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Motivated and controlled attention to emotion: Time-course of the late positive potential

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ABSTRACT

Objective: The present study examined the time-course of automatic and controlled modulation of the late positive potential (LPP) during emotional picture viewing.
Methods: Participants ($N = 32$) viewed neutral and unpleasant stimuli for 6000 ms; at 3000 ms, one of two tones signaled participants to attend either to a more or less arousing portion of the picture. The time-course of the LPP was examined both during the passive viewing and directed attention portions of the trial using the method proposed by Guthrie and Buchwald [Guthrie D, Buchwald JS. Significance testing of difference potentials. Psychophysiology 1991;28(2):240–4].
Results: During passive viewing, the LPP became reliably larger following the presentation of unpleasant pictures from 160 ms onward; the magnitude of the LPP became reliably smaller beginning 620 ms after participants were instructed to attend to the less arousing aspects of unpleasant pictures – and this difference was maintained throughout the duration of the trial.
Conclusions: The LPP reflects relatively automatic attention to emotional visual stimuli, but is also sensitive to manipulations of directed attention toward arousing versus neutral aspects of such stimuli.
Significance: These results shed further light on the time-course of emotional and cognitive modulation of the LPP, and suggest that the LPP reflects the relatively rapid and dynamic allocation of increased attention to emotional stimuli.

1. Introduction

Over four decades, researchers have utilized event-related brain potentials (ERPs) to elucidate the timing of cognitive processes (Luck, 2005; Rugg and Coles, 1996). In particular, the P300 has been used to index the relatively rapid allocation of attention following the presentation of salient stimuli. In traditional 'oddball' tasks, participants are asked to count or otherwise keep track of certain *target* stimuli; the presentation of target stimuli elicit a positivity in the stimulus-locked ERP, maximal at midline parietal sites approximately 300 ms following stimulus onset (Johnson, 1984, 1986; Magliero et al., 1984; Squires et al., 1977; Sutton et al., 1965). Data have consistently suggested that the P300 is sensitive to directed attention toward task-relevant information (Duncan-Johnson and Donchin, 1977; Nieuwenhuis et al., 2005).

Because of their intrinsic motivational significance, emotional stimuli might be considered *natural targets* – automatically processed as task-relevant. In fact, early studies reported an increased P300 in the 300–500 ms post-stimulus period following the presentation of emotional compared to neutral pictures (Johnston et al., 1986; Lifshitz, 1966; Mini et al., 1996; Radilova, 1982) – an effect observed for both pleasant (Lifshitz, 1966; Mini et al., 1996; Palomba et al., 1997) and unpleasant (Lifshitz, 1966; Mini et al., 1996; Palomba et al., 1997; Radilova, 1982) pictures.

More recent work in emotion has focused on a P300-like ERP referred to as the late positive potential (LPP). The LPP is a central–parietal, midline ERP that becomes evident approximately 300 ms following stimulus onset, and is larger following the presentation of both pleasant and unpleasant compared to neutral pictures and words (Cuthbert et al., 2000; Dillon et al., 2006; Foti and Hajcak, 2008; Hajcak et al., 2006, 2007; Hajcak and Nieuwenhuis, 2006; Hajcak and Olvet, 2008; Moser et al., 2006; Schupp et al., 2000, 2003, 2004). Unlike the more transient P300, the LPP can be increased for several seconds following the presentation of emotional stimuli (Cuthbert et al., 2000; Foti and Hajcak, 2008; Hajcak et al., 2007; Hajcak and Nieuwenhuis, 2006; Hajcak and Olvet, 2008) and even in the period following picture offset (Hajcak and Olvet, 2008).

Principle components analyses (PCA) suggest that the sustained positivity observed following the presentation of emotional compared to neutral stimuli reflects increases in multiple midline parietal/occipital ERP positivities – including the P300 and later-peaking positivities (cf., Foti et al., in press). That is, emotional

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stimuli elicit an increased positivity in the time range of the P300; additionally, emotional stimuli elicit slower, later-peaking, positivities – and the combination of these components gives rise to the apparent scalp-recorded P3–LPP complex. Larger parietal positivities following emotional compared to neutral stimuli have been discussed in terms of *motivated attention* – the notion that emotion automatically directs attention, and thereby facilitates subsequent processing (Bradley et al., 2003; Lang et al., 1998; Morris et al., 1998; Sabatinelli et al., 2005).

