of the early and late slow wave components. The simple discrimination task employed here seems to minimize ERP valence effects, although these were detectable in both the early and later components. These results also have been found for previous affective ERP studies with and without a response task. Taken together, the increased ERP amplitudes for high-arousal stimuli could reflect the task-driven engagement of attention and subsequent memory operations (e.g., Bradley et al., 1992; Delplanque et al., 2004, 2005, 2006; Dolcos and Cabeza, 2002; Olofsson and Polich, 2007). These memory-related outcomes are consistent with similar increased P3 and slow wave amplitudes for correctly remembered non-affect items (Azizian and Polich, 2007; Curran, 2004; Fabiani et al., 1986; Paller et al., 1988).

Although the exact sources of affective ERP amplitude modulations are unclear, recent results suggest that physical picture attributes such as color, complexity, and featural composition contribute to affective ERP processing. These early perceptual effects could reflect emotional content, whereas later ERP modulations appear to index fundamental motivational relevance (cf. Bradley et al., 2007; Delplanque et al., 2007; Cano et al., 2008; Codispoti et al., 2006). This interpretation implies that regardless of how specific physical variables modulate affect

responsivity, pictorial stimuli need to be well controlled to characterize arousal and valence ERP effects. Assessment of stimulus factors and systematically manipulating task demands should help to define how arousal and valence differentially contribute to ERP emotional patterns.

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Figure 1.
Grand averages from the midline electrodes of the low-arousal and high-arousal (overlapped) for the negative and positive valence stimuli from female and male subjects (n=16/gender).

Figure 2.

Mean amplitude areas of each ERP component for the low-arousal and high-arousal (overlapped) and the negative and positive valence stimuli from female and male subjects as a function of midline electrode.

Table 1
Means and standard deviations derived from a 1–9 rating scale of each picture stimulus type from the International Affective Picture System (IAPS).

		Negative-Low	Negative-High	Positive-Low	Positive-High
Valence	Mean	2.63	2.48	7.36	7.33
	SD	0.30	0.30	0.29	0.29
Arousal	Mean	4.46	6.76	4.45	6.68
	SD	0.25	0.32	0.27	0.32

Appendix

Numbers of Selected IAPS Pictures for each Stimulus Category

Valence-Arousal Category	Selected IAPS Images
Negative-Low	2205, 2276, 2375.1, 2455, 2750, 2900.1, 3300, 9000, 9220, 9265, 9280, 9290, 9320, 9330, 9342, 9561
Negative-High	2730, 3030, 3400, 6230, 6250, 6260, 6300, 6313, 6350, 6370, 6510, 6530, 6550, 8485, 9250, 9600
Positive-Low	1463, 1500, 1510, 1590, 1721, 1920, 2080, 2224, 2331, 2395, 2530, 5594, 5820, 7280, 7480, 8461
Positive-High	4607, 4608, 4660, 4670, 4680, 5621, 5629, 8030, 8080, 8180, 8185, 8186, 8370, 8400, 8490, 8501