Recent research has begun to examine emotion–cognition interactions, especially the interplay between directed and motivated attention, using ERPs. For example, Schupp and colleagues manipulated the task-relevance of certain types of stimuli by having participants count pleasant, neutral, or unpleasant pictures; results indicated that the difference between the P300 evoked by emotional as compared to neutral pictures was larger when emotional stimuli were also task-relevant (Schupp et al., 2007). More recently, Ferrari and colleagues presented emotional images as either targets or non-targets in a categorization task; by using the same stimuli in both conditions, Ferrari and colleagues were able to demonstrate additive effects of task relevance and emotional significance on the LPP (Ferrari et al., 2008). Keil and colleagues found similar effects, suggesting that directed attention may operate additively with emotion to evoke the LPP (Keil et al., 2005).

Moreover, studies also suggest that emotion-related increases of the P300 and LPP can be modulated by top-down regulatory processes; that is, that emotional processing can be modulated by cognitive control. For instance, Hajcak and Nieuwenhuis (2006) found that reinterpreting unpleasant images in a less negative way resulted in a reduced LPP (cf., Moser et al., 2006). More recently, Foti and Hajcak (2008) reported that the LPP elicited by unpleasant pictures was drastically attenuated when unpleasant images were preceded by more neutral than negative descriptions. Collectively, these data suggest that changing the meaning of stimuli can alter the amplitude of the LPP.

Along similar lines, Hajcak et al. (2006) found that the LPP was reduced when participants made non-affective compared to affective judgments about emotional stimuli. The authors interpreted these data as suggesting that non-affective categorization encouraged participants to attend to less emotional aspects of the images. In two related studies, Dunning and Hajcak (2009) recently found that the more sustained LPP could also be manipulated by having participants focus on more or less emotionally arousing aspects of unpleasant pictures. In both studies, the magnitude of the LPP elicited by unpleasant stimuli was reduced when participants focused on areas of unpleasant pictures that contained non-arousing content (Dunning and Hajcak, 2009).

Collectively, then, these results suggest that the P3–LPP complex may reflect the dynamic interplay between relatively automatic increases in attention to emotional stimuli and more controlled cognitive processes. The current study sought to simultaneously examine the time-course of these effects on the LPP. That is, to measure both the relatively automatic increase in the LPP elicited by unpleasant compared to neutral images, as well as the effect of online instructions to attend to more or less arousing portions of unpleasant images. To this end, participants first viewed either unpleasant or neutral IAPS images for 3000 ms; one of two tones was then presented, and served as an instruction for participants to direct their attention to either more or less arousing aspects of the images. Thus, the present design allowed for an examination of both automatic and controlled attentional processes indexed by the LPP within the same trials.

One of the attractive features of using ERPs to study neural correlates of information processing is their relatively good temporal resolution – it is possible to examine the neural changes occurring on the order of milliseconds using ERPs. Existing studies – especially on top-down attentional modulation – have scored the LPP in rather large temporal windows, and have therefore not fully capitalized on the excellent temporal resolution of ERPs. To quantify the early increase in the LPP and the subsequent modulation of the LPP by attentional instructions, we utilized the method of Guthrie and Buchwald (1991) to establish intervals in the ERP that varied as a function of picture type and instruction, respectively. In this way, then, we were able to examine whether the LPP was modulated by both automatic and controlled factors within the same trials, and could scrutinize the time-course of these effects.

2. Methods

2.1. Participants

Thirty two undergraduates (11 females, 21 males) participated in the study; none withdrew from the experiment once it begun. All the participants received course credit for their participation in the study.

2.1.1. Stimuli

Sixty pictures from the International Affective Picture System (IAPS; Lang et al., 2005) were selected: 40 were unpleasant and 20 were neutral.[1] In terms of normative valence ratings, the neutral pictures ($M = 5.11$, $SD = .50$) were rated as more pleasant than unpleasant pictures ($M = 2.09$, $SD = .41$; $t(58) = 24.84$, $p < .001$). In addition, neutral pictures were rated as less arousing ($M = 2.94$, $SD = .79$) than unpleasant pictures ($M = 6.13$, $SD = .61$; $t(58) = 17.26$, $p < .001$).

All the pictures were presented on a Pentium class computer, using Presentation software (Neurobehavioral Systems, Inc., Albany, CA) for the presentation and timing of all stimuli. Each picture was displayed in color and occupied the entirety of a 19-in. (48.26 cm) monitor. At a viewing distance of approximately 24 in. (60.96 cm), each picture occupied approximately 40° of visual angle horizontally and vertically.

2.2. Procedure

After a brief description of the experiment, electroencephalograph (EEG) sensors were attached; all the participants wore earbud style headphones which fit comfortably under the EEG cap. Participants first viewed a series of images from the IAPS which were not part of the experimental stimuli. On the first three practice trials, the experimenter showed how each of the unpleasant IAPS contained both arousing/negative contents, as well as more neutral/less arousing content. For instance, participants viewed an image of a shark (i.e., IAPS #1930), and the experimenter pointed out the shark's teeth and the tip of its nose as the examples of relatively arousing versus neutral portions of the image, respectively. As another example, a picture of a homeless person was displayed (i.e., IAPS #2750), and the experimenter pointed out that the person could focus on the individuals face as a more arousing aspect of the image; or, could focus on empty bottles and bread that were more neutral in the picture. Finally, the participant was shown a close-up im-

[1] The numbers of the IAPS pictures used were the following: unpleasant (1525, 2053, 2095, 2141, 2352.2, 2703, 2717, 2811, 3005.1, 3010, 3015, 3016, 3017, 3030, 3053, 3063, 3181, 3225, 3261, 3266, 3530, 6312, 6313, 6315, 6415, 6550, 6570.1, 6571, 6831, 9252, 9253, 9300, 9405, 9410, 9420, 9430, 9433, 9570, 9635.1, 9810) and neutral (2102, 2190, 2206, 2235, 2320, 2383, 2580, 2745.1, 2980, 5390, 5740, 7000, 7002, 7004, 7010, 7140, 7175, 7491, 7560, 7595).

age of a face (IAPS #3160), and was asked what they would focus on that was more arousing, and what they could focus on that was more neutral; for this image, the areas around the eyes are particularly unpleasant, whereas the nose and forehead are more neutral. All the participants answered accordingly.

Next, participants were told that their task was to direct their attention to either a more arousing or more neutral aspect of unpleasant images whenever they heard a low or high tone, respectively. The instructions involved arousal, rather than valence, to be maximally consistent with the previous work indicating that the LPP relates more closely to the arousal than valence dimension of emotion (Cuthbert et al., 2000). The low and high tones were 500 Hz and 1000 Hz tones, respectively, each lasted exactly 200 ms in duration. The correspondence between arousing/neutral instruction and low/high tones was randomized across subjects; the experimenter placed a small placard in front of the participant to remind them of the meaning of the high and low tones.

Finally, participants were told that in the actual experiment, they would either be viewing neutral or unpleasant pictures, and that they should view each picture freely until the presentation of the tone. At that point, participants were instructed to focus on a single neutral or arousing portion of the picture for the duration of the stimulus presentation. Participants were told explicitly that neutral images would always be associated with a 'neutral' tone.

Following the practice trials, a total of 60 trials (20 neutral and 40 unpleasant pictures) were divided into four blocks, with breaks between each block. All the pictures were presented for 6000 ms; the high or low tone was presented 3000 ms following picture presentation (i.e., half-way during picture presentation). Following picture offset, a black screen with a white fixation cross was presented for 2000 ms. Thus, the intertrial interval was 8000 ms, and the interstimulus interval was 2000 ms.

A tone instructing participants to focus on a neutral aspect of the image was presented on 100% of the neutral trials, and 50% of the unpleasant trials. With regard to the unpleasant pictures, whether a given unpleasant stimulus was associated with instruction indicating neutral or arousing focus was determined randomly for each participant. Thus, all the participants viewed the same 60 IAPS pictures, and whether unpleasant pictures were assigned to the arousing or neutral condition for each participant was determined randomly; the order of trial types was also randomized for each participant. All randomization occurred over the entire experiment; that is, the assignment of unpleasant pictures to the arousing or neutral condition, and the order of trial types, was not constrained within experimental blocks.

2.3. Psychophysiological recording, data reduction and analysis

The continuous EEG was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 64 scalp electrodes based on the 10/20 system, as well as from two electrodes that were placed on the left and right mastoids (M1 and M2, respectively). The electrooculogram (EOG) generated from blinks and eye movement was recorded from four electrodes: two approximately 1 cm above and below the subject's left eye, one approximately 1 cm to the left of the left eye, and one approximately 1 cm to the right of the right eye. As designed by BioSemi, the reference electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode.

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). The EEG was sampled at 512 Hz. Off-line, all data were re-referenced to the numeric mean of the mastoids and band-pass filtered between 0.1 and 30 Hz; the EEG was corrected for blinks and eye movements using the method developed by Gratton et al. (1983).[2] In addition, a semi-automated procedure was used to identify and reject physiological artifacts according to the following criteria: a voltage step of more than 50.0 μV between sample points, a voltage difference of more than 300.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100 ms intervals.

ERPs were constructed by separately averaging trials in the three conditions: neutral pictures with an attend-neutral instruction, unpleasant pictures with an attend-neutral instruction, and unpleasant pictures with an attend-arousing instruction. For each ERP average, the average activity in the 200 ms window prior to picture onset served as the baseline. Based on previous research indicating that the LPP is typically maximal at posterior and parietal sites (Foti and Hajcak, 2008; Hajcak et al., 2007; Keil et al., 2002, 2005; Schupp et al., 2000), the LPP was scored as the average activity at Cz, CP1, CPz, CP2, and Pz.

To evaluate the temporal dynamics of the LPP during both the pre- and post-instruction periods, we employed the method of Guthrie and Buchwald (1991) for computing ranges of significant differences between two ERPs. For a data set with N subjects and T time points for conditions X and Y, this method involves first calculating the autocorrelation between X and Y; then, Monte Carlo simulations are used to identify the number of successive t-tests that would be expected less than 5% of the time in a data set comprised of N subjects, T time points, and with a given autocorrelation structure. Thus, the Monte Carlo simulations indicate the minimum number of successively significant t-tests to identify portions of the ERPs that differ from one another. This method protects against Type I error rates without utilizing conservative multiple comparison methods. This method has been applied successfully to both pupilometry (Siegle et al., 2003, 2004) and ERP data (Condray et al., 2003) in the recent past.

This procedure was first implemented to compare LPPs elicited by neutral and unpleasant IAPS images in the pre-instruction period – this was done by comparing the ERP elicited by neutral and unpleasant pictures (collapsing across the type of instruction presented at 3000 ms) in the entire pre-instruction picture presentation period (0–3000 ms). Next, the Gutherie and Buchwald procedure was also used to compare the LPP elicited by unpleasant IAPS images as a function of instructions to attend to arousing or neutral aspects of these images. This was done by comparing the unpleasant picture LPPs based on instruction (arousing focus, neutral focus) from 3000 to 6000 ms. The first comparison, therefore, was used to assess relatively automatic increases in the LPP for unpleasant compared to neutral images, whereas the second com-

[2] The number of corrected eye movements differed between the neutral picture/neutral focus trials ($M = 17.48$; $SD = 10.92$), the unpleasant picture/arousing focus trials ($M = 20.58$; $SD = 11.85$), and the unpleasant picture/neutral focus trials ($M = 20.97$; $SD = 10.32$; $F(2,62) = 3.66$, $p < .05$). However, post hoc comparisons indicated that although neutral picture/neutral focus trials had more corrected eye movements than both unpleasant picture/neutral focus trials ($t(31) = 2.67$, $p < .01$) and unpleasant picture/arousing focus trials ($t(31) = 2.14$, $p < .05$), the number of corrected eye movements did not differ between unpleasant picture/arousing focus and unpleasant picture/neutral focus trials ($t(31) = .15$, $p > .95$). Thus, unpleasant images were associated with more corrected eye movements, but the number of corrected eye movements for unpleasant images did not differ as a function of attentional instruction. These data are consistent with two possibilities: either unpleasant images were more interesting and prompted more eye movements, or, participants explored unpleasant pictures more because these images were associated with having to focus on either a neutral or arousing portion (i.e., participants may have been exploring these images more in order to prepare for both attentional instructions).

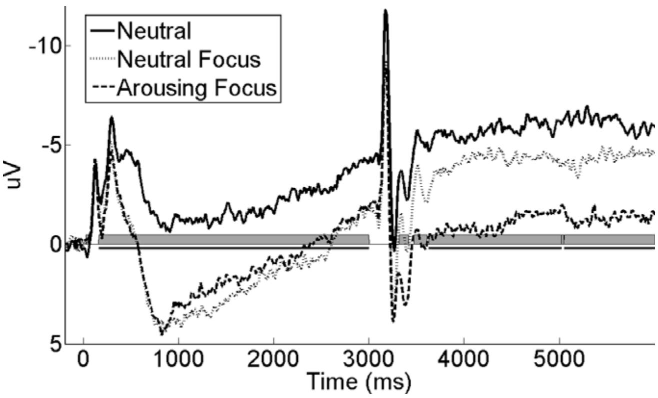

Fig. 1. Grand averaged ERPs at central–parietal recording sites elicited by each trial type: neutral pictures (solid line) were always associated with an instruction to focus on a neutral aspect of the picture; unpleasant pictures were followed by either an instruction to attend to a neutral (dotted line) or arousing (dashed line) portion of the image. Picture onset occurred at 0 ms and the instruction tone occurred at 3000 ms. Shaded regions above the *x*-axis indicate significant differences ($p < .05$) between the LPP elicited by unpleasant and neutral pictures prior to the attentional instruction (0–3000 ms) and significant reductions in the LPP following attentional instructions (3000–6000 ms). The presence of a solid line below the *x*-axis indicates periods of time in which the conditions differed from one another based on the number of successive significant *t*-tests.

parison was used to assess the effects of attentional instructions on the LPP elicited by unpleasant images.

To implement this procedure, the residual autocorrelation after accounting for variance due to relevant signals was first calculated between neutral and unpleasant images in the pre-instruction period (.9913; first eight factors were removed based on scree plot in PCA); a separate residual autocorrelation was calculated for unpleasant images following instructions to attend to more or less arousing aspects of the unpleasant images (.9914; first nine factors removed based on scree plot in PCA). Next, 1000 Monte Carlo simulations were run to determine the minimum interval of successive significant *t*-tests in each portion of the data; 220 for the first half, 205 for the second. Calculating the autocorrelation and minimum length of successive significant *t*-tests were implemented using a MatLab toolkit developed by Greg Siegle (Siegle, personal communication).

3. Results

The grand average ERPs elicited by each picture type at the central–parietal cluster are presented in Fig. 1. Fig. 2 presents the scalp distribution of the difference between unpleasant and neutral pictures from 0 to 3000 ms, and the scalp distribution of the difference following arousing and neutral instructions on unpleasant trials from 3000 to 6000 ms. In Fig. 1, the shaded portion above the *x*-axis represents time-points where there was a significant paired-samples *t*-test ($p < .05$) and the solid thin line below the *x*-axis reflects the periods of time where there was a significantly long sequence of sequentially significant *t*-tests. Consistent with the impression from Fig. 1 then, unpleasant images elicited a larger LPP than neutral pictures in the pre-instruction period. Indeed, the LPP became reliably larger following unpleasant than neutral images beginning 160 ms following stimulus onset, and continued throughout the pre-instruction period. The scalp distribution of this effect is presented in Fig. 2; consistent with previous work, the LPP was larger for unpleasant than for neutral pictures as parietal recording sites – although this difference was also evident at more central sites later in the viewing epoch (cf., Foti and Hajcak, 2008; Hajcak et al., 2007).

In the post-instruction period, by contrast, the LPP was reduced when participants were instructed to direct their attention toward neutral compared to arousing portions of unpleasant images. In Fig. 1, shaded areas above the *x*-axis from 3000 to 6000 ms indicate a significant difference ($p < .05$) in the LPP elicited by unpleasant pictures as a function of attentional instruction, and the solid line below the *x*-axis indicates significant runs of consecutive differences. Thus, the LPP elicited by unpleasant pictures was modulated by attentional instructions beginning 620 ms following attentional instruction (i.e., 3620 ms following picture onset) – and this difference was sustained for the remainder of the picture presentation period. Moreover, as evident in Fig. 2, the difference following arousing and neutral instructions appeared to have a similar, parietally maximal, scalp distribution as the LPP elicited during passive viewing.

4. Discussion

In line with several previous papers, we found that the LPP was increased following the presentation of unpleasant compared to neutral IAPS (Cuthbert et al., 2000; Dillon et al., 2006; Foti and Hajcak, 2008; Hajcak et al., 2006, 2007; Hajcak and Nieuwenhuis, 2006; Hajcak and Olvet, 2008; Moser et al., 2006; Schupp et al., 2000, 2003, 2004). Moreover, the topography of this effect was consistent with the previous studies that have reported the scalp distribution of the LPP during sustained passive viewing tasks (Foti and Hajcak, 2008; Hajcak et al., 2007).

Following the methods of Guthrie and Buchwald (1991), we found that the unpleasant minus neutral ERP difference was significant beginning 160 ms following picture presentation – and that this difference was sustained throughout the pre-instruction period of the trial. It is important to note that during the passive viewing portion of the experiment, unpleasant and neutral pictures were not presented with equal probability. Although this design allowed us to equate trial types in the post-instruction period, unpleasant pictures were presented twice as frequently as neutral pictures during the passive viewing period. If anything, this experimental design might have actually increased the LPP to neutral pictures by virtue of their being relatively rare.

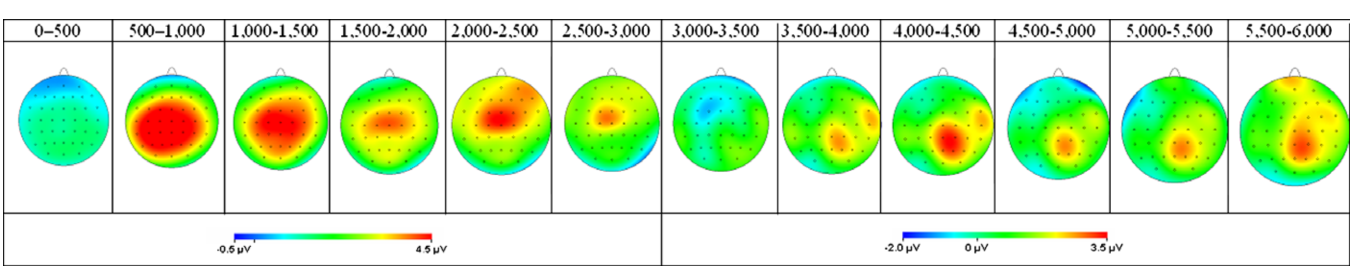

Fig. 2. Scalp distribution of the unpleasant minus neutral difference during passive picture viewing (0–3000 ms), and the distribution of the arousing minus neutral focus difference for unpleasant pictures (3000–6000 ms). Stimulus onset occurred at 0 ms; tone instructing participants to attend to neutral or arousing portions of unpleasant images occurred at 3000 ms. The LPP is observed as an increased parietally maximal positivity in both comparisons. Please note that passive viewing and directed attention comparisons have different scales.

Importantly, in the post-instruction period, instructions to attend to more or less arousing aspects of the unpleasant images dynamically modulated the amplitude of the LPP. In a previous paper, we demonstrated that manipulating where participants looked within unpleasant IAPS images was associated with a decreased LPP; this was accomplished by highlighting relatively neutral or arousing aspects of unpleasant images and instructing participants to only look within highlighted regions (Dunning and Hajcak, 2009). The present results dovetail nicely with those findings, and further suggest that a similar reduction in the LPP can be observed when the individuals are instructed to dynamically allocate their attention to more or less arousing aspects of unpleasant IAPS images. Moreover, sequential significance testing indicated that LPP modulation began approximately 620 ms following the presentation of attentional instructions.

The scalp distribution of this effect appeared quite similar to the increased LPP elicited by unpleasant compared to neutral pictures in the initial passive viewing portion of the trials. Indeed, the current LPP data highlight the important way in which emotional and cognitive processes interact in the elicitation of electrocortical activity. In future studies, it might be useful to include both pleasant and unpleasant images to examine whether instructions to allocate attention to arousing versus non-arousing foci would similarly reduce the LPP elicited by pleasant pictures; this experimental design would also provide a separation of attentional instructions from picture type, as only unpleasant pictures in the current study were associated with instructions to attend to arousing aspects.

Together, the present data underscore the way in which the LPP appears to reflect the allocation of both relatively automatic and controlled attentional processes during emotional picture viewing – even within the same trial. Modulation of the LPP by emotional stimuli has been described in terms of *motivated attention*, whereby emotional stimuli automatically capture attention and received increased processing resources (Ferrari et al., 2008). However, the present study suggests that emotional effects can be modulated by more top-down attentional processes: within 650 ms following instructions to attend toward a less arousing/more neutral aspect of unpleasant IAPS images, the LPP was reduced. Along similar lines, Ferrari et al. (2008) found that both emotion and task-relevant stimuli additively determined the amplitude of the LPP. Thus, the processes of motivated and directed attention interact in determining the amplitude of the LPP – even within the same trials in the current study. Indeed, this type of paradigm might be used to assess both initial reactivity toward emotional stimuli, and subsequent regulatory ability.

Overall, the current results fit well within a larger body of work that has examined the LPP with respect to interactions between emotional and cognitive processes. In particular, a growing body of work indicates that the LPP is sensitive to a number of contextual and regulatory factors. Specifically, Hajcak and Nieuwenhuis (2006) found that the LPP elicited by unpleasant pictures was reduced after the participants reappraised unpleasant pictures – and reinterpreted them in a less negative way. Similarly, Moser and colleagues have reported that instructions to experience emotional stimuli less intensely reduce the amplitude of the LPP elicited by both unpleasant and pleasant pictures (Krompinger et al., 2008; Moser et al., 2006). Recently, Foti and Hajcak (2008) found that neutral and negative descriptions that preceded unpleasant pictures modulated the amplitude of the LPP. That is, when unpleasant pictures were preceded by a more neutral compared to negative description, the LPP was reduced.

The current study suggests that cognitive-change based modulations of the LPP may depend on how attention is allocated within emotional stimuli. Specifically, neutral descriptions that precede unpleasant pictures, and instructions to reduce emotional intensity to unpleasant pictures, may alter how individuals attend to visual stimuli. Indeed, van Reekum and colleagues reported that gaze fixation accounted for a portion of the reduced amygdala activation following emotion regulation instructions (van Reekum et al., 2007). Future studies might similarly utilize eye-tracking in the context of meaning-based manipulations of emotion in ERP studies. In addition, the inclusion of eye-tracking in future studies would allow for a more direct examination of how and where individuals direct attention to most efficiently modulate the LPP.

Another important area for future research will be to relate variation in the LPP to other behavioral and biological measures; that is, if LPP amplitude reflects increased attention to emotional aspects of stimuli, then variation in the LPP ought to relate to other measures of emotional processing and interference. As one example, increased LPP has been related to increased memory (Dolcos and Cabeza, 2002; Koenig and Mecklinger, 2008). In addition, variation in the LPP may be a useful biological outcome measure for clinical interventions that focus on skills training in attentional control, such as mindfulness (Baer, 2002).

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